Holistic Thinking

Creating innovative solutions to complex problems

Second Edition

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Dedication

To my wife Lily always caring loving and supportive
To my children who give me much joy and some heartache
To my living friends and family who make life worthwhile
To those that have passed on who made a difference

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Other books by Joseph E. Kasser

Systems engineering

- Perceptions of Systems Engineering, The Right Requirement via Createspace, 2015.
- A Framework for Understanding Systems Engineering, The Right Requirement Ltd. via Createspace, 2nd edition, 2013.
- Applying Total Quality Management to Systems Engineering, Artech House, 1996.

Amateur radio

- Basic Packet Radio, Software for Amateur Radio, First and Second Editions, 1993, 1994.
- Software for Amateur Radio, TAB Books, December 1984.
- Microcomputers in Amateur Radio, TAB Books, November 1981.

Judaism and Jewish

- Conceptual Laws and Customs of Christmas, Createspace, 2015.
- The 87th Company. The Pioneer Corps. A Mobile Military Jewish Community, Createspace, 2015 (Editor).

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- NASSA Goddard Space Flight Center Community Service Award, 1990.
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1. Introduction

While the skills to identify and solve problems are becoming recognised as being increasingly important, there are not many good ways to help you acquire those skills. This book is designed to help you to acquire those skills so as to be able to deal with undesirable situations, identify the right problem and provide the optimal acceptable solution from the range of prospective solutions.

The needed skill for providing acceptable solutions is the ability to think differently to that of your contemporaries. You need to go beyond systems thinking and apply holistic thinking to the matter at hand. This book helps you develop that skill, building on the works of W. Edwards Deming (Quality), Peter Senge (systems thinking) (Senge, 1990), Tom Peters, Peter Drucker and Michael Hammer and James Champy (management) (Hammer and Champy, 1993) to tell you what to do, how to do it, when to do it, and provide you with the understanding of why it must be done. For example, in school, generally, you are taught to solve problems by being given a problem and then asked to find the solution. The assumption being that there is a well-defined problem and a single well-defined correct solution. Well, unfortunately the real world is not like that, because often more than one correct solution can be found. For example, you are hungry which is generally an undesirable situation. Your problem is to figure out a way to remedy that undesirable situation by consuming some food to satisfy the hunger. There are a number of solutions to this problem including cooking something, going to a restaurant, collecting some takeaway food, and telephoning for home delivery. Then there is the choice of what type of food; Italian, French, Chinese, pizza, lamb, chicken, beef, fish, vegetarian etc. Now consider the vegetables, sauces and drinks. There are many solutions because there are many combinations of types of food, meat, vegetables and method of getting the food to the table. Which solution is the right one? The answer is that the right solution is the one that satisfies your hunger in a timely and affordable manner and does not cause any gastric problems. If several of the solution options can perform this function and you have no preference between them, then each of them are just as correct as any of the other ones that satisfy your hunger. The words ‘right solution’ or ‘correct solution' should be thought of as meaning 'one or more acceptable solutions'.

While systems thinking can help you to understand relationships in situations and think systemically and systematically, systems thinking alone cannot help you provide innovative solutions to complex problems. This is because understanding situations is only the first step on the journey that provides those innovative solutions.

This book:

- Takes you along that journey going beyond systems thinking to help you find innovative solutions.
- Provides you with frameworks and classifications systemically and systematically starting by discussing thinking, then taking you through thinking about undesirable situations and problems and how to convert them to acceptable solutions. For example, there is a framework for holistic thinking in Chapter 6 and a classification of problems in Chapter 9. These frameworks provide anchor points to ensure that participants in a discussion are all on the same page.
- Is written in a style using dot points (bulleted lists) and numbered lists to help you identify the concepts.
- Is the text for my course on 'systems thinking and beyond' that teaches participants how to think systemically and systematically when faced with problems. The participant feedback from iterations of the course in Israel, Japan, Taiwan and Singapore has been very positive.

The rest of this chapter should interest you in reading the remainder of the book which will help you to change both the way you perceive things and the way you think so that you will be able to develop the skills to imagine and create innovative acceptable solutions to complex problems.

1.1. How to read and use this book

The change starts here. Don't read the book sequentially in a linear manner, but prepare for several passes through it. This book is non-fiction. Non-fiction books are different to fiction: stories, novels and thrillers that are designed to be read in a linear manner from start to finish. This book is designed to help you learn and use the content in the following manner:

1. **Skim the book.** Flip through the pages, if anything catches your eye and interests you, stop, glance at it, and then continue flip-

ping through the pages. Notice how the pages have been formatted with dot points (bulleted lists) rather than in paragraphs to make skimming and reading easier.

2. For each chapter:
    1) Read the introduction.
    2) Skim the contents.
    3) Look at the drawings and photographs.
    4) Read the summary of the chapter.
    5) Go on to the next chapter.
3. **If you don't understand something, skip it on the first and second readings.** This book uses examples from many different disciplines and domains; don't get bogged down in the details.
4. Work though the book slowly so that you understand the message in each section of each chapter. If you don't understand the details of the example, don't worry about it as long as you understand the point that the example is demonstrating.
5. Refer to the list of acronyms in Section 1.6 as necessary.
6. Imagine and create innovative solutions to complex problems using the material you have gained from this book, your reading and experience.

Step 1 should give you something you can use immediately. Steps 2 and 3 should give you something you can use in the coming months. Step 4 should give you something you can use for the rest of your life. Step 6 is the rest of your life.

Note the occasional forward reference to an example. This is done to point to:

- An example which fits better in the later context.
- Additional information in the later sections.

1.2. Why this book

Seventeen years ago when I first began to teach systems thinking I taught the need for systems thinking, the history of systems thinking and then told the students that when they were using systems thinking they would know it. Notice the gap? There was no good way to teach practical systems thinking other than showing causal loops and practicing using them. In the main, the situation is the same. This book was written to fill that gap in the literature.

Seventeen years later, there seems to be a consensus in the literature that you need to apply systems thinking to develop solutions to complex problems irrespective of whether you are facing the problems professionally as a trouble-shooter, a systems engineer, a project manager and a diagnostician or if you are facing problems in your personal life, hobby as well as in any other situation. However, the literature on problem-solving and systems thinking is still problematic. The publications, in general:

- Tell you what you need to do and what to do, but mostly lack details on how to do it.
- Are written from a single perspective based on the experience of the author with little reference to similar situations in the literature. Consequently they tend to:
    - Focus on one aspect of the situation.
    - Fail to provide a generic context and framework for supplying the concepts in your situation.
    - Lack the self-evaluation of the ideas presented in the publication.
    - Use a specific word for a specific concept, yet the concept meant by the word is different to the concept meant by the same word in another publication. For example, the meaning of the term 'systems thinking' includes both (1) thinking in a systemic and systematic manner and (2) thinking about a system as a whole. You must be made aware that is like Humpty Dumpty telling Alice that "*when he uses a word it means just what he chooses it to mean - neither more nor less*" (Carroll, 1872) irrespective of how other people use the same word.
    - Use different words for the same concept. For examples see the discussion in Section 7.7.3 regarding the use of the words 'complex' and 'complicated' and the discussion in Chapter 9 on the meanings of the words 'undesirable situations', 'problems' and 'solutions'.
    - Not go far enough because you need to go beyond systems thinking to be able to create innovative solutions to complex problems. The reason you need to go beyond systems thinking to develop innovative solutions to complex problems is because not only do you have to use systems thinking (in both its meanings) to gain an understanding of the situation, you also have to be able to observe differences and similarities in things and be able to generate and evaluate ideas about potential solutions. This book is designed to help you develop those competencies.

1.3. Mind the gap

People who develop innovative solutions to problems make changes to the way something is done (a process), a thing (a product or a system) or the way something is perceived (thinking). So these people can be called innovators in addition to their job titles because the word 'innovator' means to introduce something new or make changes in anything established'[1]. Looking into the literature on innovation, Gordon et al. provided a way to identify the difference in cognitive skills between innovators, problem formulators, problem solvers and imitators (Gordon G. et al., 1974). The difference is based on:

- Ability to find ***differences*** among objects which seem to be ***similar***.
- Ability to find ***similarities*** among objects which seem to be ***different.***

While these abilities are discussed in the literature on critical thinking not in the literature on systems thinking, the necessary competencies for the abilities are generally not identified. This book is different; it goes beyond systems thinking and uses a systems approach to address these issues. Earlier versions of some of the book's content have been published as peer-reviewed conference papers and have been used as readings in postgraduate and continuing education classes in Australia, Brunei Darussalam, Israel, Japan, Singapore, Taiwan, the UK and the USA since 2007.

1.4. Why the systems approach

Dewey stated the essence of problem-solving when he wrote the following three points (Dewey, 1933):

1. What is the problem?
2. What are the alternatives?
3. Which alternative is best?

Dewey's formulation evolved into the systems approach which is discussed in this book. "*The systems approach is a technique for the application of a scientific approach to complex problems. It concentrates on the analysis and design of the* ***whole****, as distinct from the components of or the parts. It insists upon looking at a problem* ***in its entirety****, taking into account all the facets and all the variables, and relating the social to the technological aspects*" (Ramo, 1973: page 15). "*You don't even have to be a professional to use the systems approach. When any of us has a problem – preparing a budget, choosing where to live or what job to seek, designing a*

[1] Dictionary.com, accessed on 4 November 2012

chair or a house, selecting a route for a trip – in every instance it is well to be logical, to use the wisdom we possess, to consider objectively all the factors involved, and to recognize that there are many alternatives" (Ramo, 1973: page 16). However, as Ralph Miles wrote "*the systems approach will not solve problems for you. Only you can do that. What the systems approach will do is permit you to understand the resolution – your resolution – of a problem in a logical rational manner. You are the one who must ascertain that a problem or need exits. You are the one who must develop alternatives. You are the one who must develop the criteria for selecting a suitable alternative. The systems approach will not do any of these things for you*" (Miles, 1973: page 11).

This book will help you to develop your thinking to be able to imagine and create innovative solutions to complex problems by changing the way you see the situation so as to dissolve the problem rather than by solving or resolving it. The book contains many examples ranging from situations such as making a cup of instant coffee, getting through a locked gate when the lock is broken to docking the United States (US) space shuttle to the International Space Station (ISS).

1.5. The contents of the book

The book is split into the following three parts:

Part I. Thinking and ideas.
Part II. Using the ideas in problem-solving.
Part III. Innovative solutions to complex problems.

1.5.1. Part I

Part I provides the thinking and communications tools which are used to create and communicate innovative solutions to complex problems. The chapters cover the creation, communication and use of ideas.

Chapter 1:

1. Explains how to read and use the book in Section 1.1.
2. Explains why the book was written in Section 1.2.
3. Explains the gap filled by the book in Section 1.3.
4. Explains why the systems approach is important in Section 1.4.
5. Introduces the contents of the book in Section 1.5.
6. Provides a list of acronyms used in the book in Section 1.6.
7. Provides a glossary of the meanings of some specific words used in the book in Section 1.7 since their meaning in the literature depends on the author.

Chapter 2:

1. Introduces you to thinking and introduces some of the tools you can use to assist your creative thinking.
2. Starts with an introduction to some types of thinking in Section 2.1.
3. Introduces types of thinking in Section 2.2.
4. Discusses top down and bottom up thinking in Section 2.3.
5. Discusses judgment and creativity in Section 2.4.
6. Introduces a concept map as the basic tool for thinking in Section 2.5.
7. Describes just a few of the tools that can help you to think starting with tools for generating ideas in Section 2.6 and a few tools to assist with thinking in Section 2.7.
8. Ends with a quick reference table to help you select the appropriate tool for the thinking task.

Chapter 3:

1. Discusses ways to communicate ideas because there is little point in generating ideas if you are not going to do anything with them.
2. Begins with a discussion on formal written communications in Section 3.1 namely documents and introduces a process for creating a document starting with an abstract and continuing with developing and using annotated outlines.
3. Discusses formal verbal communications and presentations in Section 3.2.
4. Alerts you to some barriers to successful communications in Section 3.3.
5. Follows up with some ways to overcome those barriers in Section 3.4.
6. Discusses Intellectual Property (IP) and ways to avoid plagiarism in Section 3.5.

Chapter 4:

1. Addresses multiple perspectives.
2. Begins with a description of analysis as an internal perspective and systems thinking as an external perspective in Section 4.1.
3. Introduces the perspective perimeter to provide anchor points for discussions from a wider set of viewpoints that go beyond analysis and systems thinking in Section 4.2.
4. Introduces nine Holistic Thinking Perspectives (HTP) as anchor points on the perspectives perimeter and more in Section 4.3.
5. Concludes by comparing the HTPs with some other versions of systems thinking in Section 4.4.

Chapter 5:

1. Introduces and provides an overview of critical thinking.
2. Perceives critical thinking from the perspectives perimeter in Section 5.1 and:

    1) Shows how the perspectives perimeter can be used to examine critical thinking.
    2) Uses perceptions from the *Functional* perspective to separate out the rules for thinking from the evaluation of ideas.

3. Discusses creating and analysing arguments in Section 5.2.
4. Introduces a number of ways of evaluating critical thinking Section in Section 5.3.

1.5.2. Part II

Part II covers the problem-solving aspect of creating innovative solutions to complex problems.

Chapter 6:

1. Summarises holistic thinking as the combination of the use of the HTPs and critical thinking (the evaluation of ideas).
2. Begins with an introduction to how to use the HTPs to store information about Case Studies and real world situations in Section 6.1.
3. Introduces Active Brainstorming in Section 6.2 as a way to increase the number of ideas generated by brainstorming using the HTPs coupled with the Kipling questions "who, what, where, when, why and how" (Kipling, 1912).
4. Introduces three problem-solving Idea Storage Templates (IST) in Section 6.3 for storing the ideas produced in the Active Brainstorming session.
5. Contains three examples of using the HTPs and ISTs in Section 6.4.
6. Contains suggestions for using the perspectives perimeter in creating innovative solutions to provide a context for the examples in Section 6.5 and those that follow in the remainder of the book.

Chapter 7:

1. Discusses the nature of systems because:

    1) Undesirable situations, desirable situations, problems and solutions tend to manifest themselves in systems.

   2) The process to change from an undesirable situation to a desirable situation incorporates the problem-solving process which often includes or overlays the System Development Process (SDP).
   3) The process is itself a system.

2. Begins with a list of definitions of a system in Section 7.1.
3. Perceives the nature of systems from the different HTPs in Section 7.2.
4. Introduces yet another definition of a system in Section 7.3.
5. Discusses basic system behaviour in Section 7.4
6. Discusses the properties of systems in Section 7.5.
7. Introduces a standard functional template for a system from which it should be possible to develop a set of reference functions for any class of system in Section 7.6.
8. Discusses complex systems in Section 7.7.
9. Discusses ways of reducing complexity in Section 7.8 including examples of how to optimise systems based on the interactions at the interfaces of the subsystems.

Chapter 8:

1. Discusses decision-making because decision-making is at the heart of problem-solving. Decision-making is the part of the problem-solving process, where the candidate solutions, options or choices are evaluated against predetermined selection criteria and a decision is made to select one or more of the options. The decision may be easy or difficult, simple or complicated. Some decisions can be made instantaneously; some decisions may require weeks or even years of study to gather the relevant information necessary to make the decision. Some people have problems making decisions; others make decisions instantaneously or intuitively.
2. Begins by discussing qualitative and quantitative decision-making Section 8.1.
3. Introduces a number of decision-making tools in Section 8.2.
4. Discusses decision traps that produce bad decisions in Section 8.3.
5. Discusses decision outcomes including how to avoid unanticipated consequences in Section 8.4.
6. Discusses sources of unanticipated consequences in Section 8.5.
7. Discusses risk and opportunity in decision-making in Section 8.6.
8. Discusses the four key elements in making decisions with several anecdotal examples in Section 8.7.

9. Summarises Decision Trees and Multi-attribute Variable Analysis (MVA) in Section 8.8.

Chapter 9:

1. Discusses problems and solutions, the assumptions behind problem-solving, and ways to remedy problems and introduces a holistic approach to managing problems and solutions.
2. Begins with the properties a of good problem statement in Section 9.1.
3. Discusses the problem posed by the different meanings of the word 'problem' in Section 9.2.
4. Discusses the initial reaction to a problem in Section 9.3.
5. Discusses the traditional problem-solving process in Section 9.4.
6. Provides some examples of the systems engineering approach in Section 9.5.
7. Examines the relationship between problems and solutions in Section 9.6.
8. Discusses the holistic extended problem-solving process in Section in Section 9.7.
9. Discusses the difference between problems and symptoms in Section 9.8.
10. Discusses the assumptions underlying formal problem-solving in Section 9.9.
11. Discusses the components of problems in Section 9.10.
12. Discusses a problem formulation template used in this book in Section 9.11.
13. Classifies problems in four ways in Section 9.12.
14. Defines the problem classification matrix discussed in Section 9.13.
15. Describes ways of remedying problems in Section 9.14.
16. Compares varieties of the problem-solving process in Section 9.15.
17. Discusses the System Lifecycle (SLC) as an example of a complex problem solving process in Section 9.16.
18. Discusses the real world including two examples of how people adapt it when problem solving often in unexpected ways in Section 9.17.
19. Discusses remedies for complex problems based on the structure of the problem rather than the complexity of the problem in Section 9.18.
20. Discusses the complex problem solving process perceived as being made up of multiple series-parallel iterations of the non-complex problem-solving process in Section 9.19.

21. Discusses the dynamic complex situational loop in Section 9.20.

1.5.3. Part III

Part III:

- Provides examples of innovative solutions to complex problems.
- Shows how the progressive perspectives go beyond systems thinking and contribute to the innovative solutions.
- Concludes by suggesting things you can do to start to become an innovator.

Chapter 10 provides examples of holistic thinking as follows:

1. The Command, Control, Communications and Intelligence (C3I) group morale issue discussed in Section 10.1.
2. The Multi-Satellite Operations Control Center (MSOCC) data switch replacement project discussed in Section 10.2.
3. Developing an optimal classroom teaching and learning environment discussed in Section 10.3.
4. Creating and guide a successful student software engineering project class when the instructor is halfway around the world discussed in Section 10.4.
5. The apartment dwellers' amateur radio antenna system discussed in Section 10.5.

Each example not only illustrates how the problem-solving process was tailored but provides examples of other aspects of finding innovative solutions to complex problems such as where things went correctly and where and how things can and did go wrong.

Chapter 11:

1. Provides macro and micro examples of perceiving several issues/systems from various points on the perspectives perimeter for different purposes, the insights obtained and the resulting innovative solutions. The issues/systems discussed in this Chapter are from a number of domains in different degrees of complicatedness and complexity to help you to relate to one or more of the examples and provide knowledge that may be applicable in your "box".
2. Provides examples of holistic thinking as follows:

    1) The National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) Pacor Panic Attack discussed in Section 11.1.

2) An alternative teaming approach for Small and Small Disadvantaged Businesses (SDB) in certain types of government contracts discussed in Section 11.2.
3) Redrawing the contractor - sub-contractor boundaries in certain types of Defence contracts discussed in Section 11.3.
4) Addressing the problem of vertically integrating Taiwan's small and medium sized enterprises discussed in Section 11.4.
5) Determination of a set of risk-indicators to predict project failure discussed in Section 11.5.
6) Dealing with the ALSEP Command Verification Word Failure (CVW) discussed in Section 11.6.

Chapter 12:

1. Provides suggestions for how you can go about creating your own innovative solutions to complex problems.
2. Summarizes practical ways to use the tools and methodologies presented in this book.
3. Discusses innovation.
4. Begins with a summary of the previous chapters of the book in Section 12.1 to refresh your memory.
5. Discusses generating ideas in Section 12.2.
6. Discusses the four steps of creativity in Section 12.3.
7. Discusses maximising creativity in Section 12.4.
8. Discusses habits that hinder creating and adopting new ideas in Section 12.5.
9. Discusses perceiving similarities where others do not and its consequences to you in Section 12.5.6 with some examples.
10. Discusses perceiving differences to dissolve paradoxes and create the impossible in Section 12.7.
11. Discusses examining complex descriptions of situations in Section 12.8.
12. Discusses pretending you are living a Case Study in Section 12.9.
13. Discusses two examples of combining parts into a new innovative application in Section 12.10.
14. Discusses perceiving things differently in 12.11.
15. Summarises the Chapter in Section 12.12.
16. Closes with a last word in Section 12.13.

1.6. Acronyms

This Section contains a listing of the acronyms used in the book to save you having to memorise those that are new to you.

ALSEP	Apollo Lunar Surface Experiments Packages
AP	Application Processor (MSOCC)
ASCII	American Standard Code for Information Interchange
ASPC	Attached Shuttle Payload Center (MSOCC)
ATM	Automatic bank Teller Machine
ATR	Associate Technical Representative (MSOCC)
ATSS	Advance Team Scheduling System
ATU	Antenna Tuning Unit
BPR	Business Process Reengineering
C3	Command, Control, Communications
C3I	C3, and Intelligence
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
CATWOE	Customers Actors Transformation Weltanschauung Owners Environment (SSM)
CBD	Central Business District
CBD	Commerce Business Daily
CDR	Critical Design Review
CES	Control And Electronics System (LuZ)
CMF	Command Management Facility (MSOCC)
CMM	Capability Maturity Model
CONOPS	Concept of Operations
COTR	Contracting Officer's Technical Representative (MSOCC)
COTS	Commercial-off-the-Shelf
CPM	Critical Path Method
CSDC	Corporate Synergy Development Center (Taiwan)
CVW	Command Verification Word
DMSMS	Diminishing Manufacturing Sources and Material Shortages
DOCS	Data Operations Control System (MSOCC)
DOD	Department of Defense (US)
DODAF	DOD Architecture Framework
DRR	Delivery Readiness Review
DSN	Deep Space Network (MSOCC)
DSTD	Defence Systems and Technology Department
EDF	Engaporean Defence Forces
FASA	Federal Acquisition Streamlining Act
FCFDS	Feasible Conceptual Future Desired Situation
FDDI	Fiber Distributed Data Interface
FP	Function Point

FRAT	Functions Requirements Answers and Test
FRD	Functional Requirements Document (MSOCC)
GIGO	Garbage-In-Garbage-Out
GDRC	Global Development Research Center
GSFC	Goddard Space Flight Center
HRS	History Recording System (MSOCC)
HTP	Holistic Thinking Perspective
IC	Integrated Circuit
ID	identification
IDB	Industry Development Bureau (Taiwan)
IDEF	Integration Definition for Function Modelling
IEAust	Institute of Engineers Australia
ILS	Index of Learning Styles
INCOSE	International Council on Systems Engineering
IP	Intellectual Property
ISBN	International Standard Book Number
ISO	International Standards Organization
IST	Idea Storage Template
IV&V	Independent Verification and Validation
JIT	Just-In-Time
LAN	Local Area Network
LEO	Low Earth Orbit
LCC	Life Cycle Costing
LOC	Local Controller (LuZ)
MATO	Multiple-Award-Task-Ordered
MCSS	MSOCC Communication Switching System (MSOCC)
MCSSRP	MSOCC Switching System Replacement Project
MOE	Measure of Effectiveness
MOEA	Ministry of Economic Affairs
MOU	Memorandum of Understanding
MPT	Mission Planning Terminal (MSOCC)
MS&T	Missouri University of Science and Technology
MSOCC	Multiple-Satellite Operations Control Center (MSOCC)
MSWE	Master of Software Engineering (at UMUC)
MTTR	Mean Time To Repair
MVA	Multi-attribute Variable Analysis
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications Network (MSOCC)
NGT	Nominal Group Technique
NIH	Not Invented Here

NMOS	Network Maintenance and Operations Support
O&M	Operations and Maintenance
OARP	Observations Assumptions Risks Problems
OCR	Operations Concept Review
OVAE	Office of Vocational and Adult Education
Pacor	Packet Processor Data Capture Facility
PAM	Product-Activity-Milestone
PDR	Preliminary Design Review
PERT	Program Evaluation Review Technique
PI	Principal Investigator
PIN	Personal Identification Number
PWC	Pair-Wise Comparison
RAF	Royal Air Force
RAFBADS	RAF Battle of Britain Air Defence System
RFP	Request for Proposal
RID	Review Item Discrepancy (MSOCC)
RRS	Reward and Recognition System
SDB	Small Disadvantaged Business
SDP	System Development Process
SDLC	System Development Lifecycle
SEAS	Systems Engineering and Services
SEGS	Solar Electrical Generating System (LuZ)
SESA	Systems Engineering Society of Australia
SETA	Systems Engineering and Technical Assistance
SLC	System Lifecycle
SME	Small and Medium Enterprise
SOI	System of Interest
SPARK	Schedules Products Activities Resources risKs
SPC	Statistical Process Control
SRR	System Requirements Review
SSM	Soft Systems Methodology
ST	Send Timing (MSOCC)
STALL	Stay calm, Think, Ask questions and analyse the answers, Listen, Listen
SWOT	Strengths Weaknesses Opportunities Threats
TCO	Total Cost of Ownership
TQM	Total Quality Management
TRIZ	Theory of Inventive Problem-solving
TT&C	Telemetry Tracking and Control
TTL	Transistor-Transistor-Logic
UAV	Unmanned Aerial Vehicle

UMUC	University of Maryland University College
URL	Uniform Resource Locator
US	United States (of America)
USB	Universal Serial Bus
VIP	Very Important Person
VOIP	Voice over the Internet
WBS	Work Breakdown Structure
WP	Work Package

1.7. Glossary

This Section contains a glossary of common words with the meanings applied herein to assist the reader because the literature abounds with descriptions of different varieties of the problem-solving process often using the same words but with slightly different meanings.

Ability	The *required* competence to perform a function successfully.
Analysis	See Section 4.1.1
Argument	Is not a dispute. It is defined as "*an arranged set of statements or propositions (the premises) advanced by an agent in order to support the truth or acceptability of another statement or proposition (the conclusion)*" (Juthe, 2005).
Claim	A belief or an opinion (*Scientific* perspective).
Complex	See Section 7.7.3.
Complicated	See Section 7.7.3.
Conclusion	An output of the reasoning process (*Scientific* perspective).
Critical thinking	See Section 5
Decompose	To separate or resolve into constituent parts or elements.
Elaboration	Work out with great care and nicety of detail.
Explanation	Clarifies a statement in some way, e.g. what it is made of, how it works, etc.
Fact	A verifiable statement of what is true.
Holistic thinking	The combination of analysis, systems thinking and critical thinking.
Myth	What people think is a fact; but is, in fact, not true (descriptive perspective).
Opinion	An output of a reasoning process (based on a combination of facts and myths).
Premise	Provides reasons for someone to accept a con-

	clusion (*Scientific* perspective).
Problem	Any questions or matters involving doubt, uncertainty, or difficulty (Section 9.2).
Satisfy	Solutions that are optimal.
Satisfice	Solutions that are acceptable.
Simple	Easy to understand, deal with, use, etc.
Situation	The state of affairs; combination of circumstances.
Skill	The *observable or measured* competence in performing the function
Solution	The remedy to a problem, answer to a question, etc.
Symptom	Any phenomenon or circumstance accompanying something and serving as evidence of it.
System	See Section 7.1 and especially 7.3.
Systems engineering	The application of holistic thinking to solving problems.
Systems thinking	See Section 4.1.2.
Thinking	The exercising or occupying of the mind, especially the understanding, in an active way; engagement in mental action or activity.

1.8. Summary

This Chapter:

1. Explained how to read and use the book in Section 1.1.
2. Explained why the book was written in Section 1.2.
3. Explained the gap filled by the book in Section 1.3.
4. Explained why the systems approach is important in Section 1.4.
5. Introduced the contents of the book in Section 1.5.
6. Provided a list of acronyms used in the book in Section 1.6.
7. Provided a glossary of the meanings of some specific words used in the book in Section 1.7 since their meaning in the literature often depends on the author.

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Part I
Thinking and ideas

Figure 1.1 The Thinker

2. Thinking and thinking tools

Solving problems requires us to think using all our mental capacities at the appropriate times to convert an undesirable situation to a Feasible Conceptual Future Desired Situation (FCFDS). Providing innovative solutions generally requires creative thinking. For without thinking up ideas, there will be no solutions, innovative or otherwise. This Chapter:

1. Introduces you to thinking and introduces some of the tools you can use to assist your creative thinking.
2. Starts with an introduction to some types of thinking in Section 2.1.
3. Introduces types of thinking in Section 2.2.
4. Discusses top down and bottom up thinking in Section 2.3.
5. Discusses judgment and creativity in Section 2.4.
6. Introduces a concept map as the basic tool for thinking in Section 2.5.
7. Describes just a few of the tools that can help you to think starting with tools for generating ideas in Section 2.6 and a few tools to assist with thinking in Section 2.7.
8. Ends with a quick reference table to help you select the appropriate tool for the thinking task.

2.1. Thinking

Figure 1.1 shows a reproduction of Auguste Rodin's bronze casting 'the thinker' first presented to the public in 1904. What is he thinking about? Nobody knows. How does he think? Nobody knows. Where do ideas come from? Nobody knows, but we can imagine or hypothesize that ideas are generated in a sequence. Something creates a thought which triggers the next thought and so on. Sometime later a different something may trigger a new thought and a similar sequence of ideas is generated. Sometimes the train of thought is interrupted and a new chain is initiated. Examples of such interrupts are loud noises, aromas, alarms, flashing lights, beautiful women, etc.

Thinking is a cognitive act performed by the brain. Cognitive activities include accessing, processing and storing information. The most widely used cognitive psychology information processing model of the

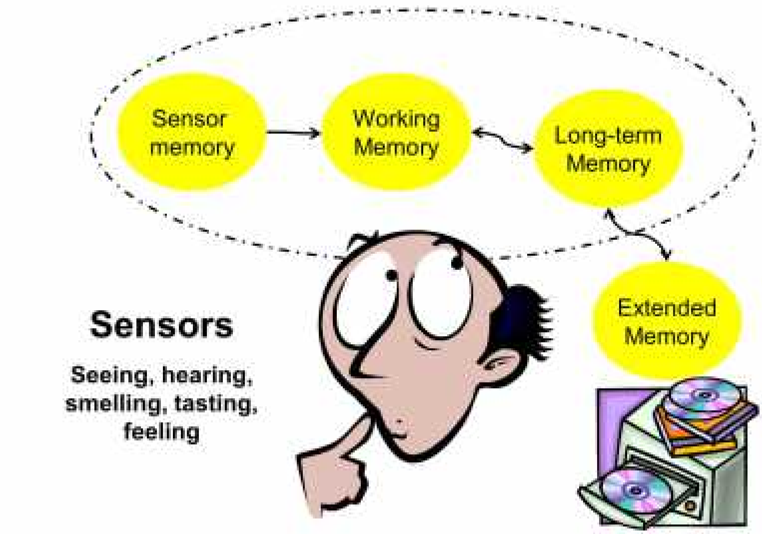

Figure 2.1 The human information system

brain based on the work of Atkinson and Shiffrin (Atkinson and Shiffrin, 1968) cited by Lutz and Huitt (Lutz and Huitt, 2003) likens the human mind to an information processing computer. Both the human mind and the computer ingest information, pro cess it to change its form, store it, retrieve it, and generate responses to inputs (Woolfolk, 1998). These days we can extend our internal memory using paper notes, books and electronic storage as shown in Figure 2.1.

When we view the world, our brain uses a filter to separate the pertinent sensory input from the non-pertinent. This filter is known as a "*cognitive filter*" in the behavioural science literature (Wu and Yoshikawa, 1998), and as a "*decision frame*" in the management literature (Russo and Schoemaker, 1989). Cognitive filters and decision frames:

- Are filters through which we view the world.
- Include political, organizational, cultural, and metaphorical, and they highlight relevant parts of the system and hide (abstract out) the non-relevant parts.
- Can also add material that hinders solving the problem[1]. Failure to abstract out the non-relevant issues can make things appear to be more complex and complicated than they are and gives rise to artificial complexity (Section 7.7.2).

[1] For example, the differences between the Catholics and Protestants in Northern Ireland are major to many of the inhabitants of that country, but are hardly noticeable to most of the rest of the world.

The brain connects concepts using a process called reasoning or thinking. Thinking has been discussed and classified in various ways in the literature including:

1. Thinking discussed in Section 2.1[2].
2. Types of thinking discussed in Section 2.2.
3. Top-down and bottom-up thinking discussed in Section 2.3.
4. Judgement and creativity discussed in Section 2.4.

2.2. Types of thinking

We use our mental capacity to think about something received from a sense (hearing, sight, smell, taste and touch). From a functional standpoint our mental capacities might be oversimplified as follows: (Osborn, 1963: page 1):

- ***Absorptive:*** the ability to observe, and to apply attention.
- ***Retentive:*** the ability to memorize and recall.
- ***Reasoning:*** the ability to analyse and to judge.
- ***Creative:*** the ability to visualize, to foresee, and to generate ideas.

2.3. Top-down and bottom-up thinking

When we think about something we tend to mix and combine top-down (analysis) and bottom-up (synthesis) thinking.

2.3.1. Analysis

Analysis is breaking a complicated topic into several smaller topics and thinking about each of the smaller topics. Analysis can be considered as a top-down approach to thinking about something and is associated with René Descartes (Descartes, 1637, 1965). It has been termed reductionism because it is often used to reduce a complicated topic to a number of smaller and simpler topics.

2.3.2. Synthesis

Synthesis refers to combining two or more entities to form a more complicated entity. Synthesis can be considered as a bottom-up approach to thinking about something.

[2] This format using "*discussed in Section …*" is an example of holistic thinking. The format provides the reader with a quick way to find the content and at the same time allows the author to check that everything in the list is present, a section is not in the list (at the time of writing) and the section heading numbers are at the correct level in the hierarchy.

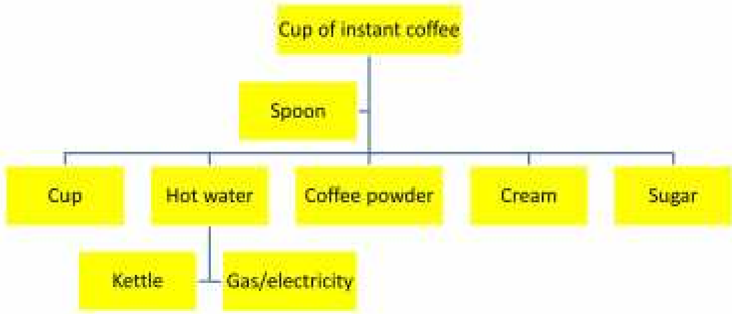

Figure 2.2 Initial set of ideas pertaining to a cup of instant coffee

2.3.3. Combining analysis and synthesis

When faced with a complex problem we break it up into smaller less-complex problems (analysis), then solve each of the smaller problems and hope that the combination of solutions to the smaller problems (synthesis) will provide a solution to the large complex problem. For example, consider the problem of making a cup of instant coffee. We use analysis to identify and list the components that make up the complete cup of instant coffee. So the coffee powder, cup, hot water, cream and sugar spring to mind. We then use synthesis to create the cup of instant coffee from the ingredients. When we think of the process, we think of mixing the ingredients and so we think of a spoon; when we think of heating the water, we think of a kettle and gas or electricity as the fuel.

A typical initial set of ideas for making a cup of instant coffee is shown in Figure 2.2. The spoon is drawn as an assistant to the cup of coffee because it is used during the process of creating the cup of instant coffee and then discarded. The kettle and gas/electricity are associated with heating the water and so are shown in a similar manner as assistants to the hot water. However, this arrangement mixes concepts at different levels of the hierarchy and a better arrangement of the ideas is shown in Figure 2.3. The insertion of an abstract or virtual 'ingredients' concept into the chart clarifies the arrangement of ideas showing which ideas constitute the ingredients and which ideas are associated with other aspects of the cup of instant coffee.

However, Figure 2.3 should only be considered as an interim or working drawing and a better final drawing is shown in Figure 2.4 which clearly distinguishes between the items associated with the cup of instant coffee and the aggregation of the spoon and kettle into an abstract concept called 'kitchen items', the constituents of which are used in the process of creating the cup of instant coffee.

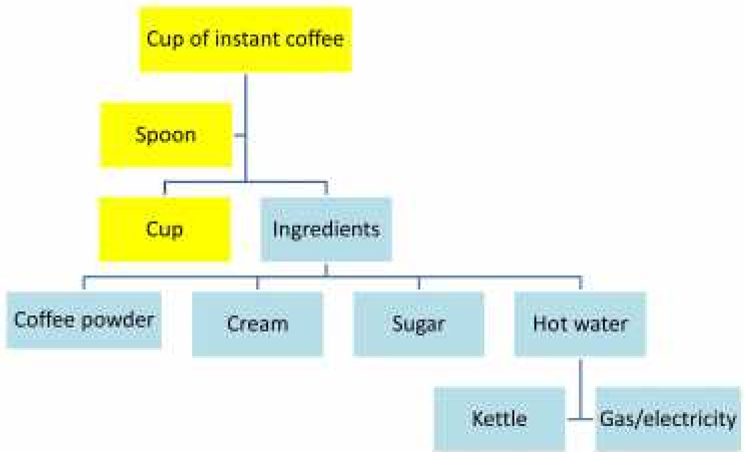

Figure 2.3 Hierarchical arrangement of ideas pertaining to a cup of instant coffee

2.4. Judgment and creativity

Our thinking mind is mainly two-fold (Osborn, 1963: page 39):

- ***A creative mind:*** visualizes, foresees, and generates ideas.
- ***A judicial mind:*** analyses, compares and chooses.

Both judgment and creativity are alike in that they both use analysis and synthesis, but they do so in different ways. In judgment we analyse facts, weigh them, compare them, reject some and keep others, and then create a conclusion (a guess or a hypothesis). Judgement is one aspect of critical thinking discussed in Section 5.1.3.2. On the other hand the creative process does much the same but uses imagination to produce ideas

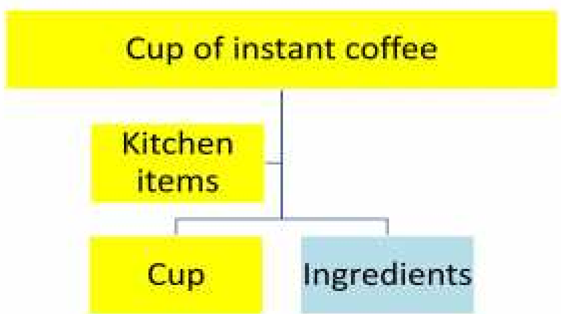

Figure 2.4 Top level hierarchical chart for a cup of instant coffee

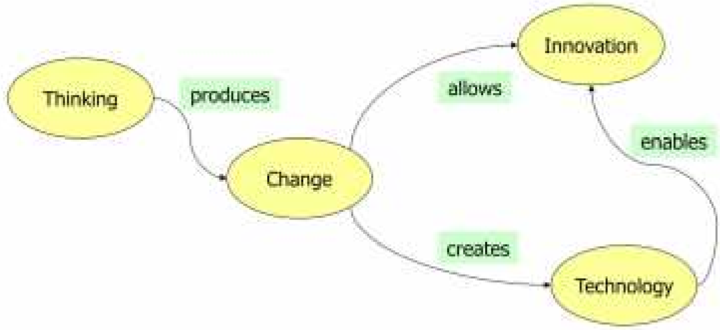

Figure 2.5 Typical concept map connecting ideas about thinking

instead of judgments[3].

2.5. Concept maps - connecting the ideas

The tool most often used to connect ideas is a concept map sometimes called an affinity diagram. A concept map is the generic name for a diagram that shows the association or connections between ideas or things. Concepts may be associated in many ways including the following:

- Linear and circular: such as in a process.
- Hierarchical: such as in an organization.
- Spider or centre outwards.

A typical concept map showing the way one person might connect the concepts of 'thinking', change', 'innovation' and 'technology' is shown in Figure 2.5. The association depicted is that 'thinking' produces 'change' which both allows 'innovation' and creates 'technology' and 'technology' enables 'innovation'. Concept maps show up in many guises, including subway and city maps, the diagrams used in Integration Definition for Function Modelling (IDEF), and process and software flow charts. Note in this instance the relationship between the concepts is shown in the diagram to clarify the connection.

The two most common mistakes made when presenting concept maps are:

1. ***Showing a mixture of ideas or objects at different levels in the hierarchy*** such as in Figure 2.6. The ideas or objects should have been sorted and aggregated prior to presentation and

[3] Note that imagination can be used to create innovative judgments!

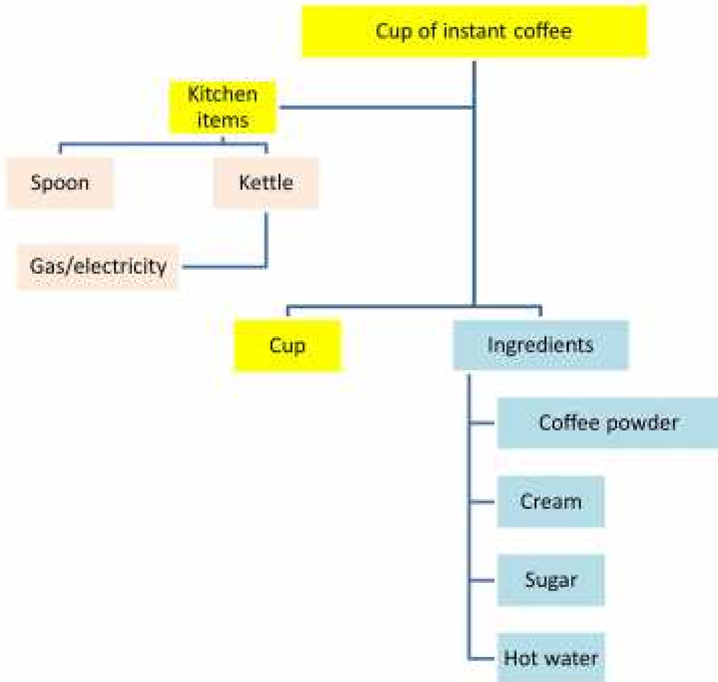

Figure 2.6 Sorted hierarchical arrangement of ideas pertaining to a cup of instant coffee

shown in the appropriate drawings as shown in Figure 2.4 and Figure 2.7.

2. ***Showing too many items in the concept map*** such as in Figure 7.11[4]. Namely, we do not remove the clutter by grouping the concepts into a hierarchy of ideas so as to make the final version of the drawing conform to Miller's rule, namely to limit the number of items in the map at 7±2 items (Miller, 1956).

2.6. Generating ideas

A number of ways of generating ideas (ideation):

- Have been developed and used over the years.
- Tend to be ways of storing and dealing with ideas once they have been generated.
- Include the following discussed in this Section:

[4] Yes, this is a forward reference because the figure is discussed in that section and is just pointed at in this Section.

Figure 2.7 The ingredients

1) Association of ideas discussed in Section 2.6.1.
2) Brainstorming discussed in Section 2.6.2.
3) Slip writing discussed in Section 2.6.3.
4) Nominal Group Technique (NGT) discussed in Section 2.6.4.
5) Lateral thinking discussed in Section 2.6.5.
6) Active Brainstorming discussed in Section 2.6.6.
7) Letter and word manipulation discussed in Section 2.6.7.

2.6.1. Association of ideas

Ideas can be generated via association by individuals or by groups. When ideas appear in succession, there is a relationship or association between an idea and the following one as mentioned in Section 2.5. This relationship can be expressed in the traditional three laws of association which go back to the time of Aristotle (384 to 322 BC) (Osborn, 1963: page 114), namely:

1. ***Contiguity:*** nearness, the association is something that reminds you of something else.
2. ***Similarity:*** the idea is similar to something.
3. ***Contrast:*** the idea is opposite or a contrast to something.

Other types of association include:

- ***Functional:*** the ideas are about something that does the same thing, even if the implementations are different. For example, travelling by bus and airplane; two different implementations of the travelling function.
- ***Temporal:*** the ideas are about things that happen at the same time.
- ***Procedural:*** the ideas always follow in a certain sequence.
- ***Operational:*** the ideas are about things that operate on the same item. For example, a brush and a comb both operate (are used) on hair.
- ***Coincidental:*** there does not seem to be any association between the ideas in the minds of the people to whom the ideas are communicated.

Association can work through sounds, pictures, aromas as well as words; in fact through any sense you have.

2.6.2. Brainstorming

Brainstorming (Osborn, 1963) as a technique for ideation in small groups is based on the association of ideas discussed in Section 2.6.2 where one idea triggers the next. In brainstorming and other ideation techniques discussed in this Section, the number of ideas generated will be greater if the participants are notified ahead of time:

1. As to the purpose of the ideation meeting.
2. The problem to be addressed.
3. Are asked to bring some ideas with them.

Osborn's original basics for brainstorming were (Osborn, 1963: page 156):

- No criticism of ideas.
- Encourage wild and exaggerated ideas.
- Go for large quantities of ideas.
- Build on each other's ideas.

Brainstorming can be performed by an individual or by a team. In team sessions, a group of people get together, are given a problem statement and ideate (produce ideas). The brainstorming team contains:

- A leader/facilitator who guides the session and enforces the rules.
- A scribe who records the ideas.
- A small number of people who will do the ideation.

2.6.2.1. Requirements for brainstorming sessions

Brainstorming sessions shall conform to the following requirements:

1. The facilitator shall introduce the session by stating a specific problem rather than a general situation.
2. The scribe shall record all of the ideas.
3. The participants shall state their ideas.
4. The participants shall suggest modifications of ideas previously stated to improve the idea or combine two or more ideas into another idea.
5. The participants shall not self-censor their ideas before stating them. This is because other people may like those ideas or see them from a different perspective and subsequently build on those ideas to produce something better.

6. There shall be no criticism of ideas during the session.
7. The ideas shall be evaluated and sorted after the brainstorming session.
8. There shall be no limit on the scope of the ideas. Wild ideas can be tamed down later if appropriate.
9. There shall be minimal discussion on ideas and only for the purpose of clarification.
10. The facilitator shall not allow the session to break up into groups.
11. The composition of the participants shall be mixed in age, sex, and experience and domain knowledge.
12. Participants should ideally be at the same level in the organizational hierarchy to minimize the intimidation effect where people lower in the hierarchy are unwilling to disagree with people higher up. If rank is mixed, lower ranks shall speak first.

While a number of variations of brainstorming have been described in the literature, they all tend to suffer from a number of defects including:

- Being a generally passive approach because they are based on waiting for the ideas to be generated before writing them down[5].
- Team sessions being prone to capture by the most opinionated person in the brainstorming session.
- Being unstructured, while allowing free range of ideas, tends to fail to focus on issues pertinent to the session.

2.6.3. Slip writing

The Crawford Slip Method (CSM) was developed by Dr C. C. Crawford, a Professor of Education at the University of Southern California in the 1920's (Mycoted, 2007) as a tool for ideation in very large groups (Ballard and Trent, 1989). The five-step slip writing process is as follows.

1. The participants are given slips of paper and pens or pencils.
2. The facilitator poses the focused question (problem) in the same manner as in brainstorming.
3. The participants write down the ideas that come to mind.
4. When the writing slows down, the slips are collected and ideas collated.
5. In many instances summaries of the ideas are provided to the participants after the session.

[5] There are variations which trigger ideas using 'what' and 'why' questions.

In some variations such as classroom sessions, the ideas are written on Post-it® Notes, one idea per sticky slip. When ideation has stopped, the participants step up to a wall or a whiteboard in turn and read out their ideas, posting the slips as one column to one idea. After the first person has finished, each subsequent person who has a similar or identical idea to a previous one posts the idea below the original idea. When everyone has posted their ideas, the breadth of the columns represent the number of ideas and the depth of a column represents the number of participants who thought of the same idea. The breadth will generally reflect the diversity of the participants.

Slip writing only collects the initial ideas. As slip writing does not include the hitchhiker effect of association of ideas experienced in brainstorming, slip writing should generally only be used as an ideation tool in large groups.

2.6.4. Nominal Group Technique

The Nominal Group Technique (NGT) is a methodology designed to allow every member of the group to express their ideas while minimizing the influence of other participants (the capture effect by the most opinionated that tends to occur in brainstorming). NGT should be used when:

- You want to generate a lot of ideas and want everyone to participate freely without influence from other participants.
- You want to identify priorities of proposed solutions or select a few alternatives for further examination.
- When you want to avoid heated conflict because the issue is controversial.

NGT has a number of variations, but the basic process is something like the following.

1. The facilitator poses the focused question stating the problem or issue.
2. The participants write down their ideas just like in slip writing.
3. After the ideation process has dried up, the facilitator asks each participant in turn to state one idea. The idea is written down on the whiteboard. No comments or discussion of each idea is allowed. After everybody has expressed an idea, the cycle repeats as long as someone has an idea to share. Participants may "pass" on their turns, and may then add an idea on a subsequent turn providing for hitchhiking of ideas generated by association.

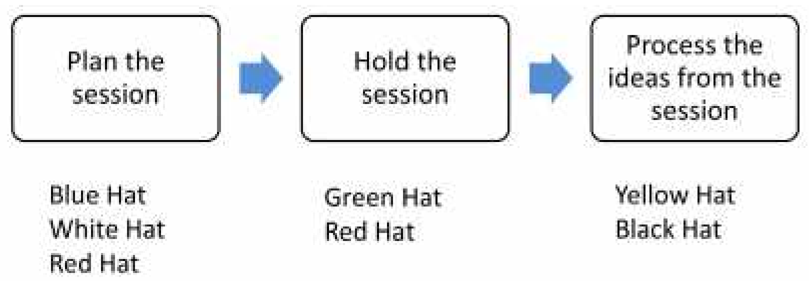

Figure 2.8 Where and when the hats fit into the process

4. The ideas are discussed in turn, and clarified as necessary. Combination and discarding does not take place at this time.
5. Each participant is then asked to privately list his or her top ten ideas in order of priority and give the list to the facilitator. If there are a large number of ideas this may be a done as a two-step process, first listing the top ten ideas, and then prioritising the ideas.
6. The facilitator then records the rankings and averages the scores. This may be done during a coffee or tea break or as a group thereby adding an element of fun, the facilitator may write the ideas on the whiteboard, flip charts or projected spread sheets and add stars next to each idea as they show up on subsequent lists, and the participants can watch the idea rankings change in a similar manner to watching election results on television.

2.6.5. Lateral thinking

Lateral thinking is a tool for handling insight and the generation of new ideas (de Bono, 1973: pages 10 to 11). De Bono claims that lateral thinking is different from traditional "vertical" thinking which moves from idea to idea in a sequential manner to reach a conclusion. The difference being that traditional vertical thinking focuses on a solution and the details associated with the solution, for example, how deep to dig a hole and how wide the hole should be; while lateral thinking produces a set of alternatives, for example it can tell you to dig the hole in a different place or even ways to achieve the objective without resorting to having to dig the hole. Lateral thinking:

- Takes place before, during and after the ideation session.
- Separates creation of ideas and judgment of ideas.
- Uses the metaphor of six coloured thinking hats.

The different thinking hats are used when planning, during and after the ideation meeting as shown in Figure 2.8 are:

1. Blue Hat thinking discussed in Section 2.6.5.1.
2. White Hat thinking discussed in Section 2.6.5.2.
3. Green Hat thinking discussed in Section 2.6.5.3.
4. Yellow Hat thinking discussed in Section 2.6.5.4.
5. Black Hat thinking discussed in Section 2.6.5.5.
6. Red Hat thinking discussed in Section 2.6.5.6.

2.6.5.1. Blue Hat thinking

Blue Hat thinking:

- Generally takes place *before* the ideation session.
- Is used when planning ideation sessions or meetings.
- Identifies the:
    - Focus of the meeting.
    - Agenda.
    - Participants who need to be at the meeting.

Questions to trigger Blue Hat thinking include:

- What roles will the attendees play?
- How long will the meeting last?
- How much time will be spent on each part of the agenda?
- How to make sure everyone participates?
- How to summarize the results?
- Who will take what action after the meeting?

2.6.5.2. White Hat thinking

White Hat thinking:

- Generally takes place *before* the ideation session.
- Assesses the relevance and accuracy of information:
    - Supplied to the meeting participants.
    - Produced as ideas.
- Separates facts from speculation
- Notes both views when there is conflicting information.

Questions to trigger White Hat thinking before the ideation meeting include:

- What do we know?
- What do we need to know?

- How will we get the missing information?

2.6.5.3. Green Hat thinking

Green Hat thinking:

- Generally takes place *during* the ideation session.
- Generates the ideas.
- Is the one used in the ideation meeting to look for:
    - New ideas and alternatives.
    - Modify and remove faults in existing ideas.

2.6.5.4. Yellow Hat thinking

Yellow Hat thinking:

- Generally takes place *after* the ideation session.
- Is used when processing ideas generated by Green Hat thinking.
- Helps to determine upsides of ideas, namely the benefits of the ideas.

Questions to trigger Yellow Hat thinking include:

- What benefit/value/return on investment does the idea offer?
- Why do we think the idea might/might not work?

2.6.5.5. Black Hat thinking

Black Hat thinking:

- Generally takes place *after* the ideation session.
- Is used when processing ideas generated by Green Hat thinking.
- Is the compliment to Yellow Hat thinking and deals with the down side of the ideas, namely risks associated with, or concerns about, the ideas.

Questions to trigger Black Hat thinking include:

- What problems are associated with this idea?
- What might go wrong if it is implemented?
- Why do we think the idea might fail?

2.6.5.6. Red Hat thinking

Red Hat thinking:

- Generally takes place *before* and *during* the ideation session.
- Is concerned about the feelings, intuition and emotion of the participants in a meeting.

- Is used:
    - When planning the meeting.
    - By the meeting facilitator during the meeting itself since participant's feelings can change over time as the result of some action taken by another participant.

Questions to trigger Red Hat thinking include:

- What are the concerns of each participant?
- How can those concerns be addressed?
- How does/will each participant feel about the agenda?
- How does/will each participant feel about particular ideas?
- How does/will each participant feel about the decisions to be taken/during or after the meeting?
- Should a participant receive special treatment?
- How does/will each participant feel about the steps to be taken after the meeting?

2.6.6. Active Brainstorming

Active Brainstorming is a systemic and systematic way of applying systems thinking and analysis to an issue and is described in detail in Section 6.1.3 because it uses the Holistic Thinking Perspectives (HTP) described in Section 4.3 which have to be described first.

2.6.7. Letter and word manipulation

Letter manipulation transposes letters in words and removes or adds letters to trigger ideas. For example, change:

- Bundle to bungle.
- Create to crate.
- Deploy to destroy.
- Draft to daft.
- Expensive to expansive or extensive.
- Explore to explode.
- Feel to fuel.
- Fuming to fusing.
- Guest to ghost.
- Point to pint.

In word manipulation change one word for another word to trigger ideas. For example, change a word to one:

- ***With an opposite meaning:*** for example, change 'good' to 'bad' or change 'cheap' to 'expensive'.
- ***Of the same generic type:*** for example, change 'dog' to 'cat'.
- ***Which sounds almost the same:*** for example, change 'illuminate' to 'eliminate'.

2.7. Tools to assist with thinking

This Section discusses a number of tools that can be used to assist thinking. These tools are:

1. Lists discussed in Section 2.7.1.
2. Concept maps discussed in Section 2.7.2.
3. Graphs discussed in Section 2.7.3.
4. Humour (cartoons and jokes) discussed in Section 2.7.4.
5. Tables and matrices including N^2 charts discussed in Section 2.7.5.
6. Software discussed in Section 2.7.6.

2.7.1. Lists

Lists:

- Contain a number of items, such as in to-do lists, shopping lists, delivery lists and laundry lists.
- Are useful tools to group concepts together. For example:
  - The list might be an end in itself when thinking about what to purchase at the grocery store or what to send to the laundry.
  - A list is a tool to use when identifying entities in a situation. In this situation, you'd make a list of the relevant items/parts and then try and build a concept map showing the relationships between the items on the list. if the concept map does not identify a relationship between two items on the list, it may be an indication that something is missing from the list.

2.7.2. Concept maps

Concept maps (Section 2.5) are diagrams used to show how ideas connect as well as showing relationships between items. Examples of these types of diagrams include:

1. Flow charts discussed in Section 2.7.2.1.
2. Cause and effect charts discussed in Section 2.7.2.2.

3. Product-Activity-Milestone (PAM) charts discussed in Section 2.7.2.3.
4. Causal loops discussed in Section 2.7.2.4.
5. Program Evaluation Review Technique (PERT) charts discussed in Section 2.7.2.5.
6. Integration Definition for Function Modelling (IDEF) charts discussed in Section 2.7.2.6.
7. Hierarchical charts discussed in Section 2.7.2.7.
8. Rich Pictures discussed in Section 2.7.2.8.

2.7.2.1. Flow charts

A flow chart is a graphic representation of the procedural association between items. It is often used when thinking about:

- The relationship among parts of a process.
- A signal (data) flow through a data processing system.

The items shown in a flow chart include:

- ***Activities:*** in sequential order.
- ***Decisions:*** by which alternative sequences of activities are chosen.

Depending on the content in which it is used, the flow chart maybe used to think about something that exists or to think about something that is desired. The rules for drawing a flow chart are:

1. All information shall flow into process inputs.
2. All information shall flow out of process outputs.
3. The chart shall show the sequential and concurrent nature of the activities.
4. The chart shall show all the potential paths an activity can take.
5. All of the decision points shall be shown accurately.

In some incarnations of flow charts, the shapes of the objects in the drawings depict specific functions, such as storage, etc. In others, the steps might be tagged with information such as in the flow chart shown in Figure 2.8

Think about the process for making a cup of instant coffee. There are three ways to do this:

1. Starting from ending and working backwards to the beginning discussed in Section 2.7.2.1.1.
2. Starting from the beginning and working forwards to the ending discussed in Section 2.7.2.1.2.

3. Starting in the middle and working backwards and forwards discussed in Section 2.7.2.1.3.

2.7.2.1.1. Starting from the ending

Here you start with a completed product, namely the cup of instant coffee and think about what you did to create it. Working backwards from the completed stirred cup of instant coffee ready for drinking, you first thought of the last step you performed to realize the product and wrote it down. After writing down the step, you thought of the items you used when you performed the step. You then conceptually moved back to the previous set of activities that you used to make sure the items were ready when you needed them. So, you would end up with a list such as, you:

1. Stirred the mixture.
2. Added the ingredients to the hot water in the cup.
3. Poured the hot water into the cup.
4. Waited for the water to boil.
5. Started to heat the water.
6. Put the water into the kettle
7. Located the ingredients (coffee powder, creamer and sugar) and kitchen items (cup, spoon and kettle).

Or you could have written, you:

1. Stirred the mixture.
2. Poured the hot water into the cup.
3. Put the ingredients into the cup.
4. Waited for the water to boil.
5. Started to heat the water.
6. Put the water into the kettle
7. Located the ingredients (coffee powder, creamer and sugar) and kitchen items (cup, spoon and kettle).

Or you could have written, you:

1. Stirred the mixture.
2. Poured the hot water into the cup.
3. Put the ingredients into the cup.
4. Heated the water.
5. Located the ingredients (coffee powder, creamer and sugar) and kitchen items (cup, spoon and kettle).

Or you could have written a similar list of sequential ideas using slightly different wording. The first process was completely sequential; the second process contained two parallel activities in that you put the ingredients into the cup while the water was heating which shortened the time to create the product. The third version of the process was also sequential. In all three versions of the process, the '1. Stirred the mixture' step contained three sub-steps, namely:

11. Picked up the spoon.
12. Stirred the mixture in the cup.
13. Put the spoon down.

Similarly, in the third example, the '4. Heated the water' step contained three sub-steps, namely:

41. Waited for the water to boil.
42. Started to heat the water.
43. Put the water into the kettle.

All three versions are correct at this time because they are just the initial ideas for the process. Note that each step is numbered and when a step is broken out into sub-steps the numbering is adjusted accordingly. In these examples, step 1 is broken out into sub-steps 11, 12 and 13, while step 4 is broken out into sub-steps 41, 42, and 43. This numbering style makes it easy to locate a sub-step in the process.

When working backwards, you can have a vision of the product in your mind and working out how you got there minimizes the probability of forgetting an ingredient (part) or a step in the process. However, when you draw the process as a flow chart irrespective if drawn forwards from the from the start or backwards from the finish the flow chart always appears as if it had been drawn from start to finish as shown in Figure 2.9.

2.7.2.1.2. Starting from the beginning

Starting from the beginning means that you have to think forwards and ask questions. Here you might have thought about:

1. Locating the ingredients.
2. Heating the water.
3. Putting the ingredients into the cup.
4. Adding the hot water into the cup
5. Stirring the mixture.

When you thought about locating the ingredients, you had to ask "what are the ingredients?" you thought for a while and came up with the hot water, coffee, sugar and creamer. Then you thought about heating the water and associated putting water into a kettle. The sequential process slowly took shape in your mind and is the same sequence of ideas as you developed starting from the ending.

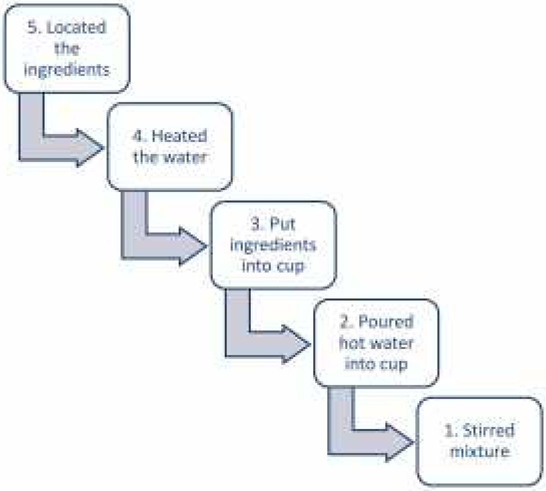

Figure 2.9 Process for making a cup of instant coffee

2.7.2.1.3. Starting in the middle

Here the ideas come in no particular sequence and you write them down as they come. You then arrange them in hierarchies showing how the parts come together to make up the product as shown in Figure 2.2, Figure 2.6 and Figure 2.4. The sequence to produce the product can be drawn as shown Figure 2.9. In this simple example, the resulting sequence of ideas is similar. But in the case of a complicated product, starting from the ending or working back from the answer (Ackoff, 1999) will generally create the most trouble-free process.

2.7.2.2. Cause and effect charts

Cause and effect charts:

- Take the form shown in Figure 2.10.
- Are also known as:
    - ***Ishikawa diagrams:*** because of (the association is with) Kaoru Ishikawa, the person who developed them.
    - ***Fishbone charts:*** because of (the association is in) the similarity in the shapes between the chart and the skeleton of a fish when there are a large number of items on the chart.
- Are a specialised flow-charting tool used primarily for tracking down the root cause (problem) of a specific symptom.
- Are often used in ideation sessions to examine factors that may influence a given situation.

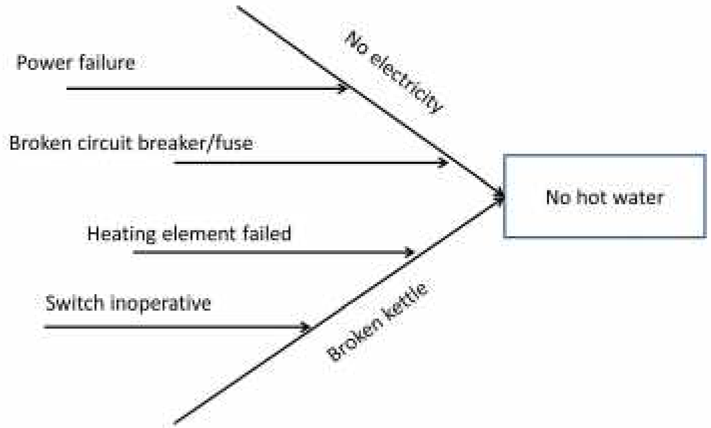

Figure 2.10 Cause and effect chart

- Facilitate:
    - Distinguishing between causes and effects.
    - Determining the relationships between causes and effects.
    - Determining the parameters associated with causes.
- Consist of three parts:
    1) ***The effect:*** a situation, condition or event produced by a cause. The effect:
        i. Is shown as a box with a horizontal arrow in the centre of the chart, pointing to, and joined to the box.
        ii. May be desirable or undesirable.
    2) ***The primary causes:*** drawn as sloping lines leading towards the effect box. The lines are labelled with "the cause".
    3) ***The secondary parameters of the cause:*** drawn as horizontal lines leading to the cause lines.

When thinking about a process, you should generally also think about things that might go wrong with the process and the appropriate concept map to link these thoughts is a cause and effect chart[6]. For example, when thinking about making a cup of instant coffee, one of the things that might go wrong is that the water does not get hot. A typical cause

[6] Thinking about the different types of things that can go wrong is known by buzz words such as contingency planning, risk management and failure analysis.

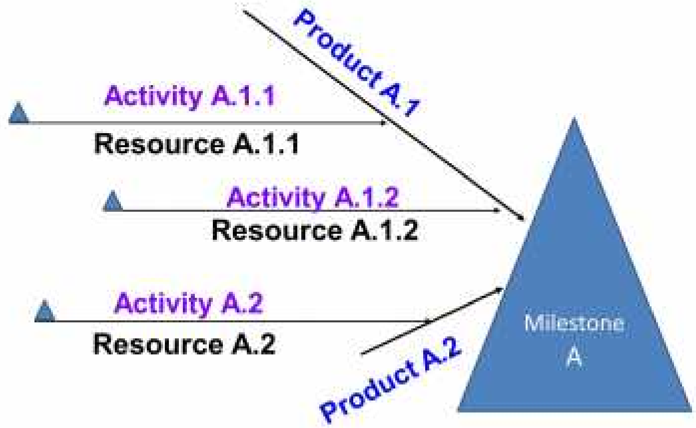

Figure 2.11 Product-Activity-Milestone (PAM) chart

and effect chart for this situation using an electric kettle is shown in Figure 2.10. The symptom is shown in the box on the right side, and in this case the symptom is 'no hot water'. After some thought, two possible causes are identified: 'no electricity' and a 'broken kettle'. Further thought postulates that 'no electricity' might be due to a power failure or a tripped circuit breaker or blown fuse; and the 'broken kettle' might be due to a failed heating element or switch. These ideas are connected as shown in Figure 2.10.

2.7.2.3. Product-Activity-Milestone (PAM) charts

The Product-Activity-Milestone (PAM) chart (Kasser, 1995a):

- Is designed to facilitate thinking back from the answer/solution.
- Is shown in Figure 2.11.
- Has been found to be a very useful project-planning tool for thinking about the relationships between the product, the activities that realize the product and the milestone by which the product is to be completed.
- Is similar to a cause-and-effect chart and is a tool to facilitate project planning by:
    - Defining a point in time (milestone).
    - Defining the product(s) or goals to be achieved by the milestone
    - Determining the activities to produce the product(s).
    - Defining the resources needed to produce the product(s).

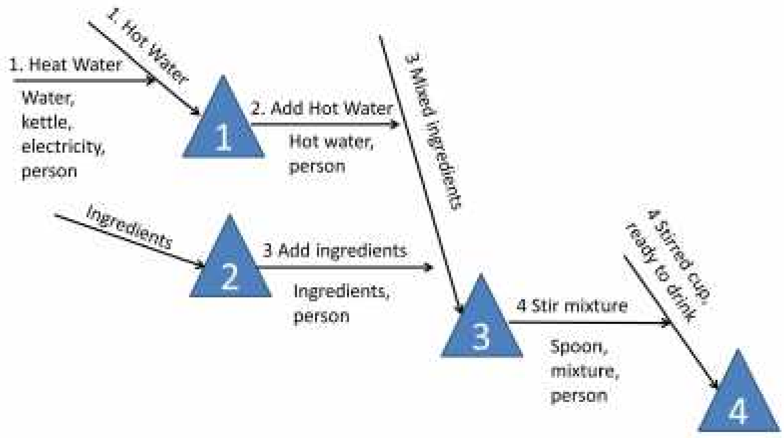

Figure 2.12 Partial PAM chart for making a cup of instant coffee

- Consists of four parts:
  1) ***The milestone:*** shown as a circle or a triangle.
  2) ***The product(s) produced:*** drawn as a sloping line(s) leading towards the milestone. Two products (A.1 and A.2) are shown in the Figure.
  3) ***The activities:*** drawn as horizontal lines leading to the product line. They are listed above the line. Labelling reflects the activities associated with the product, so activities A.1.1 and A.1.2 are associated with producing Product A.1, and activity A.2 is associated with producing product A.2. All activities shall start and end at milestones.
  4) ***The resources associated with each activity:*** shown as labels below the activity lines. They are listed below the line. Labelling reflects the resource associated with the activities, so resources for A.1.1 are listed below A.1.1, resources for A.2 are listed below A.2 etc.

To draw a PAM chart, start with a blank page. Position a milestone at the right side of the paper. Arrows are drawn on the product and activity lines to show the direction of progress. Note there may be more than one milestone within the chart. For example, consider the partial PAM chart linking the products activities, resources and milestones in making a cup of instant coffee shown in Figure 2.12. Working back from the last milestone (4) the product is a stirred cup of instant coffee ready to drink. The activity between milestones 3 and 4 is ‘stir the mixture’ and the necessary resources are a spoon, the mixture and a person to do the stirring.

At milestone 3 the product is the 'mixed ingredients' and there are two activities, adding hot water (between milestones 1-3) and adding the ingredients (between milestones 2-3). The product produced at milestone 1 is the hot water and the resources needed consist of water, the kettle, electricity and a person to do the job. The product produced at milestone 2 is the set of ingredients (instant coffee, creamer and sugar) purchased separately or as a 3-in-1 packet. Look at the figure; can you see what is missing? No, then what are you thinking of putting the water and ingredients in before stirring the mixture? The answer is, of course, the cup.

PAM charts are used for planning which takes two forms:

1. ***Activity-based:*** concentrates on the activities to be performed using resources as a starting point and then works forwards to the products.
2. ***Results-based:*** concentrates on the results to be achieved (products to be produced) and works backwards to the needed resources.

The difference between these two approaches is illustrated by the following scenario taking place in Federated Aerospace (FA) (Kasser, 1995a).

It was the Monday morning of Task Planning week. Sandra Stenson and Fred met to begin planning the activities to be performed on the facility upgrade contract.

"Let's start with Task 31, the Stage 3 Upgrade/Transition", said Sandra as she spread the task planning forms on the table.

"We have systems engineers, software developers, hardware engineers, and test personnel on the task, so we'll make each activity a cost account. This way everybody will know what to charge to" said Sandra and began to pencil in cost accounts. "Now let's figure out the deliverables for each cost account".

"Wait a minute", said Fred. "Let's look at it from a different perspective and draw a PAM chart. We are going to have an Operations Concept Review (OCR) in four months (the milestone); we'll need a Concept of Operations (CONOPS) and a Transition Plan by then (the products). We'll need the integration and test procedures two months after the review. Let's make each of those deliverables a separate cost account, and who so ever works on them (the activities to produce the product) can charge to the product, not to the engineering activity."

Sandra's approach to planning is activity-based; Fred's approach is results- or product-based. Sandra is using a planning tool that leads her

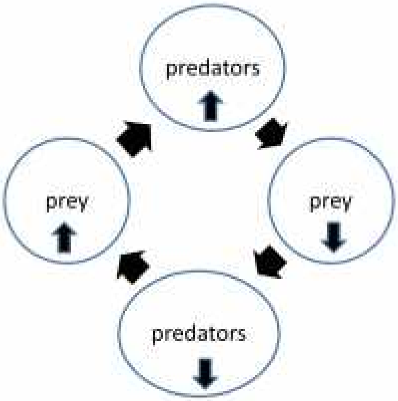

Figure 2.13 Predator – prey relationships

into the activity based planning mode. She is using the Gantt chart in Figure 2.25 as an input tool instead of as a view of the activities in the project. Using the Gantt chart as an input tool forces "activity based planning" which focuses on the activity, rather than on the outcomes of the activity.

The results- or product-based approach:

- Works back from the products to determine the activities, rather than trying to think up products for the activities to produce.
- Provides data about the time spent to produce a product. This data may be used to refine models for cost estimating additional activities and for proposal pricing.
- Produces measurable results; namely, the deliverables were or were not delivered.

Working effectively means working in a cost effective manner. Sandra's activity based planning is much less effective than Fred's results based approach, because it is always easier to work back from a known answer (the products in this case) than to work forwards towards an unknown one.

2.7.2.4. Causal loops

Causal loops are concept maps used to think about relationships; they are flow charts in the form of a feedback loop. For example, the relationships between the population of predators and prey in a given area can be drawn in form of the causal loop shown in Figure 2.13 which shows:

- How each element affects another element. For example, consider the change in the population predators and prey. As the

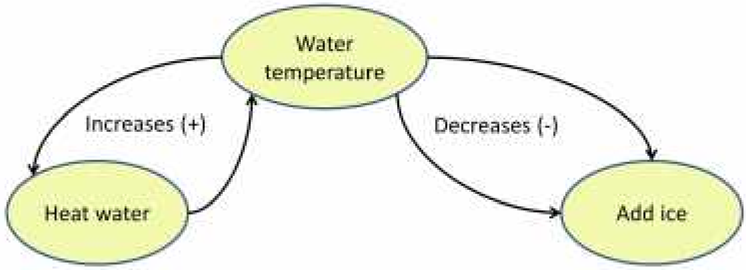

Figure 2.14 Effect of heating and cooling on water temperature

number of predators increase (indicated by the up arrow), the number of prey deceases (presumably, the predators consume more prey). However when the number of prey decreases the number of predators also decrease (presumably because the food supply becomes limited). When the number of predators decreases, the number of prey increases (presumably because the prey can multiply in the absence of predators). When the number of prey increases, the number of predators also increases (presumably their food supply has increased) and the loop enters another cycle.

- The relationship between the change in size of the predator and prey population. The causes are presumed due to observation of the behaviour of the predators and prey. This loop does not help in thinking about the time delays involved in the change of population states, or include the effect of any other element on the populations.

Another type of causal loop is shown in Figure 2.14. This one shows the effect on water temperature of (1) heating the water and (2) of adding ice to the water. There are two feedback loops:

1. ***The positive feedback loop:*** indicating that as the water is heated the temperature rises.
2. ***The negative feedback loop:*** indicating that as the ice is added to the water, the water temperature decreases.

Each loop does not help in thinking about any steady state conditions or the rate of change of temperature. The figure just shows the effect on the relationship between the elements in the loop when an element changes.

Causal loops exist in several variations. Sometimes they are drawn as in Figure 2.13, sometimes as in Figure 2.14 and sometimes in a similar format. The relationships may be shown as arrows, words or symbols:

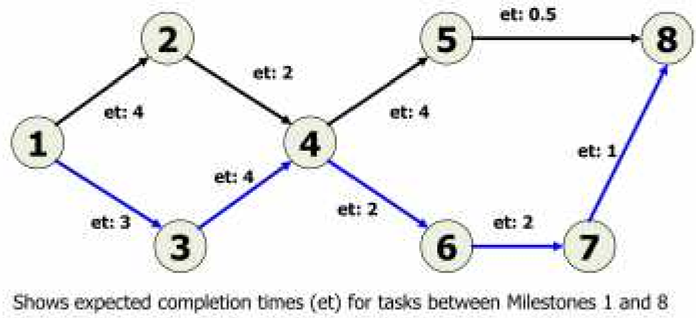

Figure 2.15 Typical PERT chart

there is no standard way of drawing these loops, just pick a way that makes the drawing easy to understand by everyone who will use the drawing. A common error when drawing causal loops is to include too many details in a single diagram which makes the drawing:

- Complex due to the extraneous details.
- Complicated to understand.

Causal loops are often identified with systems thinking because they show the relationships between various parts of a system.

2.7.2.5. PERT/CPM charts

A Program Evaluation Review Technique (PERT) chart:

- Is a project management tool used to help thinking about scheduling and coordinating tasks within a project.
- Was developed by the United States (US) Navy in the 1950's to manage the timing of research activities for the Polaris submarine missile program (Stauber, et al., 1959). The Critical Path Method (CPM) was developed for project management in the private sector to perform the same function at about the same time.
- Presents a concept map of the relationship between activities in a project as a network diagram consisting of numbered nodes (either circles or rectangles) representing events or milestones in the project linked together by labelled directional lines (lines with arrows) representing tasks in the project. For example the PERT chart shown in Figure 2.15 has eight nodes, of which nodes 1, 4 and 8 are major milestones. The tasks (arrows) are labelled to show expected completion times (et) of the tasks. When tasks are performed in parallel the longest path is known in project management as the critical path. For example, in the time be-

tween milestones 1 and 4, the critical path is the route formed by tasks 1-3 and 3-4 because it takes 9 time units as opposed to the 8 time units for the path formed by tasks 1-2 and 2-4.

While the PERT Chart is a very effective management tool, it can also be used as a communications tool to show people:

- How their work relates to the project as a whole.
- Who their input comes from (suppliers).
- Who their output goes to (customers).
- When their output is needed.

I once used a PERT chart as a communications tool in the following manner. The context was the Systems Engineering and Services (SEAS) contract (the same context as in Section 10.2) supporting the National Aeronautics and Space Administration (NASA) Goddard Spaceflight Center (GSFC) in a multi-task environment supporting the upgrading of a number of interdependent data processing and command and control facilities in which the subcontractor who I worked for was responsible for systems engineering while the contractor was responsible for management and software engineering.

At one time I tried to work out how all the tasks were related. So I printed[7] a PERT chart and coloured in the system engineering, hardware engineering, software engineering and test engineering activities in different distinctive colours. I also coloured the arrows between the activities in the same colours and highlighted the transfer points (i.e. a point in time where development transfers the system to the test team). I placed the coloured PERT chart on the wall in the corridor outside the office[8].

It didn't take very long for everyone to come out of their offices and study the chart. For the first time, everyone had a picture of the project as a whole and how their activities were related to those of the other groups working on the project. A few days later similar PERT charts appeared on the walls of other departments planning other activities.

That was the upside of the situation. A few days later I received an informal reprimand because I was a systems engineer and PERT charts were management tools which, as a systems engineer, I should not be using.

[7] Using a dot matrix printer and sticking the strips of paper together with clear tape.
[8] It was too long to go on the wall in the office.

2.7.2.6. IDEF0 charts

Integration Definition for Function Modelling (IDEF) charts are a set of flowcharts conforming to a specified format developed by the US Air Force in the late 1970's. In the commonly used IDEF0 charts, activities are represented by rectangular boxes with the name of the activity inside the box. Inputs are shown as lines with arrows pointing into the box entering into the left side of the box while outputs are shown as lines exiting the right side of the box with arrows pointing away from the box. Controls are displayed as labelled arrows entering the top of the box and resources are displayed as labelled arrows entering the bottom of the box.

2.7.2.7. Hierarchical charts

Hierarchical charts show relationships between levels in a hierarchy such as the ones shown in Figure 2.2 and Figure 2.6. Organisation charts are hierarchical concept maps showing reporting relationships in organizations. Other examples of such charts include Work Breakdown Structures (WBS).

2.7.2.8. Rich Pictures

Rich Pictures are just drawings that contain sketches, as well as symbols and images such as that shown in Figure 2.1 and Figure 8.4. The term was popularized in Checkland's Soft Systems Methodology (SSM) (Checkland, 1991) discussed in Section 4.4.1.

2.7.3. Graphs

Graphs:

- Are tools to help understand and communicate relationships between variables.
- Show what happens to one or more variables plotted on the Y-axis (vertical) when compared to the variable plotted on the X-axis (horizontal).

Consider the following common types of graphs.

1. Trend charts discussed in Section 2.7.3.1.
2. Control charts discussed in Section 2.7.3.2.
3. XY charts discussed in Section 2.7.3.3.
4. Polar chats discussed in Section 2.7.3.4.
5. Bar charts discussed in Section 2.7.3.5.
6. Gantt charts discussed in Section 2.7.3.6.
7. Pareto charts discussed in Section 2.7.3.7.
8. Histograms discussed in Section 2.7.3.8.
9. Pie charts discussed in Section 2.7.3.9.

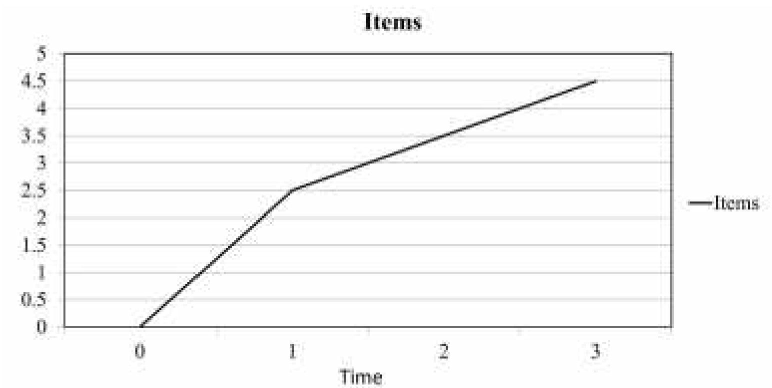

Figure 2.16 Trend chart

2.7.3.1. Trend Charts

Trend charts:

- Sometimes called run charts, show how the value of something changes over time. The usual format is to plot time along the X-axis and the parameter being depicted along the Y-axis. The example in Figure 2.16 plots (shows) the increase in Items from zero to 3.5 over three time periods. The figure shows that there was a change in the rate of increase in the first day which might need to be investigated.
- Are widely used in finance to show how the value of a stock or commodity changes over time.

2.7.3.2. Control Charts

Control charts are:

- Trend charts with upper and lower limit levels shown on the

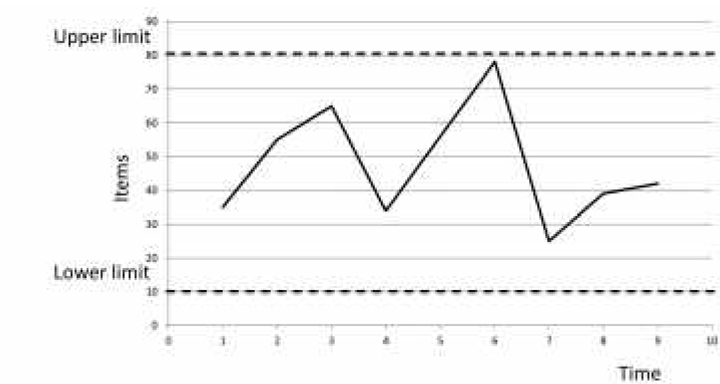

Figure 2.17 Typical control chart

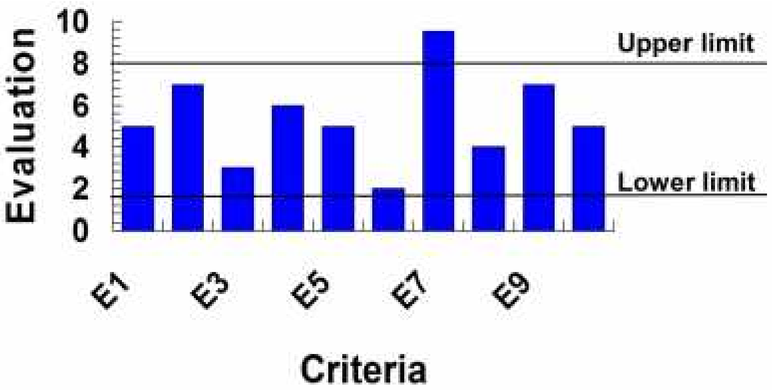

Figure 2.18 Control chart for performance evaluation

graph as in Figure 2.17.

- Used in manufacturing for various purposes including showing that pre-determined upper and lower limits have been exceeded.
- Useable in other situations as well (*Generic* perspective). For example, one use is in personal performance evaluations. Figure 2.18 shows a control chart used in performance evaluation. The person has been evaluated on nine (E1-E9) criteria and when the information is plotted in the chart, is seen to exceed the upper limit on one of them, superior performance which might be recognised. When the subsequent evaluation is added to the chart for a different person as shown in Figure 2.19 improvements can be seen. On the other hand, should the performance have dropped, someone should determine the reason.

While control charts are usually shown as trend charts using lines, in the performance evaluation scenario, the information is more easily ex-

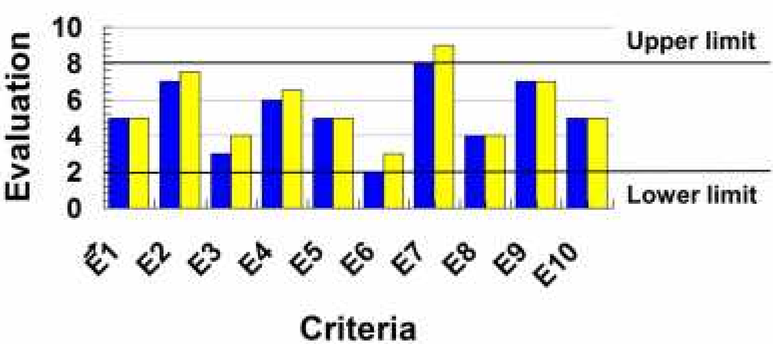

Figure 2.19 Control chart for two performance evaluation periods

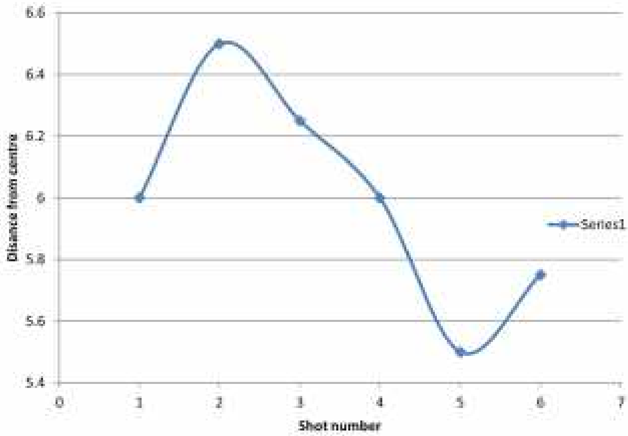

Figure 2.20 XY Chart

tracted from the bar chart view (Section 2.7.3.5).

2.7.3.3. XY Charts

XY Charts sometimes known as scatter diagrams are graphs plotted to examine the relationship (correlation) between two variables (X and Y). One variable is plotted on the X-axis, the second, on the Y-axis. The difference between a trend chart and a XY Chart is that a trend chart is always a plot of one or more parameters (Y-axis) as a function of time (X-axis). Lines between the points on the graph are optional in XY Charts. For example, Fred's hobby is shooting. After a session he draws a graph

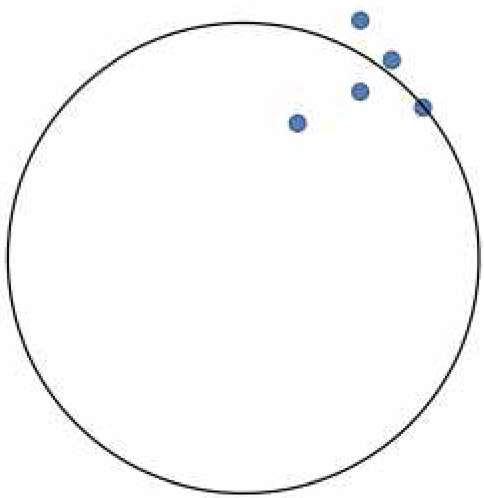

Figure 2.21 Polar plot of Fred's shots

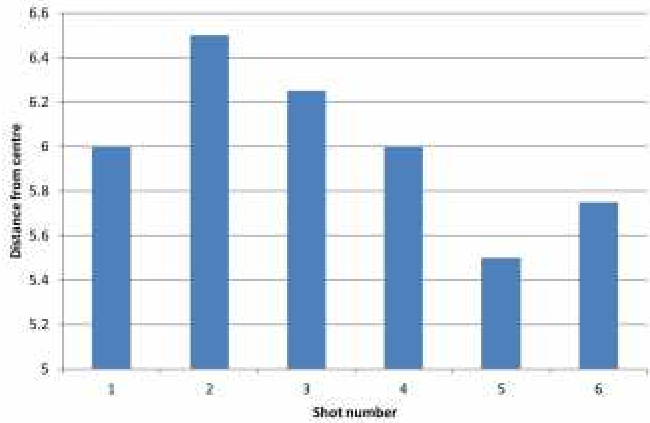

Figure 2.22 Bar chart representation of the results of Fred's session

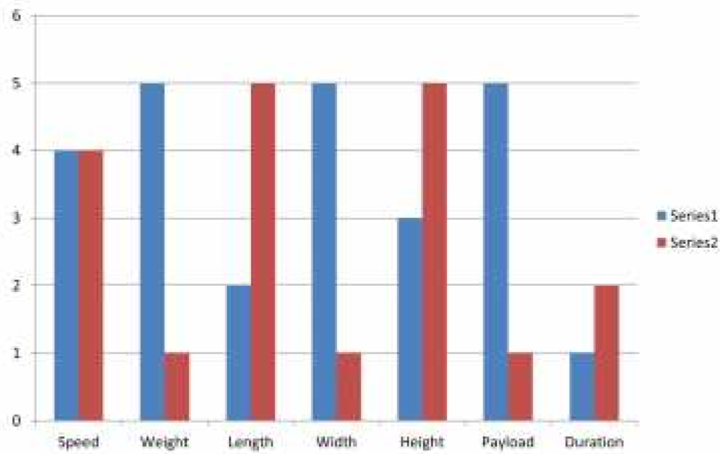

Figure 2.23 Compound bar chart for comparisons

shown in Figure 2.20 that shows the distance from the centre of the target for each of the six shots he fired. The chart plots the distance from the centre in centimetres on the Y-axis for each shot and the shot number on the X-axis.

2.7.3.4. Polar charts

Polar charts, sometimes called Kiviat charts, radar charts or spider charts are used to show comparisons of a number of variables on a single chart where each spoke or axis on the chart represents a metric and the distance from the centre of the chart represents the metric's value plotted on that spoke. Fred redrew the data plotted in Figure 2.20 as the polar plot shown in, Figure 2.21. The six-centimetre line is highlighted in the

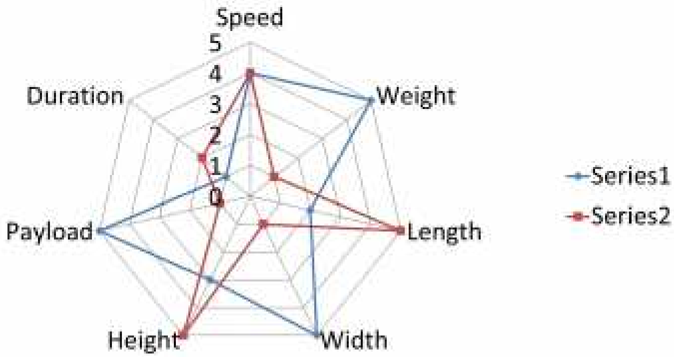

Figure 2.24 Polar plot of model aircraft evaluations

figure. Note the additional information shown in the figure. While Figure 2.20 shows the distance from the centre, Figure 2.21 also shows the grouping of the shots; providing additional information, which suggests that Fred's shooting is pretty good, but he needs to adjust the sights on the weapon. The difference in the information provided by the two figures illustrates the need to use the appropriate chart for the situation.

2.7.3.5. Bar charts

A bar chart is a way of comparing the values of independent variables on a single chart. The length of the bar represents the size of the variable. The bars may be vertical or horizontal. Depending on the chart, the bars may represent different variables at the same point of time, or the same variable at different points of time (histograms). Figure 2.22 shows the result of Fred's shooting session in the form of a bar chart. Bar charts come in various forms and may show a vertical bar per grouping or several bars as needed to present the appropriate information. Sometimes the bars are shown horizontally.

Compound bar charts can be used to compare two sets of information about some attributes of something such as in the performance evaluation control chart in Figure 2.19. In this example, the performance the speed, weight, length, width, height, payload and flight duration of two different model airplanes (series 1 and 2) have been evaluated. Each parameter has been evaluated on a scale of 0 to 5 and the resulting scores are shown in Figure 2.23. The chart shows that Series 1 is better in some respects, Series 2 is better in others and the two model aircraft received identical scores for speed. The same information is shown in Figure 2.24 but in the form of a polar plot. When comparing a small number of parameters either type of chart may be used, but when there are a large

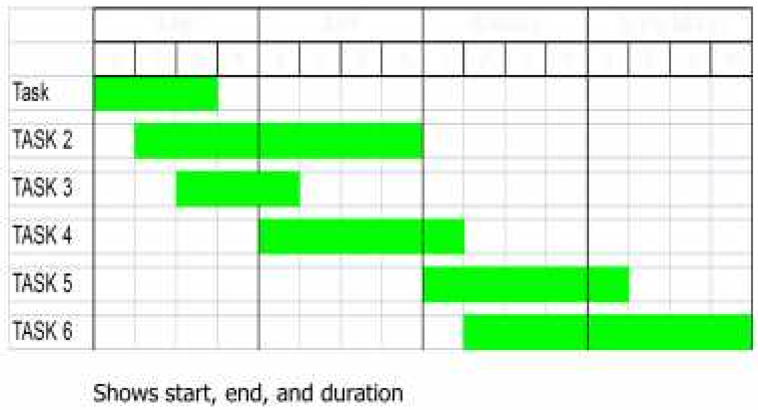

Figure 2.25 Gantt chart

number of parameters to be compared, the polar plot is a better way of presenting the comparison results.

2.7.3.6. Gantt charts

Gantt charts:

- Are a specialized type of bar charts which were invented by Henry Gantt to compare planned with actual (promises with performance) activities (Clark, 1922).
- Are thinking and communications tools widely used in project management.
- As used today represent activities with horizontal bars in a two-dimensional box as shown in Figure 2.25. The horizontal dimension represents time while the activities are shown as parallel bars in the frame. The length of the bar represents the length of time an activity takes and the colour or thickness of the bar can be used to represent things about the tasks (completed, level of difficulty, etc.).
- Show when activities start and finish and how long they take.
- Do not show dependencies between the tasks[9].

For example, the Gantt chart shown in Figure 2.25 shows a series of six tasks. The series starts with the first task and ends after the sixth task is completed. The chart also shows a number of other things such as

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[9]Some project management software does provide the capability to draw arrows between the end of one task and the start of another in the Gantt chart view. I recommend that you do not use that capability if you have more than a few tasks on the chart since the additional lines will cause clutter and may be misinterpreted. PERT charts are designed for the purpose of showing dependencies and can be drawn by the same software.

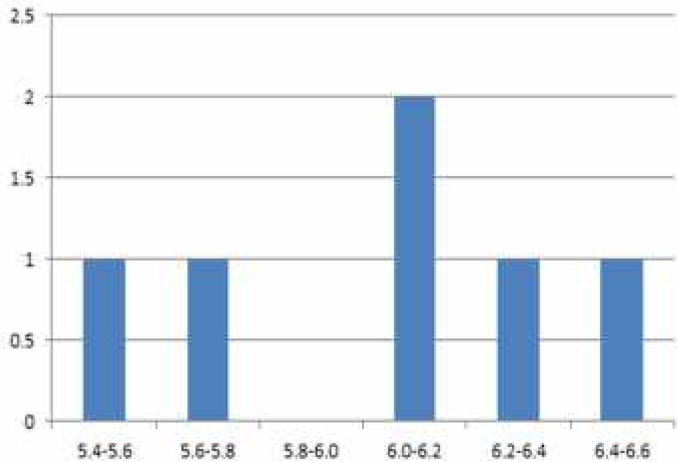

Figure 2.26 Histogram of Fred's shots

some tasks overlap in time and that Task 5 begins as soon as Task 2 ends. When tasks overlap in time, resources needed for one task may not be available for the other and alternative sources for the resources need to be considered.

2.7.3.7. Pareto charts

Pareto charts:

- Were invented by Vilfredo Pareto (1848-1923).
- Are specialized types of bar charts drawn with vertical bars showing the variables in order of increasing or decreasing length.
- Are often used to display the degree that variables or parameters contribute to problems.
- Help to identify the few significant factors that contribute to a problem and separate them from the insignificant ones. The approach used to deal with the problem is to concentrate on the largest value first, then on the next largest and so on.

2.7.3.8. Histograms

A histogram:

- Is a specialized type of bar chart used in statistics to display a graphical summary of the distribution of data rather than the data (Pearson, 1895). For example, if Fred is interested in the number of shots hitting the target at specific distances from the centre rather than the actual distances, he could plot a histogram to provide that information. Fred would create 'buckets' for

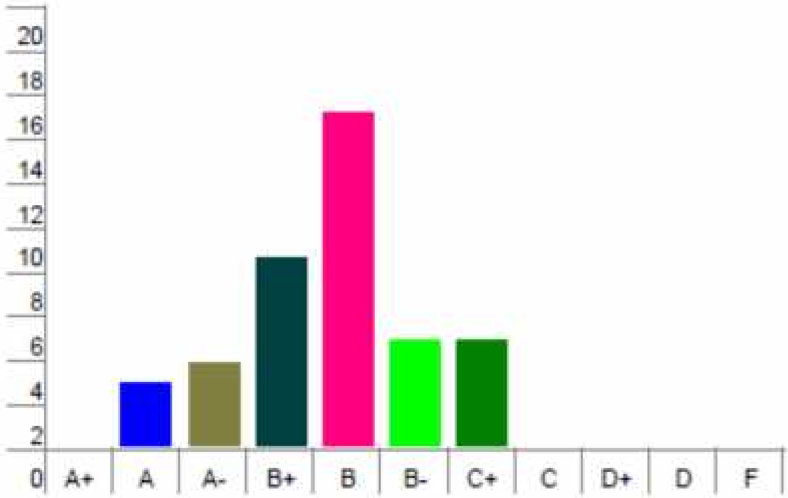

Figure 2.27 Histogram of student grades

ranges of data, such as from 5.4 to 5.6, 5.6 to 5.8 centimetres from the centre of the target at 0.2 centimetres intervals. He would then go through the data and increase the bucket count each time the value of a shot was inserted into a bucket. When he finishes the operation and displays the results the histogram would show up as depicted in Figure 2.26.

- Show the relative distributions of items in a group and when the individual number of items is large, software is used to calculate the data to be shown in the histogram such as a chart summarizing the distribution of the final grades of students in a class at the end of the semester shown in Figure 2.27. The figure shows that five students achieved a grade of A; six achieved a grade of A- and so on.

2.7.3.9. Pie Charts

A pie chart:

- Shows the relative values of each data item in a set as a percentage of the whole in the form of a circle or round pie.
- Is best used to compare the size of a particular data item or slice with the whole rather than to make comparisons between different slices.
- Is often used as a histogram to provide representations of summaries of data.

Figure 2.28 Cartoon in which the ambiguity provides the humour

2.7.4. Humour

English humour is mostly based on ambiguity which can often be used in the form of cartoons and jokes to make a point; but do not use too many. Ambiguity can be in the meaning of a word or in the phrasing of a sentence. For example, many words have more than one meaning and the joke is funny when an alternative out-of-context meaning is associated with a phrase. This type of humour often shows up in cartoons such as the one shown in Figure 2.28. Here the humour is based on the ambiguity concerning what the previous employer was satisfied about. Was the employer satisfied with the candidate's performance, or was the employer satisfied that the candidate left the job?

Sometimes humour can be used to make a point. For example, consider the following joke.

> About four hundred years ago, the Cardinals determined to expel all the Jews from Rome and persuaded the Pope to issue an edict. The Pope however understood the value of the Jewish community and decided to give them a chance to remain in Rome without appearing to overrule the Cardinals. He agreed to have a religious debate with a member of the Jewish community and should the Jewish debater win, the Jews would be allowed to remain in Rome. If the Pope won, the Jews would have to leave. The Cardinals thought the Jews had no chance of winning the debate and agreed to the condition but added the provision that the Jewish

debater would be executed when if the Jews lost the debate.

The Jewish scholars believed that they were in a no-win situation; the community did not want to leave and certainly did not want to take the chance of losing their beloved Rabbi. After much soul searching in the community, an old man named Moishe who cleaned up and took care of the synagogue volunteered to represent the community. Being poor and old, he said that he had less to lose than the others. However, he asked for one condition to be placed on the debate; the condition being that the debate would be silent; neither side would be allowed to talk. His reason was that he was not used to speaking while he cleaned up around the building since most of the community ignored him. The Pope agreed to the condition.

The day of the great debate arrived. The galleries were filled with the Cardinals and other onlookers. Moishe and the Pope sat in chairs opposite each other. After some time, the Pope raised three fingers. Moishe looked back at him and raised a single finger. The Pope then waved his fingers around his head in broad circle. Moishe then pointed to the ground between them. The Pope sighed and took a wafer and a glass of wine out of his robe and held them up to Moishe. Moishe’s immediate response was to take an apple out of his pocket and show it to the Pope.

Upon seeing the apple, the Pope stood up and announced “I give up! This man is too good! He has an answer for everything! The Jews can stay in Rome” and swept out of the chamber, followed by the Cardinals.

An hour later the distraught Cardinals gathered around the Pope and asked him what had happened. The Pope explained, “When I began by holding up three fingers to represent the Trinity, he responded by holding up one finger to remind me that both our religions stem from the same one God. Then, when I waved my finger around to show him that God was all around us, he responded by pointing to the ground, indicating that God was right here with us. When I took out the wine and the wafer to show that God absolves us from our sins, he pulled out an apple to remind us of the original sin. He had an answer for everything".

Meanwhile back at the synagogue the Jewish Community crowded around Moishe. They were astounded that this simple old man had accomplished a feat that their scholars had insisted was impossible! “What happened,” they asked.

> "Well", replied Moishe, "when the Pope started by telling me that the Jews had three days to get out of here, I held up one finger to show him that not one of us was leaving. When he waived his hand around to state that the whole city would be cleared of Jews, I pointed to the ground and let him know that we were staying right here. Then he showed me his lunch so I showed him mine".

This joke provides a great opportunity for a discussion on the context of assumptions, communications and miscommunications.

When incorporating cartoons or jokes, remember to respect intellectual property (IP) rights and use appropriate citations as discussed in Section 3.5.

Humour is also cultural since the recipients of the joke need the background to understand the joke. So, when communicating across cultures, check the joke out ahead of time on at least two different people who do not know each other. This is to avoid someone making a fool out of you or placing you in an untenable situation; something called risk management.

2.7.5. Tables and matrices

Tables and matrices are thinking and information communication tools that provide information in tabular format. Consider the following examples:

1. Comparisons discussed in Section 2.7.5.1.
2. Frameworks discussed in Section 2.7.5.2.
3. Whiteboards discussed in Section 2.7.5.3.
4. Stoplight or traffic light charts discussed in Section 2.7.5.4.
5. N^2 Charts discussed in Section 2.7.5.5.

2.7.5.1. Comparisons

Tables are often used when making comparisons between things. For example Table 2.1 shows a mapping between the capability available in a system and the scenarios that use those capabilities. For example, the table shows that capabilities 1, 2 and 4 are used in scenario A; capabilities 3, 4 and 5 are used in Scenario B and so on. A blank row would indicate a capability that is not used in any scenario and a blank column would show that the system does not have any of the capabilities needed to perform that scenario.

Table 2.1 Table showing mapping between functions and scenarios

	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
Function 1	X		X		
Function 2	X	X		X	
Function 3		X			X
Function 4	X		X		
Function 5		X	X	X	
Function 6					X

2.7.5.2. Frameworks

Frameworks are tables that illustrate where and how things fit together. A widely used format is the 2x2 format which presents a framework and then plots something in that framework. See one example in Table 6.4.

2.7.5.3. Whiteboards

You can post sticky notes on whiteboards in tabular format to keep track of many different things in different situations. Some examples include:

- ***Slip writing:*** when using the variation described in Section 2.6.3 in which the ideas are written on sticky notes and posted on a wall or whiteboard, create a tabular space and post the ideas in the appropriate area of the table.
- ***Data tracking:*** you can set up a table of data parameters and insert sticky notes into the appropriate areas.
- ***Scheduling resources:*** list the resources on a whiteboard and who is using them on sticky notes. This concept was described in 1917 using notes on paper pinned to a board as a project management tool (Farnham, 1920).
- ***Conference program organization:*** when organising a conference program with several parallel meeting tracks you should make sure that there are no clashes between the topics in each track. The process used to create the program for the International symposium of the International Council on Systems Engineering (INCOSE), held in Singapore in 2009; a symposium that had between four and six parallel tracks of sessions over four days with no content topic clash was as follows.

    1) Assign every manuscript and panel an identification number.
    2) For each accepted manuscript and panel do:

Figure 2.29 Use of whiteboard and sticky notes for conference session planning

   i. Read manuscript or panel outline to identify key words and topics[10].
   ii. Write the identification number, names of authors, key words and topics on a yellow sticky note.

3) Make a list of key words and topics counting the number of times they showed up.
4) Create a program outline on a whiteboard in the form of a table showing sessions, breaks and dates as shown

[10] Don't rely on key words.

Table 2.2 Some types of Stoplight charts

Situation	Red	Yellow	Green	Blue
Project management chart	Behind schedule	On schedule but needs watching	On schedule	Ahead of schedule
Risk management chart	Very risky	Medium risk	Low risk	No risk
Number of defects being produced chart	Much more than expected, corrective action needed yesterday (exceeding tolerance limit)	More than expected, corrective action needed soon (approaching tolerance limit)	As expected (within tolerance)	Fewer than expected

in Figure 2.29.

5) Label areas with key words and topics. If there were enough manuscripts then some topics showed up on more than one day.
6) Insert sticky notes for the appropriate topics into the appropriate area making sure to avoid scheduling an author who submitted more than one manuscript to be in more than one session.
7) Some areas will not have enough sticky notes to complete the session. Label these areas as 'miscellaneous topics'.
8) Insert remaining sticky notes into the miscellaneous topics areas making sure to avoid scheduling an author who submitted more than one manuscript to be in more than one session.
9) As authors withdrew or failed to register, advance reserve papers into the appropriate areas on the white board.
10) Copy the contents of the whiteboard into a spreadsheet at the appropriate time for printing and publishing on the conference web site.

If the information in a cell is going to be relatively permanent, it can be written directly onto the whiteboard rather than onto a sticky note. A part of the whiteboard with the sticky notes and marker text is shown in the photograph in Figure 2.29.

2.7.5.4. Stoplight or traffic light charts

Stoplight or traffic light charts show summaries in the colours of a stoplight or traffic light. For example:

- ***Green*** represents the data being summarized is good.
- ***Red*** indicates that something is seriously wrong or broken.
- ***Yellow*** indicates that something needs to be watched.
- ***Blue*** is used to indicate that the data being summarized is much better than good.

  Table 2.2 provides examples of the types of information stoplight charts that can be used to represent information in different situations. The colours can be added to existing tables, inserted into summary tables or used to tag other types of graphics.

2.7.5.5. N^2 charts

The N^2 chart:

- Was invented by Lano (Lano, 1977). It is a table that shows relationships between entities, functions, people, organizations, equipment, etc.

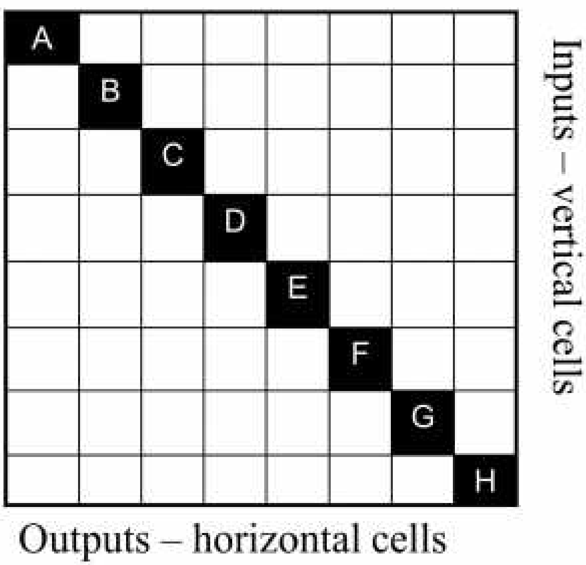

Figure 2.30 The N^2 chart (Lano, 1977)

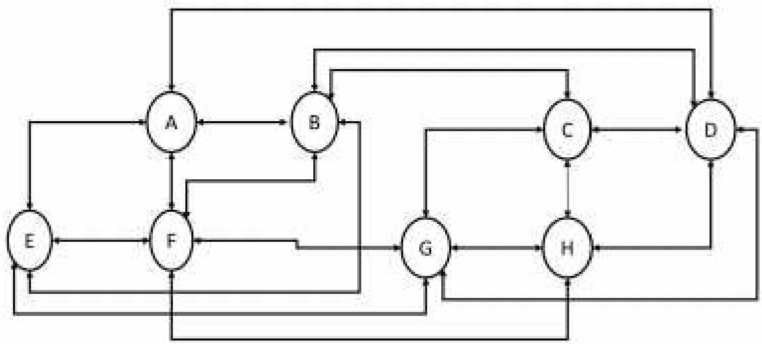

Figure 2.31 Concept map of relationships between functions

- Is shown in Figure 2.30. The entities are listed across the columns and down the rows. Since an entity does not connect to itself, the common cell in the table is blocked out and contains the row and column designator as shown in the figure. Inputs between entities are shown as a connection in a column, outputs as a connection in a row. So for example if there was a connection between the output of entity A and the input of entity C, an indication of the connection would be inserted in the cell in row A column C. As well as containing a simple mark that a connection exists, cells can be populated with information such as priorities in the event of conflict or concurrency, data pertaining to interface such as type of connectors, data types and rates, etc.
- Appears in many different guises including the waterfall view of the System Development Process (SDP).
- Performs the same function as the Design Structure Matrix (Eppinger and Browning, 2012) invented at about the same time but which reverses the function of the rows and columns.

Consider the following example of using N^2 charts for aggregating entities. The set of functions shown in concept map format in Figure 2.31 needs to be aggregated or combined into a smaller but more complex set of functions. The concept map view of the functions in Figure 2.31 is not very useful for this purpose since it is difficult to see any useful pattern in the interconnections between the entities. However, when the functions are drawn in the form of the N^2 chart as shown in Figure 2.32, you can see patterns in the interfaces. For example, entities B, C and D all have inputs and outputs from each other, so could be combined into one higher-level BCD entity. Entities E, F and G show a similar pattern of interconnections and could likewise be combined into a higher-level EFG entity. The resulting higher-level representation of Fig-

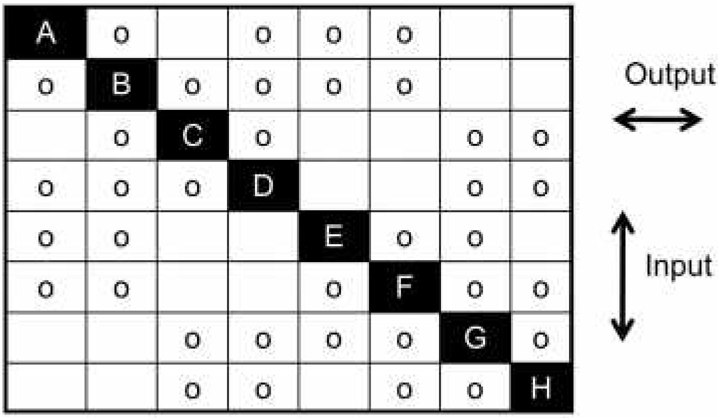

Figure 2.32 N^2 chart of the relationships in Figure 2.31

ure 2.31 is shown in N² and concept map formats in Figure 2.33. Figure 2.33 is less complex than Figure 2.31 but the elements BCD and EFG have become more complex due to their containing three elements.

Note that while the N² chart shows patterns suitable for aggregation, it does not show you which pattern to choose. In this instance, one of the alternate groupings is ABEF, CD and GH, while another grouping is ABD, CGH and EF.

The examples shown in this Section only show that a link exists between the inputs and outputs of the system elements. There is no reason why the linking cells could not contain information about the way the connection is made such as in the example in Table 6.5.

2.7.6. Software

Software provides many types of tools to assist thinking including the

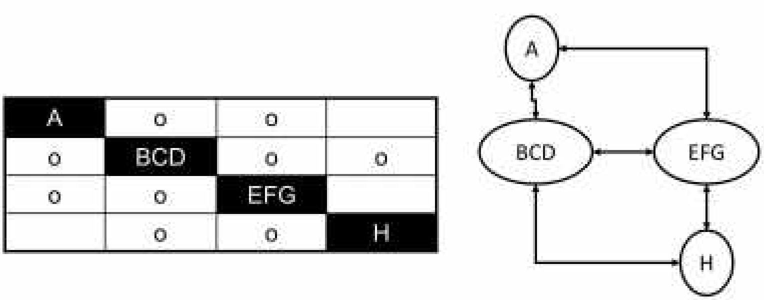

Figure 2.33 Higher level (more complex, less complicated) representations

Table 2.3 Thinking tools to use when thinking about

Thinking or communicating about	Thinking tool
Relationships between concepts	Concept maps, mind maps
Relationship between products, activities and resources	PAM charts
Interfaces between entities	N^2 charts
Processes	Flow charts, IDEF0 charts
Relationships between entities	Causal loops, cause and effect charts, flow charts, N^2 charts, tables
Sequential relationships between activities	PERT/CPM charts and N^2 charts
Calendar time for activities	Gant charts

following:

- Spreadsheets.
- Mind or concept mapping.

Consider each of them.

2.7.6.1. Spreadsheets

Spreadsheets:

- Consist of a combination of a computer program and a table of information where the areas or cells can contain information such as numbers, letters and words, or mathematical equations that operate on the information in other cells and indicate the result of the computation in the cell.
- Contain powerful algorithms that allow you to perform various types of mathematical operations on the information, including statistical analyses.
- Have the ability to show the information in different types of graphs, bar charts, pie charts, etc.

2.7.6.2. Mind or concept mapping

A mind map is another word for a concept map (Section 2.5). You can draw mind maps using drawing tools ranging from pencil and paper to generic computer drawing software to specialized software for drawing mind maps.

2.8. Summary

This Chapter:

1. Introduced you to thinking and introduced some of the tools you can use to assist your creative thinking.
2. Started with an introduction to some types of thinking in Section 2.1.
3. Introduced types of thinking in Section 2.2 and discussed top down and bottom up thinking in Section 2.3.
4. Discussed judgment and creativity in Section 2.4.
5. Introduced a concept map as the basic tool for thinking in Section 2.5.
6. Described just a few of the tools that can help you to think and communicate starting with tools for generating ideas in Section 2.6 and a few tools to assist with thinking in Section 2.7.
7. Ended with Table 2.3, a quick reference table to help you select the appropriate tool for the thinking task.

--oo--

3. Communicating ideas

This Chapter:

1. Discusses ways to communicate ideas because there is little point in generating ideas if you are not going to do anything with them.
2. Begins with a discussion on formal written communications in Section 3.1 namely documents and introduces a process for creating a document starting with an abstract and continuing with developing and using annotated outlines.
3. Discusses formal verbal communications and presentations in Section 3.2.
4. Alerts you to some barriers to successful communications in Section 3.3.
5. Follows up with some ways to overcome those barriers in Section 3.4.
6. Discusses intellectual property and ways to avoid plagiarism in Section 3.5.

One of the most important things you can do with an idea is to communicate it to someone else. In most instances, we generally use verbal and written communications, each of which can be formal and informal. Communications uses words which are symbols for the ideas used to communicate ideas, not the ideas themselves. While this Chapter discusses ways of communicating ideas, barriers to communication and ways of overcoming the barriers in the context of a conference paper and presentations, the concepts also apply to briefings, reports, and other situations when verbal and written formal or informal communications are to be made.

3.1. Formal written communications

Formal written communications tend to be in the form of documents, notes and emails. This Section focuses on documents. Thinking before sending a written communications is crucial, because once received it cannot be taken back. Letters can be kept for years, these days they can be scanned and copies kept in an electronic archive. When an email is received at the recipient's computer host, the email is archived and can be accessed for up to several years if not longer. It is often useful, to write a letter an email or a document and then wait 24 hours before editing it and sending it. If you make major changes to the letter or email, then another waiting period would be useful.

3.1.1. Documents

When you sign off on a document you have written, reviewed or approved, you are stating that the document meets your personal quality standards. Your signature on that document shows your level of competency to everyone who subsequently reads that document (Kasser, 1995a). This Section discusses the concepts involved in writing good documents.

The format and flow of the document should depend on the type of document. Typical documents used in the workplace include:

- Marketing and sales documents and presentations.
- Business plans and presentations.
- Reports and term papers, etc.
- Technical documents, such as requirements documents, project plans, etc.
- Master's and Doctoral theses.

Currently, while there are guidelines as to the style and format of documents, and there are various methodologies for specifying the layout of a document, there are no precise guidelines on exactly what constitutes quality in the content of a document (Kasser, 1995a). Too often, the technical document preparation process takes the following form. A document is written in the form of a "brain dump". This approach results in a document (Kasser, 1995b):

- Written in the writer's language, not that of the users.
- Containing gaps in the flow of information. These gaps are due to the detailed knowledge of the writer, which allows the writer to make an association between one concept and the next, while the reader who does not have that background information misses the connection and is confused.
- Containing information in an illogical order from a reader's perspective.
- Containing replicated and/or redundant information.
- Containing the information the author provides, which is not necessarily the same as the information the reader needs.

W. Edwards Deming stressed the importance of avoiding errors in transactions in a service industry when he wrote, "*production of an illegible figure anywhere along the line is as bad as starting off with defective material in manufacturing*" (Deming, 1986). If an illegible figure is bad, a defective document is much worse. In general, the current approach to producing a document is not very effective because the document often does not present the author's intent in a clear, concise and readable manner. In addition the document may be incomplete or incorrect so that some parts or even the entire document has to be rewritten; i.e., doing the job twice.

3.1.2. Process for creating the document

This process for document preparation avoids later rewrites (minimizes scrap). If a document is written once, and meets these requirements, the result will be a better document at a lower cost, due to the reduced number of changes in the review cycle (Kasser and Schermerhorn, 1994a). The following list was presented as the requirements for writing documents; actually they are requirements for the content of documents:

1. The information shall be written in the reader's (customer/user) language.
2. The information within the document shall be pertinent to the reader.
3. The information in a document shall be complete.
4. All definitions shall be unambiguous.
5. All information shall be organized in a logical manner.
6. All wording shall be clear and concise.
7. Redundant or replicated information shall not be included in the document.
8. All specifications or requirements shall be stated in a manner that makes them verifiable.

The goals of the following document preparation progress are to:

- Produce a useful document that communicates the correct concepts between the writer and the reader.
- Minimize the time spent producing the document.

The following sequence of activities fits those requirements (Kasser, 1995b):

1. Locate and evaluate a similar document discussed in Section 3.1.2.1.
2. Develop metrics for the document discussed in Section 3.1.2.2.
3. Create the abstract discussed in Section 3.1.2.3.
4. Prepare an annotated outline discussed in Section 3.1.2.4.

5. Perform the iterative part for filling in the annotated outline discussed in Section 3.1.2.5.
6. Hold an informal document review/walkthrough discussed in Section 3.1.2.6.
7. Publish draft copy of document discussed in Section 3.1.2.7.
8. Update document based on reviewer's comments discussed in Section 3.1.2.8.
9. Publish document discussed in Section 3.1.2.9.

3.1.2.1. Locate and evaluate a similar document

Before you create a document, apply the lesson's learned concept from previous documents. Look for at least one similar document or template to use as a basis. Examine them for good and bad points, and then proceed through the document generation process described below. If you can't find a similar document, then look for reference methodologies, company standards or anything that will provide you with a first cut at the material the document has to contain.

3.1.2.2. Develop metrics for the document

This step allows you to anticipate how the reviewers will evaluate the document. Metrics for specific types of engineering documents may be generated from Military-Standard 2167A (MIL-STD-2167A, 1998) if appropriate and other sources such as the set of categories for evaluating a systems description provided by Teague and Pidgeon (Teague and Pidgeon, 1985: page 197). Their categories are:

- ***Completeness:*** the presence of all pertinent information and the lack of irrelevant and redundant information.
- ***Consistency:*** ensuring that the terminology, style and descriptions are identical throughout a specific document and within the whole set of system documents. This category applies to the graphics as well as to the text.
- ***Correctness:*** the information must be correct. There are two types of errors:
    - ***Syntax/typographical***: easy to find by means of a spelling checker or visual inspection.
    - ***Logical:*** difficult to find, since you need an understanding of what is being described in the document to know that the document is incorrect.
- ***Communicability:*** a measurement of how well the document communicates the pertinent information to the reader. This category relates to the page layout, legibility, terminology and the use of appropriate wording. Words such as "it", "this" and

"these" may be ambiguous and should be avoided unless you are really up against the page size limitation.

3.1.2.3. Create the abstract

An abstract is an overview of the document written to entice the reader into reading the whole document. A typical abstract should contain the following three parts:

1. The undesirable situation which triggered the work described in the document.
2. An outline of the anecdote or idea or proposal.
3. The outcome, results or resulting benefits.

The process for creating the draft abstract is to use bullets or dot points in the form of an outline list to create a draft abstract. The draft abstract list should only be converted to the prose version of the abstract once the paper is complete. This is a time saving process because the content of the document may change as the paper is being written and if the full abstract is written in prose at the beginning of the process, the time spent composing that prose will be wasted since the abstract will have to be rewritten at the end of the process.

The following provides an example of a draft and fleshed-out abstract containing all three parts using the **[ ]** signs to separate the parts[1]. The abstract is for a paper that discusses improving the way difficult concepts in systems engineering are taught.

The draft abstract is:

```
1.   Relationships difficult to explain
2.   Used modified FRAT[2] in class with
     positive results
3.   Paper uses FRAT for LuZ
4.   Lessons learned
```

The fleshed out abstract is:

Abstract. [In teaching systems engineering the relationship between functions, physical decomposition and requirements during the process of defining, designing and developing the system, has been difficult to get across to the students.**]** **[**While trying to improve the learning process, an explanation of the relationship between functions, physical decomposition and requirements during the

[1] The **[ ]** are for educational purposes only and should be removed from the final version of a document.

[2] See Section 6.3.2.2 for details of FRAT.

process of defining, designing and developing the system based on a modification of the Functions Requirements Answers and Test (FRAT) views of a system (Mar, 1994) was tried on undergraduate students at the University of South Australia in 2006-2007 with positive results (Kasser, et al., 2007).**][**This paper uses the adapted FRAT as a frame in which to describe the relationship between functions, physical decomposition and requirements using as an example the definition, design and development of the control and electronics part of the LuZ Solar Electrical Generating System (SEGS-1) in 1981-1983 (Kasser, 1984). The paper also provides some lessons learned from the project.**]**

The following is an example of a draft and fleshed-out abstract of a paper on thinking about thinking. This abstract however only contains the first and last parts.

The draft abstract is:

1. Thinking about thinking
   Emerging paradigm
   Need for multiple perspectives
3. Proposes a set of perspectives
   Use RAFBADS as example[3,4]
   The two flaws
   Observations on the state of systems ngineering

The fleshed out abstract is:

Abstract. [This is a paper on thinking about thinking. Systems engineering is an emerging discipline in the area of defining and solving problems in the manner of Wymore (Wymore, 1993). The emerging paradigm for problem-solving is "systems thinking". Both systems engineering and systems thinking have recognized the need to view a system from more than one perspective.**][**This paper proposes a set of perspectives for applying systems thinking in systems engineering and then defines a systems thinking perspective set of views for a system, the use of which will provide one way of aligning systems thinking to systems engineering. The paper then provides an example of applying the set of perspectives to the Royal Air Force Battle of Britain Air Defence System (RAFBADS) and shows that not only does the set of perspectives provide a way to model the system; it also picked up two

[3] See Section 6.4.3 for details of the RAFBADS.

[4] Acronym is allowed in draft abstract since it will only be seen by the author.

```
potentially fatal flaws in the system. The paper
then concludes with some observations on the state
of systems engineering from a number of the
perspectives.]
```

Both of these examples communicate what their papers are about. Readers who:

- ***Are not*** interested in the topic will skip the paper, not wasting time reading it and finding it of little value.
- ***Are*** interested in the topic will continue to read the paper. Hopefully the contents will hold their interest.

Opinions are split as to whether abstracts should contain citations to source documents. My preference is to insert them unless the style guide for the publication precludes including the citations. My general rule is when in doubt, cite!

3.1.2.4. Prepare an annotated outline

Once the draft abstract is ready, the usual flow in the documentation production process is to begin with an outline. This outline takes the form of a table of contents. The outline is agreed to, and the production of the document proceeds. However, in many instances, a table of contents is not good enough since it does not indicate the proposed content of each section. The author and reviewer can and often do interpret the meaning of the titles differently.

The process can be improved by replacing the table of contents with an annotated outline, which contains the table of contents, together with a paragraph or two on each section describing the contents of the section (Kasser and Schermerhorn, 1994a). The paragraph might begin with the words, "This Section will contain …". This approach:

- Organizes the author's brain dump in a somewhat more structured manner.
- Provides a clue as to what to expect in the document.

Think of an annotated outline as a design for the document. Before starting to prepare the annotated outline, think of the document as a presentation. Each transparency or PowerPoint slide is a chapter. The bulleted (dot pointed) lines on the slides are the section headings, and the written text is the verbal expansion of the points made by the presenter. These guidelines can be modified according to the length of the document. Plan the contents so the document flows in an orderly manner. Develop the contents as a list of headings using the inverted pyramid or newspaper writing style wherein the information begins with a general overview and then branches out to specific details. This way the audience can read as far as they need to. The outlining capability of modern word processors facilitate this implementation approach because you can see the appropriate levels of detail and readily expand sections of the document as appropriate. Annotate each heading with a description of the future contents. If the material exists, inserting the material at this time will clutter the document with too much detail. Instead, so do not insert it into the initial version of the annotated outline, insert the material after the review and approval of the annotated outline.

The writing process should only begin when the annotated outline is approved. Good examples of detailed annotated outlines can be seen in document templates that specify the contents of each section.

The following example contains annotated outlines for two of the sections of a study guide:

```
Section 2 The classroom sections
     This Section will contain the schedule
     and 14 paragraphs, one paragraph for each
     session, each providing details of:
    Objectives – a list.
    Knowledge – the topics to be covered in
     the session.
    Skills – to be learned/developed or
     exercised.
    Exercise – a description of the functions
     performed by the students.
    Readings – a list of required readings
     containing the knowledge to be learnt
     during the session.
    Student presentation – the nature of the
     topic the students will present.

Section 3.2 requirements of assignments
     This Section will contain the complete
     set of requirements for the individual
      assignment.
```

These annotations to the section headings communicate the future contents of the section to the reader. Annotated outlines can be thought of as document templates when applied to specific types of document such as study guides, requirements documents, proposals, contracts, etc.

While the abstract introduces the document, the last part of the document summarises the document and draws the attention of the reader to the main points in the document. Sometimes the summary may be a copy of the abstract or the introduction but written in the past tense explaining what the document did. For examples see the summary of this

Chapter in Section 3.6, the summaries of the other chapters and the summary of the book in Chapter 12. The summary should be finalized at the same time as the abstract is updated, namely at the end of the preparation part of the process.

3.1.2.5. Perform the iterative part or filling in the annotated outline

The iterative part of the process of writing the document converts the annotated outline to a document. The following iterative part is performed as long as the schedule allows:

1. Obtain and review pertinent literature or source information documents. Mark or extract (copy) all pertinent information or pointers to relevant data. Build a file to refer to when creating your document.
2. Hold informal fact finding meetings. Talk with cognizant personnel who can supply:
   - Source documents.
   - Information that is not written down.
   - Directions for obtaining additional pertinent information.
3. If you borrow documents and you can't extract the information you need in a timely manner scan or photocopy any pertinent information. Return the documents in a timely manner.
4. Document facts received during fact-finding meetings. If possible record the meeting but not without the permission of all the participants. Summarize all pertinent information discussed. Send a copy of the summary to the people you spoke with and get their concurrence that the information you documented is correct. Find out where to obtain other pertinent information if necessary.
5. Research further source information. If your discussions identify missing information, research the subject and obtain the necessary data. Do not ask others to do your research for you and provide you with the required information[5].
6. Write up sections. As you write the document, each section containing "This Section will contain …" is replaced by the true contents. You should:
   - Use the appropriate style guide or template consistently.

[5] Unless they work for you.

- Use a software tool for managing the styles of citations and references: it is a great timesaver.
- Use a spelling and grammar checker. Typographical erros [sic] make a document look sloppy and are so easy to fix.
- Adhere to the page limit if one is set.
- Avoid jargon.
- Spell out acronyms the first time they are used.
- Write the text to flow logically (to the reader).
- Apply critical thinking to the content and the order of presenting information as discussed in Chapter 5.
- Stay focused on the topic.
- Avoid irrelevant and (interesting to you) clutter.

Unlike works of fiction which are usually read in sequential order from start to finish, most people do not read technical documents unless they really need to know the details; they tend to scan the document instead. So, format the document so that pertinent information is readily seen. This book is an example of using the technique.

You shall not plagiarize, see Section 3.5.1 for details on how to build on other people's work and give them credit.

7. Discuss write-ups of sections as they are produced in informal walkthroughs, inspections and other discussion meetings. These review sessions build the quality into the product during the production process. It is always cheaper to make changes to draft manuscripts than to signed-off documents. There is a trade-off between upfront costs of doing it right, and generating a draft and revising it after a meeting or review.

The hardest part of creating a document is to produce the first draft. If everyone is responsible for quality then changes after the first review cycle are part of the process and not due to defects. It is easier at times to use the draft as a focus for discussion or to identify missing but needed information and ask the reviewers to supply same, as compared to spending a lot of time trying to dig out information the reviewer would have instant access to. There is an optimal point for each document, where it is cost effective to review a draft document, and incorporate changes at one time; as compared to spending more time developing the document, then holding the review and making changes.

3.1.2.5.1. Produce peer review copy of document

When you have gathered enough information, and written up enough sections, produce the peer review copy of the document. It doesn't have to be complete, but it does have to identify the anticipated contents of any missing sections. This could be the original, "This Section will contain …" parts of the annotated outline or new sections written in a similar manner. The peer review copy is the first informal draft of the document.

3.1.2.5.2. Circulate document for comment

Documents have to be checked for style, format and technical content. The technical content is best checked by a peer review process. Circulating the document at this time provides:

- Early feedback of the correctness of the information.
- Pointers to missing information.

Provide copies of the document to everyone in the project (stakeholders) as well as at least one person outside the project because:

- Project members will tend to catch errors in the document (errors of commission (Ackoff and Addison, 2006)).
- Outside personnel will tend to note missing information (errors of omission (Ackoff and Addison, 2006)).

Circulate the document to potential customers and users as well (more stakeholders). For example, circulate a requirements document to the designers who will use the document before signing off on the document. This will allow them to:

- Identify the need for clarification of any ambiguous elements.
- Provide an indication of missing information (something they think they will need, that is lacking from the document).

3.1.2.5.3. Request and receive comments

There's little point in circulating a draft if you don't get any comments back. Ask for the comments by a specific date which provides enough time for people to read the document and is not too far in the future. If the date is too far in the future, your reviewers may set the document aside in favour of a more urgent task and forget all about the document. Send them a gentle reminder a few days before the document is due. Make it easy for busy people to make constructive comments by providing a way to trigger their thoughts.

Think about what you'd like other people to provide you with, when they ask you to review one of their products. Ask for comments to be marked in the document in red ink (red lined). Don't require formal typed comments at this time. Provide a review form with space for specific comments as well as general comments such as:

- Great document; couldn't have done better myself.
- Not bad, but still needs work in the sections listed below.
- You left out the following points: leave space for some points.

3.1.2.5.4. Evaluate and incorporate comments

When the comments come back, evaluate all comments and incorporate any that clarify the contents of the document. There is a good probability that some of the comments will conflict with others. Resolve these conflicts by talking with the people who wrote the comments to try to understand why they suggested their changes. This process was used to good effect in the anecdote told in Section 10.2.

When you evaluate the comments, see if there is a pattern or trend. You may find the same type of comment occurs on several pages. Should this situation be true, you may want to rethink how you are presenting the information.

3.1.2.6. Hold an informal document review/walkthrough

One good way to ensure that comments are received in a timely manner and to resolve conflicting comments is to schedule a document review meeting. The number of days to wait after the document is sent out for review will depend on the type of document and the urgency of getting it published. As mentioned in Section 3.1.2.5.3, the delay should not be too long or people will put the document aside and forget it. People should have time to review the document and mark up any comments before the meeting. At the meeting, go through the document section by section and try to obtain consensus on changes. If consensus cannot be achieved on any specific section, agree to disagree and skip to the next section and rethink.

3.1.2.7. Publish formal draft copy of document

This is the draft that goes to the reviewer or even to the customer for formal comments. Since you have been working closely with the customer during the iterative phase, this state should just be a formality for contractual purposes.

3.1.2.8. Update document based on reviewer's comments

In the event the reviewer desires changes in the document, they may be incorporated into the document at this time.

3.1.2.9. Publish the document

Publish the document and distribute a copy to all people with a need to know. Put a copy in the project library and send courtesy copies to outside personnel who provided information or constructive comments.

If you are working with your organization's publications department:

- Agree on what they will do to your text before you authorize any work at all.
- Ensure they are cognizant of the entire process and the date you:
    - Expect to provide them with the manuscript.
    - Need the finished document.
- Feed draft graphics to them according to an agreed schedule. Remember they will be working on other documents, and the artist may only be a part time member of your team.
- Provide them with machine-readable text that is compatible with their publishing software. Ensure they do not have to retype any text to minimize errors.
- If the publications department makes any errors, you will probably be paying them to make the errors and then paying them again to correct the errors.
- Check all pages carefully, even the ones they were not supposed to touch.
- Return the document to them for publishing, and remember that it takes them time to print the document, and machines tend to break down.

3.1.3. Keeping the reader's interest

There is little point in making presentations and writing documents if people do not attend and listen to the presentation or read the document. A literature review of a sample of at least 200 modern and classic works of fiction[6] identified that the author kept the reader's interest by including something the reader can[7]:

- Relate to.

[6] Thrillers, detective and romance
[7] Notice the association of ideas

- Think about (but not to the extent that they are not following the presentation or the document).
- Expect to see later in the presentation or document.

In setting up expectations, in each work of fiction, irrespective of the plot, the author first set up expectations for something to happen, and while it was taking place, the author set up expectations for something else to happen. This feed-forward technique continued throughout the book until the end. In presentations, you can achieve holding the interest of the attendees by agenda slides as discussed in Section 3.2.1 and the occasional, "as I shall explain in a moment" or similar statement. You may also have already noticed a number of these feed forward points in this book starting with the introduction in Chapter 1 and the forward references for the same reason, and because the information fits better in the context of the later section.

3.2. Formal verbal communications

A speech, sometimes called a prepared statement, is a formal verbal way of communicating ideas between the speaker and the audience. A presentation is a speech reinforced with text and graphics used in the presentation slides. Presentations can be formal and informal. In the same away as the abstract or executive summary is a hook to entire the reader to read the full document, in many instances, the presentation is the advertisement for the document/paper it is summarizing. That means you must use the presentation to excite the audience into reading your document/paper and making use of the content. Generally you have 2-3 slides (minutes) to catch their attention. This Section discusses:

1. Factors that contribute to effective presentations in Section 3.2.1.
2. Effective use of text and graphics in Section 3.2.2.
3. Using backup slides in Section 3.2.3.
4. Using humour as previously discussed in Section 2.7.4.
5. Using multimedia in Section 3.2.4.
6. Rehearsing the presentation in Section 3.2.5.
7. Making the presentation in Section 3.2.6.
8. What happens after the presentation in Section 3.2.7.
9. Learning from other people's presentations in Section 3.2.8.

3.2.1. Effective presentations

Presentations need to be effective. Some of the factors that contribute to effective presentations are:

- Starting the presentation with a summary of the benefits to the people attending the presentation. This could be in the form of:
  - The objectives of the presentation.
  - An agenda.
  - A list of topics.
- Organizing the presentation about a key idea and using examples and graphics.
- Not speaking for more than two minutes on the same slide. People receive concepts in various ways, including listening and seeing. Redundant channels can be good when presenting to people from other countries who may not understand the spoken language as well as the written language.
- Do not read the slides word for word[8]. Many members of the audience can read faster than you can speak the slides and they will get bored quickly. At that point they will tend to tune you out and not receive any further thoughts.
- Holding the attention and interest of the audience as discussed in Section 3.1.3.
- Periodic progress slides which act as a road map to allow the audience to keep track of where you are in the flow of ideas.
- Numbered slides to allow for quick and easy reference to specific sides during a discussion on the presentation.
- One or more concluding slides to allow you to summarize the presentation and let the audience know that the presentation is over, namely to provide closure. The concluding summary slide can also remind you, and gives you a chance, to mention something you forgot to mention during the presentation.
- A metric to determine the degree of success of the presentation. The metric will depend on the purpose of the presentation. It may be as simple as the number of people clapping at a conference, or the number of units sold following a sales presentation. In an educational environment, the metric might be the grade received by the student making the presentation.

3.2.2. Effective text and graphics

The text and graphics in each slide should be effective, namely they should communicate in an easy way. There is no reason to have the audience try to work out what you are trying to communicate when you can

[8] Unless your audience consists on non-native English language speakers. In such a situation, read the slides word for word but expand on the words when you get to the end of the slide.

Table 3.1 Example of a dense table

Table 5. Systems Engineering Effort Categories Evident in the Standards

SE Categories	ANSI/EIA-632	IEEE-1220	ISO-15288	CMMI	MIL-STD-499C
Mission/purpose definition	Not included in scope	• Define customer expectations (Req Anlys)	• Stakeholder needs definition	• Develop customer requirements (Req Devlp)	Not included in scope
Requirements engineering	System Design • Requirements definition	• Requirements analysis • Track requirements and design changes	• Requirements analysis	• Req'ments development • Requirements mgmt	• System requirements analysis and validation
System architecting	System Design • Solution definition	• Synthesis	• Architectural design • System life cycle mgmt	• Select product-component solutions (Tech sol'n) • Develop the design (Tech sol'n)	• System product technical req'ments anlys/validation • Design or physical solution representation
System implementation	Product Realization • Implementation • Transition to Use	Not included in scope	• Implementation • Integration • Transition	• Implement the product design (Tech sol'n) • Product integration	Not included in scope
Technical analysis	Technical Evaluation • Systems analysis	• Functional analysis • Requirements trade studies • Functional trade studies • Design trade studies	• Requirements analysis	• Decision analysis and resolution	• Functional analysis, allocations and validation • Assessments of system effectiveness, cost, schedule, and risk • Tradeoff analyses
Technical management/ leadership	Technical Mgmt • Planning • Assessment • Control	• Technical mgmt • Track analysis data • Track performance – project plans, tech plans • Track product metrics • Update specifications • Update architectures • Update plans • Maintain database	• Planning • Assessment • Control • Decision mgmt • Configuration mgmt • Resource mgmt • Risk mgmt	• Project planning • Project monitoring & control • Measurement and analysis • Process and product quality assurance • Configuration mgmt • Integrated project mgmt • Quantitative project mgmt • Risk mgmt	• Planning • Monitoring • Decision making, control, and baseline maintenance • Risk mgmt • Baseline change control and maintenance • Interface mgmt • Data mgmt • Technical reviews/audits
Scope management	Acquisition & Supply • Supply • Acquisition	Not included in scope	• Acquisition • Supply	• Supplier agreement mgmt	• Technical mgmt of subcontractors/vendors
Verification & validation	Technical Evaluation • Requirements validation • System verification • End products validation	• Requirement verification • Functional verification • Design verification	• Verification • Validation	• Verification • Validation	• Design or physical solution verification and validation
In the standard, but not in agreement with other standards			• Operation • Disposal • Enterprise mgmt • Investment mgmt • Quality mgmt	• Org'n'l process focus • Org'n'l process definition • Org'n'l training • Org'n'l process perf • Causal analysis resolution • Org'n'l [illegible]	• Lessons learned and continuous improvement

easily make it simple. Factors that contribute to the effectiveness of text and graphics include:

- ***Simplicity:*** using slides that conform to Miller's rule of no more than 7±2 items (Miller, 1956) to assist in comprehension of the contents of the slide.
- ***Readability:*** keeping the font size large, 20 pts. should normally be a minimum size. How many times have you heard a presenter say something like, "*I know you can't read this but* …?" There is a better way but it takes time and effort because you have to figure out exactly what it is that you are trying to communicate. For example, consider the information shown in Table 3.1[9] (Honour and Valerdi, 2006)[10]. Such a table is useful in a written document where the text can be read, and discussed in writing if the discussion covers several or all of the areas of the table. However, in a presentation, you need to find a way to make each point in an easily viewable manner. In a conference context, or when providing a verbal summary of a report, many people just copy the table out of the document and paste it into the presentation. If the point to be made is to identify what information expressed by rows in the table are not present in the systems engineering

[9] Yes, you can't read the text. That is the point.
[10] For the record, Eric Honour did not use this table in his presentation, it is in the paper.

SE Categories	MIL-STD-499C	ANSI/ EIA 632	IEEE-1220	CMMI	ISO-15288
Conceptualizing problem and alternative solutions	No	No	No	No	No
Mission/purpose definition	No	No	✓	✓	✓
Requirements engineering	✓	✓	✓	✓	✓
System architecting	✓	✓	✓	✓	✓
System implementation	No	✓	No	✓	✓
Technical analysis	✓	✓	✓	✓	✓
Technical management/ leadership	✓	✓	✓	✓	✓
Verification & validation	✓	✓	✓	✓	✓

Figure 3.1 Alternate way to present a comparison of coverage in systems engineering Standards

standards expressed as columns then do not show the table and point to the areas containing the words "not included in scope". They are shaded in the table to help you locate them. Do not use a dense table with shaded areas in a presentation even though the shading helps to focus the audience's eyes on the pertinent part of the table. Remember the point of the presentation is to communicate the concept not reuse the table. Use something like Figure 3.1 which makes the point clearly and concisely. Note that creating drawings such as Figure 3.1 can take up a lot of time and thought, which is the usual reason for not doing it.

Use Table 3.1 in the document, but use Figure 3.1 in the presentation. Moreover, few if any people will realise the elegance of what you have done.

- ***No typographical errors:*** just because the spelling has bean [sic] checked does not mean that the spelling is correct. You may have accidently used a synonym which passed the check but is the wrong word in context. Did you note the spelling of 'bean' in this paragraph? Typographical errors are distracting to the audience and easy to eliminate.
- ***Lack of ambiguity:*** ambiguity is a major contributor to miscommunications.
- ***Contrast:*** the contrast between text and background should be such that the slides can be read under all lighting conditions. Just because you can see it at the terminal when preparing the presentation does not mean that the audience will be able to see the projected version.

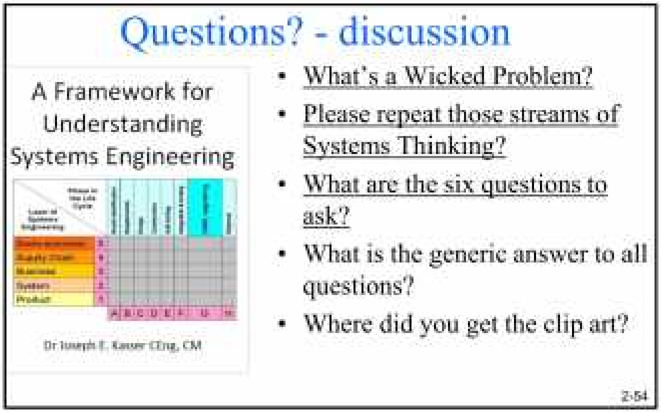

Figure 3.2 Example of final slide of a presentation

- ***Appropriate to the presentation:*** snazzy photographs can be distracters as the audience look at the photograph and wonder why it is being shown instead of listening to the presentation.
- ***To the point:*** reinforcing the words being spoken.
- ***Consistent:*** using the same word for the same concept each time it occurs. Synonyms can introduce ambiguity and misunderstandings.

3.2.3. Using back up slides

Time-limited presentations should flow without getting bogged down in details. However, there are usually one or more persons attending the presentation who will ask for details. You generally do not have enough time to go in to all the details, so go into none of them but anticipate the questions. Prepare back-up slides providing detailed information that is likely to be requested. You might even prepare hyperlinks from the final slide such as the one shown in Figure 3.2 and end the presentation with a reminder about the graphic and a question to the audience asking them which details they would like within the constraints of the remaining time. Information in the back-up slides can include:

- ***Anticipated technical questions:*** the audience might want to know how something works.
- ***VIP hot buttons:*** know the Very Important Persons (VIP) your audience and their interests and anticipate the questions.
- ***Supporting data:*** in the form of charts and pictures together with source citations to assist in the credibility, and indicate the timeliness, of the information.

Before the era of electronic presentations, it was simple to create back-up transparencies and select them in response to a question and then display them. In PowerPoint and other presentation tools, it is more difficult when you first begin to use the software tool. But, you can create the backup information in various ways including:

- Using hidden slides and providing hyperlinks to and from the hidden slides.
- Locating the backup slides at the end of the presentation and:
    - Scanning though them to find the appropriate ones with which to respond to a question.
    - Using a menu slide in the backup section with hyperlinks to select the appropriate slide. In this situation, each backup slide should contain a hyperlink back to the menu slide.

3.2.4. Using multimedia

Multimedia enhances a presentation and is very easy to use. However, do not use multimedia just for the sale of using multimedia. Films such as '2001: A Space Odyssey' (Kubrick, 1968) and 'Star Trek: The Motion Picture' (Wise, 1979) stopped the action to show off the special effects, and, while the special effects were innovative, they were a tad overdone. The purpose of the films should have been to entertain by telling an anecdote, not show off special effects. The purpose of your presentation is to communicate ideas not demonstrate your mastery of presentation technology. Use multimedia to make a point or to provide context without drawing attention to the special effects as was done very well in the first Star Wars film (Lucas, 1977) and its sequels. Consider some uses of various types of multimedia as follows.

1. Photographs discussed in Section 3.2.4.1.
2. Video discussed in Section 3.2.4.2.
3. Audio discussed in Section 3.2.4.3.
4. Animation discussed in Section 3.2.4.4.

3.2.4.1. Photographs

If you can, use photographs to assist describing things rather than drawings. Personal experience in the form of anecdotes brings a presentation to life. Even without the anecdotes, photographs are generally more interesting than a graphic drawing. However, do not overuse photographs, you are not showing your vacation pictures, just use the photographs to make a point. These days, suitable photographs with Creative Commons licensing can be found on the Internet on sites such as Flickr which specialize in providing photographs. When you use photographs, remember to cite the source.

Note if your audience consists of engineers you may be better off sticking to technical drawings.

Photographs can be distracting if they do not directly support the message the slide is trying to communicate. If your audience is trying to work out what the photograph is showing, they are not listening to you.

3.2.4.2. Video

Short videos can be used to effectively communicate ideas, reinforce concepts and expand the horizon beyond the presentation location. There are a large number of videos available from many sources including Internet sites such as YouTube. When you use videos, remember to cite the source.

3.2.4.3. Audio

Sound snippets can also be used but often need to be introduced and explained. Sound effects can provide emphasis and wake up members of the audience who have dozed off during your presentation. Use them sparingly.

3.2.4.4. Animation

Animation of objects in the presentation draws attention to the item. Use sparingly because too much can distract the audience from the presentation.

3.2.5. Rehearsing the presentation

Effective presentations are rehearsed specialty when you are trying to communicate new ideas. Suggested activities for rehearsing the presentation are:

- ***Timing the presentation:*** keeping to time is the most important part of the presentation. If you go longer than the allotted time, the audience will start to think about where they should be and what they should be doing in that time and stop listening. If they are not too polite to leave, they may start to leave while you are still speaking.
- ***Rehearsing in front of a video camera:*** watch the video. Make sure you do not have any unconscious distracting behaviour such as waiving your hand about and fidgeting with the laser pointer.

- ***Rehearsing in front of peers:*** watch their body language to see where you start to lose their attention. As a rule of thumb if you speak for more than two minutes on a single slide you will start to lose the audience.
- ***Using the feedback from your peers*** to update the presentation both in terms of the contents of the slides (text and graphics) and what you say.
- ***Keeping it current:*** if you are going to be presenting at a symposium or conference, update the presentation during the event if you can to include something current from a pertinent presentation you attended. If you can't alter a slide, you can always make the reference verbally. In other types of presentations try to refer to some current pertinent event during the course of your presentation.
- ***Rehearsing:*** perform a final rehearsal the night before the presentation.
- ***Finding the room beforehand:*** this will:
  - Help make sure that you will not be late to your own presentation; which can be very embarrassing.
  - Let you see if there is anything you should be aware of, and compensate for, such as lighting, size of room, etc.

3.2.6. Making the presentation

Things you should know and consider when making your presentation include:

- ***Keep to the allocated time:*** the most important thing about the presentation is keeping to time.
- ***Introduce the topic:*** tell the audience what you are about to tell them during the rest of the presentation. In other words give them an overview of the presentation as your introductions[ii]. You might also want to thank the audience for attending your session if they have a choice between your session and other sessions.
- ***Be enthusiastic!*** How can you expect the members of the audience to be enthusiastic about your presentation if you aren't?
- ***Expect people to leave in the middle:*** they leave for various reasons such as lack of interest, waking up to the fact they are in the wrong room and answering a call of nature. When someone

[ii] Notice the feed-forward concept.

leaves, don't comment, keep going but if everyone leaves you can stop talking.

- ***Use of notes:*** this is a personal issue. If you are comfortable speaking without notes, do so. If you need notes, use them. If you have some control over presentation location or computer you may be able to use two screens, the projected screen showing the presentation graphic and the local presenter's screen showing the notes part of the slide.
- ***Eye contact with audience:*** make eye contact with the audience. Do not focus on a single person, but slowly move around the audience making and holding eye contact for at least five seconds at a time. Watch the body language of the audience; if people nod as you speak they probably agree with your points. If they are nodding with their eyes closed, they are probably falling asleep[12].
- ***Summarize the main concepts:*** do this at the end of the presentation as part of summarizing the paper using concluding slides as discussed in Section 3.2.1.

3.2.7. What happens after the presentation

After you have concluded your presentation, and invited questions or comments, the audience may or may not have a question.

3.2.7.1. No questions

In the event that nobody asks a question or makes a comment then from the *Continuum* perspective:

- Nobody was interested.
- You did a good job.
- You overwhelmed the audience with ... .

Don't worry about it; you can't wind the clock back and redo the presentation. You can however prevent the situation by passing a written question or two to the session chair to ask you in the event that nobody else poses a question before you make the presentation. The type of question could be to explain an issue you raised in the presentation (and have prepared backup slides) or to focus on something you wanted to mention but didn't fit into the main theme. Once the first question is asked and answered the ice has been broken and other questions tend to follow.

[12] This is an example of using a perception from the *Continuum* perspective to make poor jokes as discussed in Section 2.7.4.

3.2.7.2. Dealing with questions

Members of the audience generally make several types of questions or comments after a presentation, including:

- ***Clarification of something you said:*** in which case answer the question. If you don't know the answer, don't try and bluff. Admit that you don't know, but not by saying that you don't know the answer. After all you are supposed to be the expert. Instead say that you do not have enough information to answer the question at this time and ask the questioner to send you an email and you will provide an answer within a reasonable time. Don't accept a business card and promise to respond for two reasons:

    1) You may not remember the question.
    2) People often ask questions when they are not really interested in the answer, at least in the long term.

    Asking for an email, means the person has to want the answer enough to send you an email. This approach used to cut out the dilettantes and reduce the speaker's workload. Unfortunately, these days with Wi-Fi, the questioner can send you an email from right there in the presentation room, so it is not much of a deterrent.

- ***Request for additional information:*** respond to these with a request for an email as discussed, or if you have the information on your computer with you, ask the questioner to see you later with a Universal Serial Bus (USB) memory stick and you will download the information from your computer onto their memory stick.
- ***Questioner wishes to make their point:*** let the person speak and leave controlling the dialogue to the session chair.
- ***Requests for copies of your presentation graphics:*** respond to these in the same way as to a request for further information. However be aware of Intellectual Property (IP) issues and don't pass out copies of copyrighted material when you don't own the copyright.

3.2.8. Learning from other people's presentations

When you watch other people presenting watch what they are doing and presenting while thinking about the ideas they are presenting. You will see good and bad ways of presenting information. Adopt the good and make sure that your presentations are not as bad. If you like a presentation, let the presenter know either in person or via an email. If you also ask a question in the email you may be on your way to developing a new colleague or even a new friend. If you disagree with the presenter or think the presenter was wrong, ask a polite question. If the presenter does not accept your opinion or answer your question, or even understand your question, you may find it better to remain silent. In any event never make anyone lose face in a presentation. If you must ask embarrassing questions do so in private.

If the content does not interest you and you have no other place to be at, then look at the way the information is presented (good and bad). I learnt this lesson many years ago when I went to see the London production of the musical Cabaret (Prince, 1968). I was bored by the songs and dances and the slow plot development and felt like leaving. But then I became interested in the use of the lighting[13] and the choreography and all of a sudden the technical aspects of the play were interesting and I learnt a lot.

3.3. Barriers to communications

When trying to communicate with someone, you have to understand that there are barriers that can block the transfer of meaning. Barriers to communications include the following:

- Cultural differences in perception discussed in Section 3.3.1.
- Emotion discussed in Section 3.3.2.
- Language discussed in Section 3.3.3.
- Signal-to-noise ratio discussed in Section 3.3.4.

3.3.1. Cultural differences in perception

People in different cultures perceive the same situation differently. For example, in western Anglo-Saxon culture it is polite to clear the plate when eating a meal as a guest. In Chinese culture, it is polite to leave some food on the plate to signal that you have had enough. Clearing the plate leaves an empty plate which signals that you are still hungry and want more food. Any Anglo-Saxon visiting a Chinese home for dinner needs to be aware of this difference to avoid becoming fed up (pun intended). Cultures differ in organizations and nations as discussed herein.

3.3.1.1. Organization

Organizations have their own way of doing things, often called "culture". Communications may flow through channels in specific ways and your

[13] I trained as an electrical engineer.

communication has to be adapted to enter the other organization and communicate the message in a clear and concise, non-ambiguous manner. Moreover if the organization does things in a different way, or lacks a common frame of reference for the concept, the other organization may be unable to comprehend your concept. For example, try explaining the concept of colour to a blind person.

3.3.1.2. National

Nations are an instance of a class or type of organization and inherit the properties of organisations discussed in Section 3.3.1.1.

3.3.2. Emotion

Emotion can be a barrier. If you are angry with someone, will you be willing to listen to what they say? If you are in love with someone, will you listen and evaluate comments made about that person by someone else? If you determine that there is an emotional barrier, then be patient, and wait until the appropriate time for the communications.

3.3.3. Language

When people speak different languages the barrier is obvious. However, the general solution of speaking louder is incorrect. Translators are employed to overcome this barrier. Even when you speak the same language, you still may not communicate for the following reasons:

- ***Different words for the same concept:*** this situation gives rise to miscommunications and unnecessary complicated situations. This situation can arise when people in different disciplines address the same concepts and the people in one discipline define new terminology rather than reuse the terminology for those concepts that exists in another discipline[14].
- ***Different concepts for the same word:*** this situation can cause major communications problems when the concepts are close enough that the subtle differences are not noticed at the time, and each party subsequently proceeds in different directions. Kasser and Shoshany discussed the subtle differences in the meaning of words used by systems engineers and software engineers and how to bridge that communications gap (Kasser and Shoshany, 2000; 2001). As another example, the word 'capability' has different meanings in different parts of the system or product lifecycle.

[14] On the other hand, in academic circles, the use of different terminology tends to result in research grants.

As one more example, during a visit to Yamaguchi, Japan in 1980 I went into a department store to purchase a child's kimono for my six-year old daughter as a present. It was a slack time in the store so as time went by, more sales assistants joined in the conversation. Nobody seemed to speak English but using a combination of pointing and phrases from the Berlitz phrasebook all went well. An appropriate kimono and obi were selected and then before concluding the purchase I wanted to know how to clean the garment. So I looked up the Japanese word for 'cleaning' and stumbling a bit over the language asked in Japanese for instructions on how to clean the kimono. The sales assistants started whispering amongst themselves and looking at me strangely. After a minute or so, I opened the phrasebook and showed the chief sales assistant the word I had used. He looked, smiled and said something in Japanese to the remainder of the crowd. Everyone smiled and a number of people exclaimed, "dry clean"! Using a mixture of language and pantomime I was politely informed that the word I had used for 'clean' actually was normally only used in the context of 'cleaning the floor' (and they were wondering why I would want to wash the floor with this expensive kimono). In this situation[15] since the context was obviously wrong, the unintentional misuse of the word 'clean' was recognized immediately and corrected.

- ***Opposite concepts represented by the same word:*** an example of this situation is the notion that Great Britain and the United States are separated by a common language (Shaw, 1925). The ramifications of this notion are subtle and it is not an easy concept to understand unless one has been sensitized to it. An example of the situation occurred in the mid 1970's during contract negotiations between personnel representing the US based Communications Satellite Corporation and British Aerospace. The language of the meeting was English. The meeting became stuck on one point. Someone then suggested tabling the issue. Both sides agreed and the meeting deteriorated further. The situation was much improved when the interpreter who spoke English and American pointed out that the verb "to table" means:

    1) To place the subject *on* the table for immediate discussion - in English.
    2) To place the subject *under* the table for later discussion - in American.

[15] They agreed that foreigners were strange, but not that strange.

- ***Different perceptions of the meaning of the same word by different people:*** People use words with a specific meaning in mind, which is different to the meaning perceived by another person. This is similar to the 'different concepts for the same word' example discussed above. This situation is akin to Humpty Dumpty telling Alice that, "*when he uses a word it means just what he chooses it to mean - neither more nor less*" (Carroll, 1872). The different meanings in the words may overlap the meanings of other words or contradict the meaning of the same word in another publication[16]. For one example see the discussion on the overlap between 'complex' and 'complexity' in Section 7.7.3. For another example, consider the word "secure". When told to "secure" a building it has been related that in the US Department of Defense (DOD):

    - ***The Navy*** issues a purchase order for the building.
    - ***The Air Force*** locks the doors and turns on the alarm systems.
    - ***The Army*** first evacuates the personnel, then locks the doors and turns on the alarm systems.
    - ***The Marines*** assault the building using ground troops and air support, and then deploy squads in and around the building checking the credentials of all who aspire to enter and leave the building.

    This example illustrates a subtle communications problem. When one hears unknown words, such as in a foreign language, the failure to communicate is obvious. However, when one hears words that sound correct in the context, the failure to communicate is not realised and sometimes produces serious consequences. This situation can happen when communications takes place between different organisations, different national cultures and even different engineering specialties.

- ***Use of the wrong word for a concept:*** when the word is obviously wrong, this barrier is visibly present and can be corrected. However, this situation can cause major communications problems when the word is appropriate in context even though it is incorrect. For example, Fred was working at an overseas location and he wanted to have a wall painted. He showed off his language skills by requesting that it be painted "lavan" using the local language. However, his use of the language was not that per-

[16] Which is the reason for the glossary in Section 1.7.

fect and he (accidently) used the word for “white’ while thinking “grey”. The painter received his instructions; white is a valid colour in the context for painting a wall, so he did not question Fred’s choice. Fred came back a day later and surprise, the wall was painted white. Fred called in the painter showed him the wall and reminded him that he had wanted the wall painted “lavan” thinking “grey”. The painter couldn't understand why Fred was making a fuss. Fred asked him to paint it “lavan” and it was “lavan”. The painter is using “lavan” thinking “white”. The discussion started something like:

“Why did you do this, I asked you to paint it “lavan” (thinks grey)” said Fred.

“What’s the problem, I painted it ‘lavan’ (thinks white)” replied the painter.

“No you didn’t!” replied Fred. And so on.

In the ensuring discussion they were both using the same word (“lavan”) with a different meaning in the same context and since both meanings make sense in the context they didn’t realize what kind of situation they were in for a while.

3.3.4. Signal-to-noise ratio

We are all subjected to information overload and it is sometimes difficult to separate pertinent information from the mass of information we received. Electronic engineers call this sorting the signals out of the noise.

3.4. Overcoming the barriers

In many cases, preparing or formulating and asking questions and using various techniques in a dialogue to verify that the concept has been communicated may overcome the barriers. Question and answer is most often thought of as taking the form of a dialogue. Questions and answers can take many forms including:

- The dialogue between the lawyer and the witness in a courtroom.
- Examination questions and answers.
- Invitation to bid for a contract and the bid.
- Request for a tender or proposal and the tender or proposal.
- Feasibility studies which answer the questions concerning the feasibility of something.

This Section discusses:

1. Questions in Section 3.4.1.

2. Answers in Section 3.4.2.
3. Active listening in Section 3.4.3.

3.4.1. Questions

This Section discusses:

1. Types of questions in Section 3.4.1.1.
2. Attributes of a good question in Section 3.4.1.2.
3. The most useful types of questions in Section 3.4.1.3.
4. Preparing questions in Section 3.4.1.4.

3.4.1.1. Types of questions

Questions can be closed or open where:

- ***Closed questions:*** include all the solutions in the question. These are generally:
    - Multiple-choice questions that limit the decision about the answer to the options in the question.
    - Questions that require a 'yes' or 'no' response.
- ***Open questions:*** do not include any solutions in the question. An example of an open question is "what are the three most important things you learnt from this chapter?"

3.4.1.2. Attributes of a good question

The attributes of a good question include:

- ***Clarity and conciseness:*** maximizes the probability that you will be understood.
- ***Contains only one main idea/concept:*** prevents long multi-part questions where the early parts of the original question are forgotten. If you have to ask a multi-part question, announce that fact and how many parts there will be in the question, then address each part in turn.
- ***Brevity:*** you want to listen to the answer not talk. You learn more from listening than from talking.
- ***Unbiased:*** don't bias the answer. Questions that bias the answer are known as leading questions in courtroom dialogue.
- ***Grammatically correctness:*** use correct grammar, it not only helps to get your meaning across, it shows that you are educated.
- ***Consistency***: applies within a single question and to a set of questions Use the same word for the same meaning each time. Do not use synonyms or words with slightly different meanings.

For example do not use the words "spade" and "shovel" to refer to the same tool for digging holes in the ground[17].

- ***Insensitiveness to errors in interpretation:*** the question should be asked so that there is a low probability of error. For example in an emergency situation, after a disaster, when someone reports that they think someone else is dead, they should not be asked to "make sure that the person is dead"[18]. They may interpret the question as an instruction to make sure the person is really dead by taking an appropriate action.

3.4.1.3. The most useful types of questions

The most useful questions to ask are the Kipling questions "who, what, where, when, why and how" (Kipling, 1912). Each type of question initiates the exchange of concepts in different perspectives about different attributes of a concept. Consider a cup of instant coffee for example, the answers to the:

- ***Who*** questions provide information about who is going to do operate, create or … something. In this instance the answers provide information about who:
  - Is going to prepare the cup of coffee.
  - Serve the cup of coffee.
  - Drink the cup of coffee.
- ***What*** questions provide information about the object associated with the concept. In this instance the answers provide information about the ingredients and the equipment used to prepare the cup of coffee (cups, spoons, electric kettle, etc.).
- ***Where*** questions provide information about where things happen. In this instance the answers provide information about where the cup of coffee will be prepared and drunk. These answers may lead to further thoughts about transporting the cup of coffee from the place where it is prepared, to the place where it is drunk.
- ***When*** questions provide information about when things happen. In this instance the answers provide information about when the cup of coffee will be prepared and drunk.
- ***Why*** questions:

[17] They are different tools with different shaped blades, not synonyms for the same digging tool.

[18] See video joke on YouTube at http://www.youtube.com/watch?v=By0oe7BUDWQ last accessed on 26 July 2015.

    - Provide information that helps you understand something, such as the cause of a problem, the need, or how the situations arose. In this instance, the answers to the why questions provide the reasons why the cup of coffee is being drunk.
    - Are useful for drilling down into the reasons for symptoms to determine the underlying cause, and are used in a concept called, "The 5 why's" developed by Sakichi Toyoda for the Toyota Industries Corporation (Serrat, 2009).
- ***How*** questions:
    - Often provide information about the process. In this instance, how the cup of coffee will be prepared and how it will be drunk. For example, if the coffee is drunk in sips over an hour or so, then you may need to serve the coffee in an insulated cup. If it is drunk within a few minutes, then a regular cup would be in order.
    - Can also provide quantitative information such as "how much will it cost?"

3.4.1.4. Preparing questions

When preparing questions to ask, you have to consider several things including:

- ***What do you want the respondent to do?*** Do you want the person to:
    - Recall and repeat the information.
    - Apply information.
    - Analyse and use data or information.
    - Evaluate something.

So you need to consider:

- ***How easy will it be to recall and repeat the information?*** You may have to allow for different response times and ways of delivering the answers depending on the nature of the topic and the type of question. Some types of questions may evoke an immediate written or verbal response, and some may need a study lasting months with written reports.
- ***How easy will it be answer the question?*** This factor governs how much research needs to be done, how much time needs to be spent and possibly the cost of the resources used to determine the answer.

- ***How difficult will it be to evaluate response?*** One reason for multiple-choice questions in examinations is that they are very easy to evaluate.
- ***How easy will it be to communicate the results*** to those that need to make use of the information? This factor may govern how you want the responses delivered. Written responses are easier to distribute than verbal responses.
- ***The validity of the question:*** this factor produces a response containing the desired or pertinent information. Ambiguity reduces validity.
- ***The reliability of the question:*** this factor produces consistent similar responses from different respondents.

3.4.2. Answers

Questions and answers can be simple, complicated and complex. The general rule in answering questions is to make it easy for the person who asked the question to realise that (1) the question has been answered and (2) to understand the answer.

Have you ever asked a question and instead of receiving an answer, you were faced with another question? Wasn't it annoying? Think about the process. The recipient received your question, thought about it and asked for further information or clarification as a prelude to answering the first question. Well you can defuse the annoyance of receiving a question instead of an answer is to use the words "*it depends*" as the initial answer to most questions. Then go on and discuss what it depends on. This approach will open a dialogue which will hopefully enable the concepts to be communicated. So, remember, never ever answer a question with another question, answer the question with the words "it depends" instead.

3.4.3. Active listening

Active listening is a standard technique for applying the feedback principle to inter-personal communications to minimize errors in conveying meaning from one person to another. Active listening first recognizes that during a conversation, most people do not listen to what the other person is saying: they are too busy planning what they will say when the other person pauses. Standard active listening comprises the following multi-step process:

When the other person speaks gives them your full attention and look them straight in the eyes. Then begin the following iterative loop.

1. Listen to everything the other person says and try to understand it fully.
2. Ask questions to clarify anything you don't understand and analyse the response.
3. Rephrase what you have heard in your own words and ask the speaker if they meant what you are about to say. Use words such as, "if I understand you, then …", or "Do you mean …" This is the principle of applying feedback.
4. If, after you have rephrased what has been said and the person says, "No that's not it!" or the equivalent, then go back to Step 2. You may need to invoke the STALL technique at this time to regulate matters[19]. STALL is an acronym for:

   - ***S***tay calm.
   - ***T***hink.
   - ***A***sk questions and analyse the answers.
   - ***L***isten.
   - ***L***isten.

   You have two ears and one mouth, use them in that ratio.

5. When the speaker finally agrees with you, then you have (most probably) actually communicated and shared meaning.

In modifying active listening by the use of pattern matching, change Step 3 to incorporate the pattern by adding words such as, "this reminds me of the [Type A Scenario]", and "isn't this similar to [Type B scenario]" and explain why you find a similarity in the current situation. Use a metaphor appropriate to the other party such as sport.

Active listening can be used in other forms. For example, in the classroom instead of lecturing an overview of the readings or just requesting the students to read the readings, instruct the students to both read and present (Kasser, 2013):

- A summary of the reading.
- The main points of the reading.
- Some analysis of the reading.
- A comparison of the reading with other literature.

This simple change to a class:

- Ensures that if the students misinterpret the readings the instructor can correct the misinterpretations by the next class session.

[19] Stalling for a while, but not too long, is a good way to initially deal with most undesirable situations.

- Some of the students actually read the readings.
- Allows the students to see that different people/groups summarize readings slightly differently, in other words receive different messages from the same readings.

3.5. Intellectual Property

Intellectual Property (IP) is the product of the intellect or mind. It generally comprises documents, graphics, music, etc. and is protected by law by several methods including copyrights. When using IP in communications you must get permission from the owner unless the IP is in the public domain or released under a Creative Commons license in which the owner of the IP reserves ownership but allows the work to be freely copied[20]. The law makes provision for the fair use of copyrighted IP in educational and not for profit settings. Cartoons are a common form of IP used in presentations and books to facilitate communicating ideas. You should never use IP, be it copyrighted or not, without crediting the source.

3.5.1. Plagiarism and leveraging on other people's work

Plagiarism is using someone else's work and passing it off as if it was your own. If you plagiarise you might get away with it for a while, but sooner or later you will be found out, and then your reputation will be destroyed forever. You will never be able to restore it. However, it is so easy to prevent that from happening. You should incorporate someone else's work in your own to build on what has been created before, BUT do it right. All you have to do is *give credit where it is due* citing the source in the appropriate format discussed in Section 3.5.2.

When using material from various sources, apply the following rules.

1. Don't use too much from a single source. If you are unsure, then you are probably using too much.
2. Don't use figures and drawings from other sources without attribution[21]. Request permission if you include the figure or drawing in a publication for profit. Clip art, which is in the public domain, is excluded from this rule.
3. Use of figures and drawings from other sources is generally permissible in a not for profit presentation such as in a classroom, but not in the hand-outs.

[20] Exactly how the IP may be copied and used depends on the type of Creative Commons license.

[21] In the caption as well as in the text to preclude people citing you as the source of the figure. See examples in this book.

4. Do not post your content (which contains figures and drawings from other sources) on the Internet; that constitutes 'publishing'.
5. If the material you incorporate is available under Creative Commons licensing, then conform to the specific version of the license.

Check these rules with your legal department.

3.5.2. Citing sources or incorporating references

Citing or referencing other people's work and then building on their work gives your publication credibility as well as showing that you are conversant with the literature. Citing sources can be done in various ways and tend to be publication specific. That is different publishers have different styles. The most common ways of citing sources are:

- (Author [last name, initials], date). This is the style used in this book and there are numerous examples. There are varieties of this style where the author and date may be separated by a space character or a punctuation mark such as a comma or the author and date may be enclosed in square brackets.
- Numbered in square brackets as in [1], [2], [3] etc. note that the order of numbering also varies, in some instances the order is by appearance in your document and in other instances the order can be chronological by publication date, or in alphabetical order.
- As footnotes.

If citing a source from a book, add the page number to facilitate looking up the reference. This allows readers of your work to check the source and lets you find it again after you have forgotten where in the source book the concept was mentioned.

When citing Internet web sites, the citation should include the Uniform Resource Locator (URL) and the date of access, since unlike the static printed page; contents of web pages are dynamic and can be changed by their owners. This means that something seen on a web page today may not be there in a week; hence the need to provide the access date. You should incorporate the citation using the appropriate style and format.

Citations can be to primary sources or to secondary sources. This book contains many citations in the (author, date format). The following sections contain examples of citations to primary and secondary sources with explanations of the purpose of the citations.

3.5.2.1. Citing primary sources

Primary sources are those that you have seen. The following are examples of citing primary sources:

- An example of citing other people supporting a statement made by the writer.

  In a paper discussing the differences between systems engineering and project management in the literature, the author wrote, *"depending on their perspective, authors have written that the activities performed in producing the ancient pyramids, the canals and railways of the 19th century and other systems of the past are those embodied in systems engineering (Kasser, 1996a) or project management (George, 1972)".*

- An instance of citing a source to support a statement.

  In the same paper as before, the writer makes the following statement, *"For example, the activities in the 1930's that led to the creation of the Air Defence System used by the Royal Air Force in the Battle of Britain have been called systems engineering with hindsight (Haskins, 2006)".*

- An example where the citations are used to support the "*there have been many*" part of the quotation.

  In the same paper as before, the writer makes the following statement, *"There have been many discussions in the literature about the overlapping of, and differences in, the roles of systems engineering, operations research, systems architecting, and project management, e.g. (Brekka, et al., 1994; Roe, 1995; Kasser, 1996a; Sheard, 1996; Mooz and Forsberg, 1997; Friedman, 2006)".*

- An example of a citation used as a lead into quoting the source in the words that follow the '...'.

  In the same paper as before, the writer makes the following statement, "*Mooz and Forsberg wrote that systems engineering and project management should be integrated "(Mooz and Forsberg, 1997). They state that* ...". Note the double use of the author's names. The first time the text mentions that the authors wrote something, the second use provides the citation. The text read should clearly as if the citations were invisible. So while it may look desirable to use the form, *"(Mooz and Forsberg, 2009) wrote that systems engineering and project management should be integrated"*, and avoid double mention of the authors (in the author date format), you should resist the temptation.

- An example where the author names and cites a source in the first part of the quotation and then adds a conclusion in the last sentence. The citation at the end of a sentence also makes it clear which part of the paragraph is cited and which is not.

  In a paper on education the author wrote, "*As van Peppen and van der Ploeg wrote 'typically, an educational program is carefully designed, giving attention to the individual elements of the curriculum, the learning environment, and their interdependencies' (van Peppen and van der Ploeg, 2000)".* A curriculum design (a specific sequence of knowledge-base and skill-building courses) specifies the criteria for course design (a specific combination of learning objectives, course materials, teaching methods, and tests), as well as the staffing of teaching faculty, course scheduling, and teaching facilities. Thus designing a curriculum is an example of systems engineering of both the product and the process, hence...".

- Another example where the author cites a source in the first part of the quotation and then adds a conclusion in the last sentence.

  In the same paper as before, the author makes the following statement, "*Students could even fail to complete the post-class assignment and still pass the course (albeit with a minimum passing grade)" (Kasser, et al., 2005)".* The students were learning to do systems engineering by numbers!

- An example where the author begins with a cited quotation which is then followed by a conclusion.

  In the same paper as before, the author makes the following statement, "'*Effective systems engineering calls for careful coordination of process, people and tools. 'Such coordination cannot be learned from books' (Hall, 1962 page v)",* these needs levelled requirements on the pedagogy to add something to the book learning.

3.5.2.2. Citing secondary sources

Secondary sources are sources that are cited by a primary source. You should never cite a secondary source as a primary source, namely pretend that you have seen the primary source. Sometimes the secondary source quotes the earlier document out of context or makes an error. Using the secondary source format absolves you from an error made by the primary source, and shows respect to both sources. This form of respect goes back at least 2,000 years and can be found in the Jewish Talmud in the form of citations such as, "*Rabbi Judah said in the name of Rabbi Zechariah that ...".* Secondary sources can be cited in the form, *"text being cited (Kasser, 2008) as cited by (Hari, 2009)*". In this instance, (Kasser, 2008) is the secondary source and (Hari, 2009) is the primary source.

3.5.2.3. Paraphrasing

Citations also need to be used when paraphrasing source materials. For example, in one paper on education a concept (intellectual property) from a source in the literature was paraphrased to support the work being documented in the paper. The original text in Vélez and Sevillano stated, *"In a digital hardware design course, students should work similarly to digital hardware engineers in a company (Vélez and Sevillano, 2007)".* The statement was incorporated in the paper to support the work being documented. As incorporated in a paper, the concept was rewritten as, *"The immersion course format was developed to allow the students to perform systems engineering in the classroom in a systems engineering environment. This concept is supported by Vélez and Sevillano who stated that students in a digital hardware design course should do the same type of work as digital hardware engineers perform in a company (Vélez and Sevillano, 2007)*".

3.5.2.4. In line citations

The following example illustrates why the citation should not be used as part of the text. In the author - date format the text is written as, "*Mooz and Forsberg wrote that systems engineering and project management should be integrated" (Mooz and Forsberg, 1997).*

In the numbered format the text is, "*Mooz and Forsberg wrote that systems engineering and project management should be integrated" [3].*

If the citation had been incorporated in the text, using the author-date format, the text would have read as, "(*Mooz and Forsberg, 1997) wrote that systems engineering and project management should be integrated*" which makes the source clear, but if the citation had been incorporated using the numbered format the text would have read, *"[3] wrote that systems engineering and project management should be integrated*" which does not provide the author information unless you refer to the list of references at the end of the text.

Remember the goal of writing a document is to make it easy for the reader to follow the flow of concepts and understand what you are trying to communicate.

3.5.3. Citation management software

You should also use a software tool for managing the styles of citations and references: it is a great timesaver. Consider the following text written using a style in which the two citations are shown as (author, date).

> *"As a consequence, demand for skilled, knowledgeable, Systems Engineers in government, industry, and academia is increasing around the world (Arnold, 2006). However, in general, systems engineering seems to be poorly practiced (Kasser, 2007)".*

In the following version of the text, the same citations are numbered in the brackets style.

> *"As a consequence, demand for skilled, knowledgeable, Systems Engineers in government, industry, and academia is increasing around the world [4]. However, in general, systems engineering seems to be poorly practiced [52]".*

If sections of text have to be included in different documents with different requirements for citation styles then retyping citations wastes a lot of time. There are software tools such as EndNote and RefWorks that help you collect, store, and manage reference information. The tools allow you to insert citations into documents as fields and can change the format of the citation and bibliography of an entire document with a few mouse clicks.

3.6. Summary

This Chapter:

1. Discussed ways to communicate ideas because there is little point in generating ideas if you are not going to do anything with them.
2. Began with a discussion on formal written communications in Section 3.1 namely documents and introduces a process for creating a document starting with an abstract and continued with developing and using annotated outlines.
3. Discussed formal verbal communications and presentations in Section 3.2.
4. Alerted you to some barriers to successful communications in Section 3.3.
5. Followed up with some ways to overcome those barriers in Section 3.4.
6. Discussed Intellectual Property (IP) and ways to avoid plagiarism in Section 3.5.

--oo--

4. Systems thinking and beyond

Creating innovative solutions incorporates the skill to perceive things from multiple perspectives (inputs) rather than from a single perspective, as well as the skill to perceive multiple potential outcomes (outputs) rather than a single outcome. This Chapter:

1. Addresses multiple perspectives.
2. Begins with a description of analysis as an internal perspective and systems thinking as an external perspective in Section 4.1.
3. Introduces the perspective perimeter to provide anchor points for discussions from a wider set of viewpoints that go beyond analysis and systems thinking in Section 4.2.
4. Introduces nine Holistic Thinking Perspectives (HTP) as anchor points on the perspectives perimeter and more in Section 4.3.
5. Compares the HTPs with some other versions of systems thinking in Section 4.4.

4.1. Analysis and systems thinking

Consider analysis and systems thinking. Both have their place in developing an understanding of a system (Hitchins, 1992: page 14) but some perspectives are lacking as explained below.

4.1.1. Analysis

Traditional thinking focused on analysis which contains the following three steps (Ackoff, 1991):

1. Take apart the thing to be understood.
2. Try to understand how these parts worked.
3. Assemble an understanding of the parts into an understanding of the whole.

This is reductionism because it reduces the parts to smaller components.

4.1.2. Systems thinking

The literature on systems thinking abounds with:

- Publications advocating the use of systems thinking, e.g. (Flood and Jackson, 1991).
- Philosophical and academic theories of systems thinking, e.g. (Flood and Jackson, 1991).
- The need to view problems from various perspectives, e.g. (Morgan, 1997).
- Descriptions of causal or feedback loops as the major component of systems thinking (Senge, 1990).

However, the literature on how to actually apply systems thinking to get something done[1] seems to be mostly absent. Consider the following extracts from a LinkedIn discussion in June 2010 in chronological order as typical examples (LinkedIn, 2010):

- *"Systems thinking is a way of thinking? You know it when you see it".*
- *"If you're considering something in its totality along with its characteristics as well as it's interaction with its environment and considering its parts along with the interactions between the parts then you are thinking systemically".*
- *"Approach to a system with love, understand it holistically and heuristically".*

The first dot point is informative but does not explain how to do systems thinking. The second dot point begins to explain the nature of systems thinking, while the third dot point is totally useless[2].

4.1.3. Types of systems thinking

The literature on systems thinking can be sorted based on the interpretation of the word system into the following two types:

1. ***Systemic:*** meaning thinking about a system as a whole.
2. ***Systematic:*** meaning employing a methodical step-by-step manner.

Since both types of systems thinking are needed (Gharajedaghi, 1999) consider each of them.

4.1.3.1. Systemic thinking

Systemic thinking has three steps (Ackoff, 1991):

1. A thing to be understood is conceptualized as a part of one or more larger wholes, not as a whole to be taken apart. Senge

[1] Other than for using causal loops
[2] How would you teach this?

Table 4.1 Traditional business thinking vs. Richmond's systems thinking skills

Traditional thinking skill	Richmond's Systems thinking skill
Static thinking which focuses on particular events.	***Dynamic thinking*** which frames a problem in terms of a pattern of behaviour over time.
System-as-effect thinking which views behaviour generated by a system as being driven by external forces.	***System-as-cause thinking*** which places responsibility for a behaviour on internal factors who manage the policies and plumbing of the system.
Tree-by-tree thinking which believes that really knowing something means focussing on the details.	***Forest thinking*** which is believing that to know something you must understand the context of relationships.
Factors thinking which lists factors that influence or are correlated with some result.	***Operational thinking*** which concentrates on getting at causality and understanding how behaviour is actually generated.
Straight-line thinking which views causality as running one way, with each cause independent from all other causes.	***Closed-loop thinking*** which views causality as an on-going process, not a one-time event. With the effect of feeding back to influence the causes, and the causes affecting each other.
Measurement thinking which searches for perfectly measured data.	***Quantitative thinking*** which accepts that you can always quantify something even though you can't always measure it.
Proving-truth thinking which seeks to prove models to be true by validating them with historical data.	***Scientific thinking*** which recognizes that all models are working hypotheses that always have limited applicability.

wrote, "*Systems thinking is a discipline for seeing wholes*" (Senge, 1990).

2. An understanding of the larger system is sought.
3. The system to be understood is explained in terms of its role or function in the containing system.

Proponents of this type of systems thinking tend to:

- Equate causal loops or feedback loops with systems thinking because they are thinking about relationships within a system, e.g. (Senge, 1990; Sherwood, 2002).

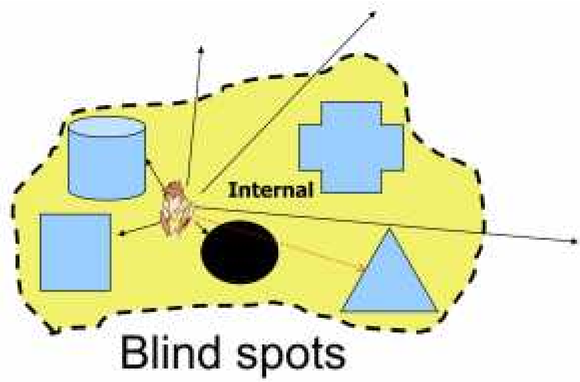

Figure 4.1 Internal from a single perspective -1

- Define systems thinking as looking at relationships (rather than unrelated objects), connectedness, process (rather than structure), the whole (rather than its parts), the patterns (rather than the contents) of a system and context (Ackoff, et al., 2010: page 6).

4.1.3.2. Systematic thinking

Systematic thinking is discussed in the literature on problem-solving, systems thinking, critical thinking and systems engineering.

4.1.4. Systemic and systematic thinking

The one organized approach to practical thinking in a systemic and systematic manner discovered in the literature on systems thinking was Richmond's seven skills of system thinking (Richmond, 1993). Richmond applied a reductionist approach to thinking and identified seven different complementary cognitive processes or thinking skills. He contrasted seven traditional business-thinking skills with his seven systems thinking skills as summarized in Table 4.1.

4.2. The perspectives perimeter

The concept that a single perspective may lead to errors in understanding what is being viewed has been known for centuries if not longer. For example the parable of the blind men perceiving a different part of an elephant and inferring what animal they are perceiving (Yen, 2008). Since each man perceives a different part of the elephant, they each infer that

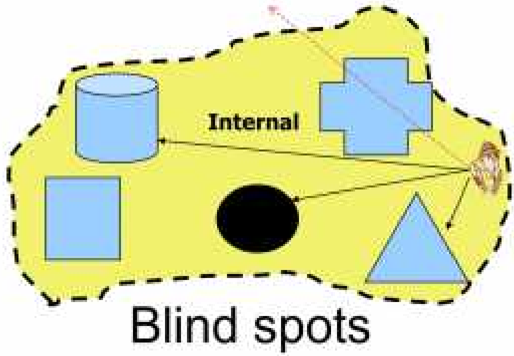

Figure 4.2 Internal views from a single perspective-2

they perceive a different animal. It takes a combination of the perceptions to understand the true nature of the animal being felt[3].

The advantages of this type of systems thinking has also been known for centuries, for example:

- "*When people know a number of things, and one of them understands how the things are systematically categorized and related, that person has an advantage over the others who don't have the same understanding*" (Luzatto, circa 1735).
- "*People who learn to read situations from different (theoretical) points of view have an advantage over those committed to a fixed position. For they are better able to recognize the limitations of a given perspective. They can see how situations and problems can be framed and reframed in different ways, allowing new kinds of solutions to emerge*" (Morgan, 1997).

But how can you learn to perceive things from different points of view? Well, consider the act of thinking about different aspects of a situation while perceiving the situation from different perspectives, some internal (analysis) and some external (systems thinking). Consider the example shown in Figure 4.1 where the view of the observer is blocked by the round object. This situation produces blind spots or locations that cannot be seen from that viewpoint. A holistic thinker then changes the perspective and views the situation once more as shown in Figure 4.2. A well-chosen second perspective reveals information located in the first perspective's blind spots. Sometimes a third or fourth internal perspective is needed to fully understand a situation. Figure 4.3 shows that a sin-

[3] Is this true? Because without the sense of sight, would someone be able to combine the individual perceptions and infer that the animal was an elephant? Perhaps, but probably only if prior experience had shown that the elephant manifested itself as different animals under different conditions.

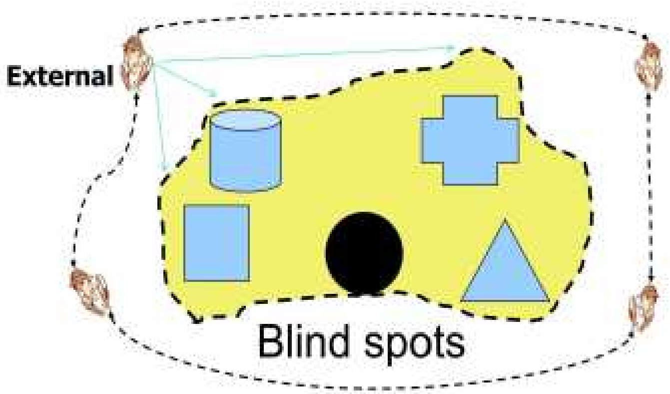

Figure 4.3 External perspectives

gle external perspective also has blind spots so a number of external perspectives are also needed.

Using this principle, draw a circle about a situation. Consider the internal perspectives in Figure 4.1 and Figure 4.2 and the external perspectives in Figure 4.3 as chords (areas) on the perimeter of a circle in the metaphoric representation depicted in Figure 4.4. Call the perimeter of the circle in Figure 4.4 the *perspectives perimeter*. Now when thinking about a situation, problem or issue some minds:

- Seem to only range over a limited part of the perimeter and perceive the issues from a limited number of perspectives.
- Seem to range over the entire perimeter and perceive the issues from the set of perspectives but do not seem to do so in a systemic and systematic manner.

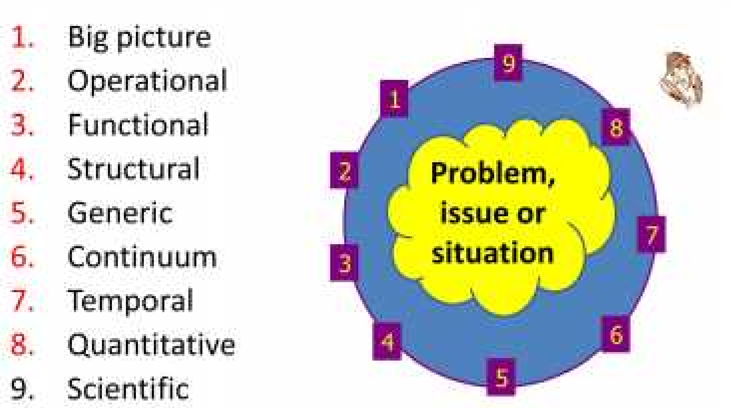

Figure 4.4 Viewing from different perspectives on the perspectives perimeter

- Seem to range over the entire perimeter and perceive the issues from the set of perspectives and seem to do so in a systemic and systematic manner.
- Seem to be fixed at one point on the perimeter and observe the issues from a single fixed perspective.
- Can't seem to stop moving round the perimeter which leads to a situation commonly known as "analysis-paralysis".

Since there are no standard stopping points along the perspectives perimeter, each time communications between two parties takes place, time is spent ensuring that both parties to the communication are viewing the issue from the same perspective (stopping point on the perspectives perimeter). This situation can be observed by the use of phrases such as, "*are we on the same page*?" and, "*are we on the same wavelength?"* etc. A standard set of perspectives or "anchor points" is needed to facilitate communications.

4.3. The Holistic Thinking Perspectives

This Section now builds on the work of Richmond (Richmond, 1993) and introduces a set of viewpoints on the perspective perimeter called the Holistic Thinking Perspectives (HTP) which can be used to provide a standard set of anchor points for thinking and communicating in a systemic and systematic manner. These viewpoints go beyond combining analysis (internal views) and systems thinking (external views) by adding quantitative and progressive (temporal, generic and continuum) viewpoints. This approach:

- Separates facts from opinion.
- Provides a standard format or template for storing information about situations that facilitates storage and retrieval of information about situations such as those documented in Case Studies.

The nine HTP external, internal, progressive and other anchor points shown in Figure 4.4 are as follows:

1. The external perspectives discussed in Section 4.3.1.1.
2. The internal perspectives discussed in Section 4.3.1.2.
3. The progressive perspectives discussed in Section 4.3.1.3.
4. The other perspectives discussed in Section 4.3.1.4.

4.3.1.1. The external perspectives

The external perspectives are:

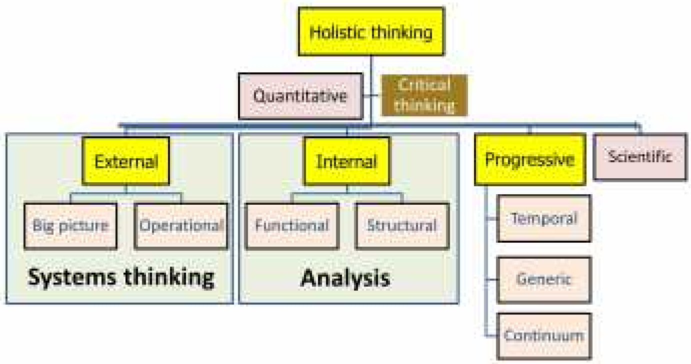

Figure 4.5 The HTPs (*Structural* perspective)

1. ***Big Picture:*** includes the context for the system, the environment and assumptions.
2. ***Operational: what*** the system does as described in scenarios; a black box perspective.

4.3.1.2. The internal perspectives

The internal perspectives are:

3. ***Functional: what*** the system does and how it does it; a white box perspective.
4. ***Structural:*** how the system is constructed and organised. For example the perceptions of the HTPs from the *Structural* perspective are shown in Figure 4.5.

Each function may or may not be used in an operational scenario. For example, Table 2.1 provides an example of mapping the functions performed in a system (*Functional* perspective) to the scenarios in which the functions are used (*Operational* perspective). In this example, the table shows that Functions 1, 2 and 4 are used in Scenario A.

4.3.1.3. The progressive perspectives

The progressive perspectives, where holistic thinking begins to go beyond analysis and systems thinking are the:

5. ***Generic:*** perceptions of the system as an instance of a class of similar systems; perceptions of similarity.
6. ***Continuum:*** perceptions of the system as but one of many alternatives; perceptions of differences. For example, when hearing the phrase "*she's not just a pretty face*"[4] the thought may pop up

[4] Which acknowledges that she is smart

from the *Continuum* perspective changing the phrase to "she's not even a pretty face"[5] which means the reverse.

7. ***Temporal:*** perceptions of the past, present and future of the system.

4.3.1.4. The other perspectives

The other perspectives are:

8. ***Quantitative:*** perceptions of the numeric and other quantitative information associated with the other descriptive perspectives.
9. ***Scientific:*** insights and inferences from the perceptions from the descriptive perspectives leading to the hypothesis or guess about the issue after using critical thinking.

The first eight perspectives are descriptive, while the ninth (*Scientific*) perspective is prescriptive. While the HTPs provide a standard set of perspective, perceptions from the *Continuum* perspective point out that there are other perspectives including emotional, cultural, personal, the other party's (in a negotiation), etc. These other perspectives should be used as and when appropriate.

4.3.2. Descriptions and examples of the HTPs

This Section provides descriptions and examples of the HTPs as follows:

1. The *Big Picture* perspective discussed in Section 4.3.2.1.
2. The *Operational* perspective discussed in Section 4.3.2.2.
3. The *Functional* perspective discussed in Section 4.3.2.3.
4. The *Structural* perspective discussed in Section 4.3.2.4.
5. The *Generic* perspective discussed in Section 4.3.2.5.
6. The *Continuum* perspective discussed in Section 4.3.2.6.
7. The *Temporal* perspective discussed in Section 4.3.2.7.
8. The *Quantitative* perspective discussed in Section 4.3.2.8.
9. The *Scientific* perspective discussed in Section 4.3.2.9.

4.3.2.1. The Big Picture perspective

The *Big Picture* perspective incorporates Richmond's forest thinking and:

- Is an external perspective.
- Shows the purpose of the system.
- Provides the bird's eye or helicopter view showing the context of the system providing a view of the forest rather than the trees.
- Looks down from the meta-level in the hierarchy of systems perceiving the System of Interest (SOI) within the context of its

[5] Which means that not only is she not smart, she is also not pretty.

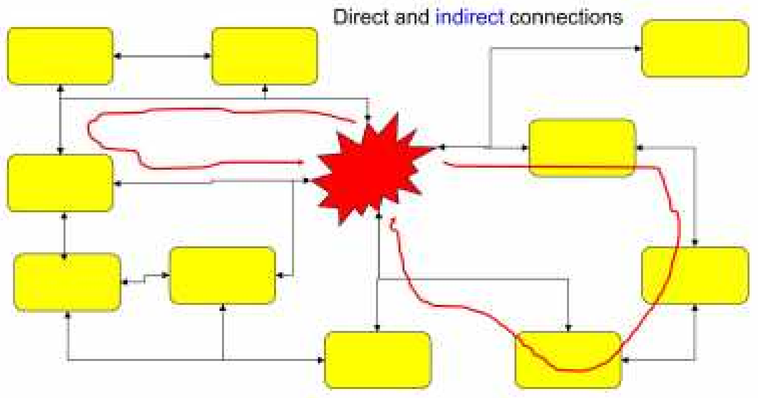

Figure 4.6 The *Big Picture* perspective - system of interest and adjacent systems

containing system - its environment, the closely coupled adjacent systems with which it interacts and any pertinent loosely coupled more distant systems with which it may indirectly interact as shown in Figure 4.6.

- Shows the external boundary of the system.
- Contains the assumptions behind the location of the external boundary.

4.3.2.2. The Operational perspective

The *Operational* perspective incorporates Richmond's operational thinking and:

- Is an external perspective.
- Corresponds to the traditional black box 'closed system' view.
- Provides a view of the normal and contingency mission and support functions performed by a system.
- Tends to be documented in the form of use cases, Concepts of Operations (CONOPS), 'to-be' and 'as-is' views and other appropriate formats.

4.3.2.3. The Functional perspective

The *Functional* perspective incorporates Richmond's system-as-a-cause and closed-loop thinking and:

- Is an internal perspective.
- Corresponds to the traditional white box 'open system' view.
- Provides a view of the functions or activities (and the relationships between them) performed within the system without refer-

Figure 4.7 A train departure information board at Munich railway station

ence to which of the physical elements in the system performs those functions.

- Can be a view of what is being done or how it is being done depending on the level of system elaboration.

4.3.2.4. The Structural perspective

The *Structural* perspective is an internal perspective incorporating the traditional physical, technical and architectural framework views of a system. This perspective provides views of:

- Hierarchies.
- Structural elaboration.
- Architectures.
- Internal subsystem boundaries.
- Physical and virtual components.
- Effects on the system due to its internal structure.
- The interconnections between physical elements and subsystems.

4.3.2.5. The Generic perspective

The *Generic* perspective:

- Is a progressive perspective.
- Looks at and for similarities.
- Provides information about the class or type of system.

Figure 4.8 A flight information display at Changi airport in Singapore

- Considers a system as an instance of a class of systems which leads to the realization that your system inherits desired and undesired functions and properties from the generic class of system.
- Show similarities between the system and other systems in the same or other domains.
- Leads to the:
  - Ability to perceive connections where others don't.
  - Understanding of analogies/parallelism between systems.
  - Adoption of lessons learned from other projects and determination if those lessons are applicable to the current project.
  - Adoption of innovative design approaches using approaches from other domains.
  - Use of pattern matching.
  - Use of benchmarking.

Consider the information displays shown in Figure 4.7 and Figure 4.8. One shows aircraft departures, the other train departures. One is electronic, the other electro-mechanical. Yet they both perform the same function namely providing travellers with information as to where to go at what time to catch transportation to specific destinations[6].

A well-known application of the *Generic* perspective is the Theory of Inventive Problem-solving (TRIZ)[7]; a problem-solving process that has evolved over the last 50 years whose underlying concept is, "*Somebody someplace has already solved this problem (or one very similar to it.) Creativity is now finding that solution and adapting it to this particular problem*" (Barry, et al., 2007), namely incorporating lessons learned from other people into the problem-solving process by definition.

4.3.2.6. The Continuum perspective

The *Continuum* perspective is a progressive perspective which looks at, and for, differences and recognizes that:

1. Alternatives exist discussed in Section 4.3.2.6.1.
2. Any solution or issue is located on at least one continuum of some kind discussed in Section 4.3.2.6.2.
3. Things are not necessarily 'either-or'; there may be states in between discussed in Section 4.3.2.6.3.
4. Changing conditions may cause movement along a continuum discussed in Section 4.3.2.6.4.
5. There may be more than one correct solution to a problem discussed in Section 4.3.2.6.5.
6. There may be more than one way to achieve an objective discussed in Section 4.3.2.6.6.
7. Systems sometimes fail partially as well as completely discussed in Section 4.3.2.6.7.
8. There may be more than one objective for a system discussed in Section 4.3.2.6.8
9. Things can and must be seen from different viewpoints discussed in Section 4.3.2.6.9.
10. Changes are not necessarily improvements discussed in Section 4.3.2.6.10.
11. Different people see things differently discussed in Section 4.3.2.6.11.

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[6] Note the use of function language which describes the function performed by the displays irrespective of the location and physical nature of the display in an airport or railway station.

[7] Altshuller named it Teoriya Resheniya Izobreatatelskikh Zadatch which has been translated into English as the 'Theory of Solving Inventive Problems' (TRIZ) to maintain the sound of the acronym.

12. When examining a situation there still may be other unknown variables that may or may not affect the situation discussed in Section 4.3.2.6.12.

4.3.2.6.1. Alternatives exist

This insight realizes that alternatives always exist when faced with making decisions. Sometimes the alternatives:

- Are obvious.
- Have to be searched for.
- May be uncertain and involve risks and opportunities as discussed in Section 8.6.
- Identify different solutions.
- Define different problems. For example Henry Ford wrote, "*Our policy is to reduce the price, extend the operations and improve the article. You will notice that the reduction of price comes first. We have never considered costs as fixed. Therefore we first reduce the price to a point where we believe more sales will result. Then we go ahead and try to make the price. We do not bother about the costs. The new price forces the costs down. The more usual way is to take the costs and then determine the price, and although that method may be scientific in the narrow sense, it is not scientific in the broad sense because what earthly use is it to know the cost if it tells you that you cannot manufacture at a price at which the article can be sold?"* (Ford and Crowther, 1922: page 146). The usual question was "what does it cost to produce X?" from the alternative perspective, the question was, "how can X be produced for $Y?" The key is to articulate the correct question, or in holistic thinking terms define the correct problem.

4.3.2.6.2. Any solution or issue is located on at least one continuum of some kind

This insight realizes that any solution or issue is located on a continuum of some kind, within a spectrum, or on a scale of some kind. Consider the following examples:

1. The spectrum of synchronicity discussed in Section 4.3.2.6.2.1.
2. The system solution implementation continuum discussed in Section 4.3.2.6.2.2.
3. The public-private continuum discussed in Section 4.3.2.6.2.3.
4. The continuum of change discussed in Section 4.3.2.6.2.4.

4.3.2.6.2.1. *The spectrum of synchronicity*

In the educational domain, these days technology provides many enhancements to the traditional face-to-face classroom. In fact, there are a

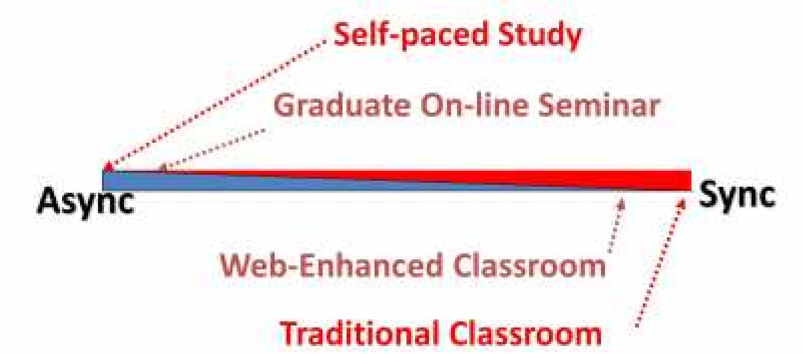

Figure 4.9 The spectrum of synchronicity

large number of possible classes with various mixes of synchronous[8] and asynchronous[9] techniques. These classes are spread out along a continuum of possibilities, the spectrum of synchronicity shown in Figure 4.9.

The traditional face-to-face classroom lies at the synchronous end of the spectrum. The traditional class can be augmented with a web page, a Listserver, and other synchronous and asynchronous techniques. When web augmentation takes place, the web augmented traditional classroom moves away from the edge of the synchronous end of the spectrum towards the centre. A face-to-face class that uses a web page for proving copies of hand-outs and readings to the students is not 100% synchronous. However, while the class is not 100% synchronous it is often referred to as a synchronous class.

At the other end of the spectrum is the totally asynchronous classroom. This represents the self-paced studies, correspondence schools and other techniques in which there is no synchronous contact between anyone in the class. A graduate school seminar that is mostly asynchronous does generally allow for synchronous student to instructor and student-to-student communications via the traditional telephone system or via a Voice over the Internet (VOIP) system. Therefore, while the graduate seminar is not 100% asynchronous, it has so many of the characteristics of an asynchronous class that it is often referred to as an asynchronous class.

4.3.2.6.2.2. *The system solution implementation continuum*

The system solution implementation continuum or design space is shown in Figure 4.10. When considering candidate designs for a system, each

[8] Where everybody is in the same place at the same time and things happen in real-time.

[9] Where people are not in the same place at the same time and things do not happen in real-time.

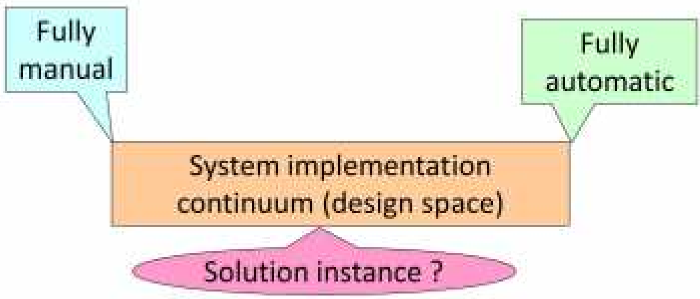

Figure 4.10 Solution system implementation continuum

candidate will lie on a different point on the implementation continuum with a different mixture of people, technology, and a change in the way something is done, etc.

The concept of designing a number of solutions and determining the optimal solution, which may either be one of the solutions or a combination of parts of several solutions, comes from the *Continuum* perspective. A benefit of producing several solutions is that one of the design teams conceptualizing the solutions may pick up on matters that other teams missed.

4.3.2.6.2.3. *The public-private continuum*

There is a continuum for services rendered in society. Private enterprise lies at one end of this continuum, government lies at the other, with a range of various private and public partnerships in between the ends. There are some public services that should be within the realm of government, some within the realm of private enterprise, and some that can be in either realm. The wrong allocation often leads to problems.

4.3.2.6.2.4. *The continuum of change*

Any specific change can be thought of as being located on a continuum ranging from highly adaptive to highly innovative (Kirton, 1994). Where:

- ***Adaptive improvements*** and changes tend to:
  - Solve and resolve problems by introducing solutions from within the current paradigm.
  - Are more readily implemented than innovative ones.
  - Improve the current paradigm.
  - Face less resistance than innovative changes (Kuhn, 1970).

    - Tend to formulate the problem in terms of existing implementation paradigms, then adapt and modify the products and procedures. These remedies result in improvements and "doing better". Adaptive improvements however also lead to the point of diminishing returns (*Quantitative* perspective).
    - Reduce costs over a time, yet the rate of reduction slowly reaches the point of diminishing returns. This is the point where an innovative change is the only way to obtain any large degree of improvement.
- ***Innovative improvements*** and changes tend to:
    - Dissolve the problem by introducing solutions from outside the current paradigm. These remedies result in breaking moulds and "doing it differently".
    - Introduce a new paradigm.
    - Be perceived as riskier, and consequently tend to be resisted more than adaptive changes (Kuhn, 1970).

4.3.2.6.3. Things are not necessarily 'either-or'; there may be states in between.

This insight leads to the replacement of 'either-or' questions such as "is systems engineering an undergraduate or a postgraduate subject?" by questions in the form of, "to what degree is systems engineering a postgraduate subject?" or better, phrasing the question as, "what is the knowledge needed by a systems engineer and how much of it can be taught as an undergraduate subject?" This redefining of the nature of the problem statement is a very different perspective to the traditional 'either-or' 'one right way' perspective.

The ability to redefine the problem is a key component of the ability to create innovative solutions to problems.

4.3.2.6.4. Changing conditions may cause movement along the continuum.

This insight leads to the realization that systems can exhibit different types of behaviour in different situations rather than always behave in the same way and that the transition conditions causing that change in behaviour may not be known. In the case of human systems, perceptions from the *Continuum* perspective point out that:

- Maslow's hierarchy (Maslow, 1970) may not be a pyramid, but may be a pie, and motivating people becomes a matter of figuring out which slices of the pie to offer them (Kasser, 1995a).

- Theory X and Theory Y (McGregor, 1960) behaviour may lie at the two ends of a situational continuum of behaviour rather than be two opposing behaviour patterns. Consequently:
    - Which one to use may be situational. For example, in the military, there are times when an order such as "everybody down" on the battlefield has to be obeyed instantaneously without any discussion.
    - An individual's need to be motivated may be situational. For example, is there a difference in the way you (1) motivate your children to clean up their rooms and (2) motivate them to come to the table for a dish of ice cream?
- Theory Z (Ouchi, 1982) may lie in the middle of the continuum[10].

This insight also leads to the recognition that systems have states and can change from one state to another at transition points (Section 7.5.1).

4.3.2.6.5. There may be more than one correct solution to a problem

This perception indicates that there may be more than one correct solution to a problem discussed in Section 9.6 tends to be discussed in the literature on critical thinking. This aspect of the *Continuum* perspective can be illustrated from Maslow's observation of human behaviour which illustrates the non-holistic thinking approach, "*I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail*" (Maslow, 1966: pages 15 and 16). Applying the *Continuum* perspective you would note that:

- Nails are the solution to one class of problems.
- Nails might be a solution to other classes of problems (although not necessarily optimal).
- The other classes of problems should be monitored while you get the correct tool to tackle those classes of problems.

In addition, there may be times when the need to do something about the problem is so urgent, and in the absence of any other alternative, that nails are the only available solution. As an example, if you need to cut a plank in half, it can be done by hammering a series of nails along the line to be cut, extracting the nails and then scoring the line of holes until the plank breaks. However, it would be better to get and use a saw to do the job unless you need that plank cut before someone can bring the saw.

[10] This is a hypothesis, see *Scientific* perspective.

4.3.2.6.6. There may be more than one way to achieve an objective

This perception indicates that there may be more than one way to achieve the same result leads to:

- Consideration of the use of different technologies in the product or solution domain.
- Consideration of different production or implementation approaches to achieve or realize the objective. In the military domain, this concept would be that objectives could be captured by flanking attacks as well as frontal attacks, or by a combination of both. In the civilian domain this concept means that there may be several roads to a particular destination.
- The realization that an objective may be reached by reformatting the problem statement. For example:

    Years ago when smoking was permitted in public places two seminary students were studying together in the library. After a while David said to "Moishe, I'm dying for a cigarette, do you think the Rabbi will permit me to smoke?"

    "I don't know" was the reply, "why don't you ask?"

    So David got up and went over to the Rabbi. "Rabbi is it permitted to smoke while studying" he asked.

    "Certainly not!" the Rabbi replied.

    David returned to his seat dejectedly and related what had happened.

    "You asked the wrong question" said Moishe, "let me have try".

    He got up, went over to the Rabbi and asked "Rabbi, is it permitted to study while smoking?"

    "Of course" came the response.

4.3.2.6.7. Systems sometimes fail partially as well as completely

This perception indicates that systems sometimes fail partially or 'fail soft' as well as failing completely leads to an analysis of failure modes for the system and each of its components. The analysis may influence the *Structural* and *Functional* perspectives in the design of the system. The concept also leads to a risk analysis of the probability and effect of internal and externally induced failures and ways to mitigate those failures. Internal failures are failures of components due to aging and normal wear and tear (Moubray, 1997); external failures are those inflicted from without, such as natural disasters, sabotage and enemy action.

4.3.2.6.8. There may be more than one objective for a system

This perception indicates that different stakeholders may have different objectives leads to the win-win principle in negotiation, which recognises that when different parties to the negotiations want different outcomes, it may be possible to give each party what they want.

4.3.2.6.9. Things can and must be seen from different and multiple viewpoints

The perception that things can and must be seen from different viewpoints leads to the realization that:

- One man's rubbish may be another man's treasure.
- The HTPs are not the only set of viewpoints on the perspectives perimeter and there are others that can and should be used in the appropriate situations.
- There may be different perspectives on the nature of something. For example, consider the statement that heaven and hell are located in the same place. How can that be? Consider the following observation of human behaviour. A preacher who has been thundering away from the pulpit for an hour or so is enjoying giving the sermon; he is in heaven. Now think about the situation from the viewpoint of the congregation suffering through the same sermon. They are both in the same place, but whether they are in heaven or in hell is a matter of perspective.
- The boundary of the system is not fixed for all purposes. This concept is a key insight for dealing with complexity. For example, consider:
    - ***A camera:*** when we consider:
        - The device that takes the photograph or captures an image, we draw the system boundary around the camera.
        - The act of taking the photograph we redraw the system boundary to include the photographer.
        - Transporting the camera, we redraw the system boundary to include the transportation elements.

      Developing one system representation that includes all the elements for photographing and transportation and then requiring the elements under consideration for a specific situation to be abstracted out of the representation, creates unnecessary complexity. The three separate simpler views, abstracted out of the real world are simpler for understanding the various aspects of the use of a camera in photography.

- ***A human being:*** some areas of the real world can only be fully understood by examining the internal components of the system and observing it in action in its environment. Mechanical systems may be disassembled and reassembled, but some systems such as biological systems cannot be disassembled without destroying the sample. Consider a human being, a biological system. To learn about:
    - The interaction between internal subsystems we may have to observe the sample in action in specific situations and either observe or infer the interaction.
    - The internal subsystems we have to dissect a sample of the system. Once dissected, an individual example cannot usually be restored to full functionality. However we have learnt something about the class of systems it represents which can be applied to other instances of the class of systems.
- ***Two theories of electromagnetic wave propagation in physics:*** scientists use the:
    - ***Wave theory*** (Huygens, 1690) to explain some aspects of electro-magnetic radiation.
    - ***Particle theory*** (Newton, 1675) to explain other aspects[ii].

4.3.2.6.10. Changes are not necessarily improvements

Changes are not necessary improvements. Sometimes changes are forced on us such as the need to upgrade perfectly good software for a later version simply because the information storage format used by the later version is not compatible with the earlier version.

4.3.2.6.11. Different people see things differently

This difference can manifest itself in several ways including:

[ii] Mind you this could also form the basis of an argument that there is no underlying theory of electronic-magnetic radiation.

Figure 4.11 Different perceptions of the same woman

- People can see different things in the same picture and draw different conclusions from the same data. This concept is often discussed in the context of an optical illusion in the black and white sketch shown in Figure 4.11 which was published in 1915 adapted or based on an anonymous German postcard from 1888 (Weisstein, 2012). When seeing the picture for the first time, some people see an old woman and some people see a young woman. It is important to make sure that you and the person with whom you are having a discussion see the same things in the data you are discussing or at least understand what the other person is seeing as discussed in Section 3.4.
- Different people have different ways of seeing things and belief systems, known as Weltanschauung (Checkland and Scholes,

1990), worldviews or paradigms (Kuhn, 1970). They may perceive problems, or want different (and perhaps contradictory) remedies (solutions) to an undesirable situation or have different concepts of what the situation is all about. For example a pub or bar could be:

- ***A profit making system*** from the perspective of the owners.
- ***An employment system*** from the perspective of the (potential) employees.
- ***A recreational system*** from the perspective of the customers.
- ***A social system*** from the perspective of the local residents.
- ***A revenue generating system*** from the perspective of the taxation authority.

An understanding of this concept:

- Leads to the recognition of the usefulness of interdisciplinary teams.
- Led to the speedy identification of the undesirable situation in the example of using SSM discussed in Section 10.1.
- Leads to the ability to perceive things from the other person's perspective which is very useful in negotiations and other interactions.
- Leads to the understanding that the same words may have different meanings to different people which can be a barrier to communications as discussed in Section 3.3.3.

The difference in meanings of words can also be a result of ambiguity since many words have more than one meaning as discussed in Section 3.3.3. Perceptions from the *Continuum* perspective allow you to identify humour in situations that non-systems thinkers do not, and make (poor) jokes and puns such as the one about heaven and hell being in the same place. For example:

- ***Humour based on ambiguity:*** humour in English is often based on ambiguity; the difference in the meaning of words in a different context such in the cartoon in shown in Figure 2.28.
- ***Humour based on perceiving opposites:*** consider the cartoon shown in Figure 4.12. The cartoonist used the opposite perspective to reverse the normal situation where dogs mark their territory by peeing on fire hydrants. Gary Larson's The Far Side®

Figure 4.12 Hydrant pees on dog

cartoons are excellent examples of this type of humour (Larson, 1984).

4.3.2.6.12. When examining a situation there still may be other unknown variables that may or may not affect the situation

Perceptions from the *Continuum* perspective and critical thinking indicate that there still may be other unknown variables that may or may not affect the situation. This situation is known as Simpson's paradox (Savage, 2009).

Savage provides the following example of Simpson's paradox. An experiment was performed to measure the amount of weight loss per day due to the addition of a dietary supplement on a number of male and female test subjects. When the results are plotted:

- For the combined male and female test subjects shown in Figure 4.13 show an average of 1.5 pounds lost per gram of dose.
- Separately by male (dark dots) and female (light dots) subjects, the results shown in Figure 4.14 show the opposite, both subject groups had a gain in weight.

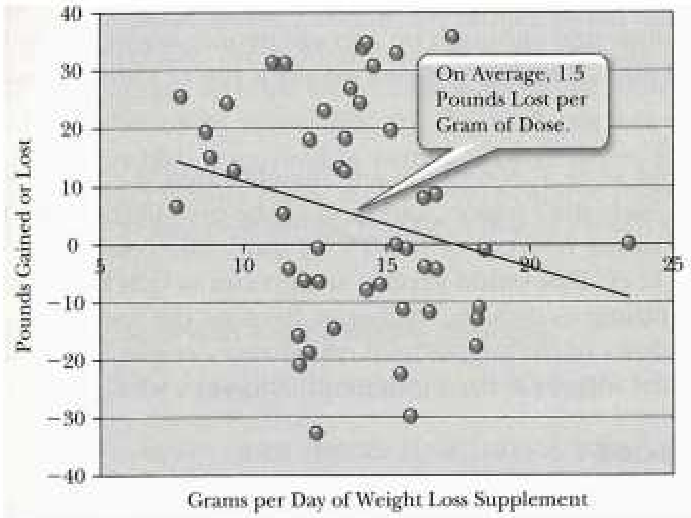

Figure 4.13 Weight loss due to dietary supplement (Savage, 2009)

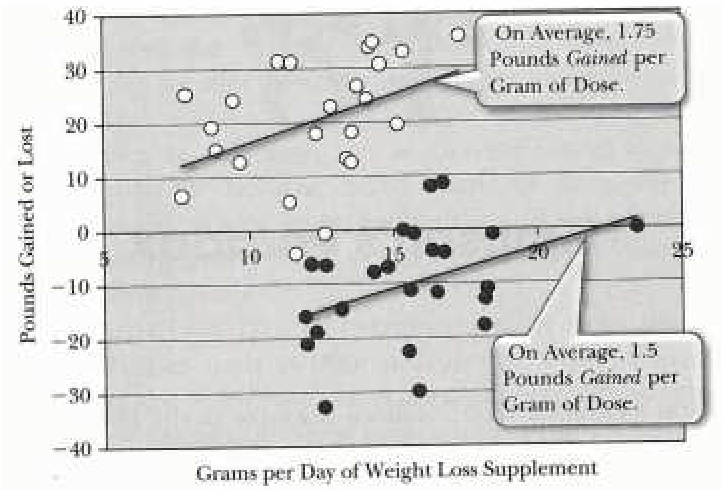

Figure 4.14 Weight change versus daily intake by sex (male denoted by dark, female by light) (Savage, 2009)

- The contradictory results imply that there are other factors at work that need to be determined.

4.3.2.7. The Temporal perspective

The *Temporal* perspective is a progressive perspective which incorporates Richmond's dynamic thinking and considers the system as it was in the past, is in the present and will be in the future. If the system exists, past patterns of behaviour are examined and future patterns are predicted using this perspective. Insights from this perspective include:

- The consideration of:
    - Availability.
    - Maintenance.
    - Logistics.
    - Obsolescence.
- The concept of prevention of problems.
- Lessons to be learned from the system implementation and improvements for future iterations of the system. Reflecting on the past provides lessons learned from the system.
- The concept that past performance may not be a useful predictor of future performance unless the factors contributing to the past performance are understood.
- The concept of unanticipated emergence, namely that even if the implemented solution works it may introduce further problems that may only show up after some period of time. In manufacturing, these problems are known as latent defects. These time delays were grouped as (Kasser, 2002b):
    - ***First order:*** noticeable effect within a second or less.
    - ***Second order:*** noticeable effect within a minute or less.
    - ***Third order:*** noticeable effect within an hour or less.
    - ***Fourth order:*** noticeable effect within a day or less.
    - ***Fifth order:*** noticeable effect within a week or less.
    - ***Sixth order:*** noticeable effect within a month or less.
    - ***Seventh order:*** noticeable effect within a year or less.
    - ***Eighth order:*** noticeable effect within a decade or less.
    - ***Ninth order:*** noticeable effect within a century or less.
    - ***Tenth order:*** noticeable effect after a century or more.
- The need to consider change and resistance to change. Paradigm shifts do not occur without a great deal of resistance, especially when people have to unlearn what they know to be correct (Kuhn, 1970). Anyone who understands Kuhn's concept of how paradigm shifts occur could predict the failure of 'reengineering' in the 1990's just by looking at the cover of the book that introduced the topic; the key words being, "*forget what you know about how business should work-most of it is wrong!*" (Hammer and Champy, 1993).
- Understanding the implications of a proposed change in the problem, solution and implementation (realization process) do-

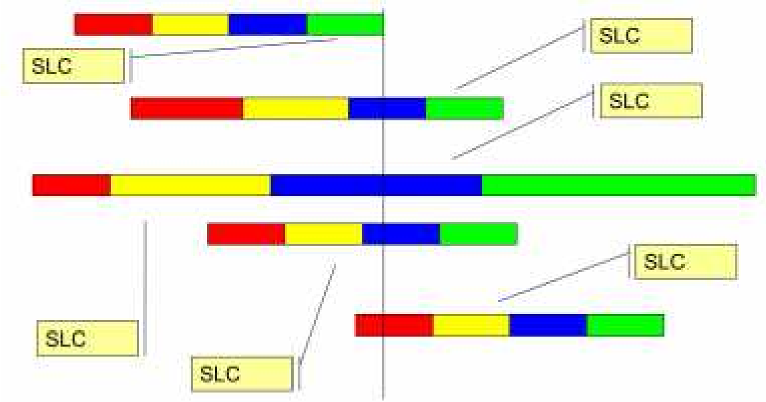

Figure 4.15 Parallel evolution

mains. For example, an undesirable situation due to traffic congestion (problem domain) may be remedied by a subway system (solution domain) that will be constructed by digging tunnels etc. (implementation domain).

- Learning curves and how systems may improve over time as the personnel become more familiar with its capabilities.
- The need to consider the effects due to aging, the need for upgrades and replacement and the effect of Diminishing Manufacturing Sources and Material Shortages (DMSMS) and the technology to be used in the system.
- The need to consider the evolution of adjacent systems so that the solution system being implemented will interface with the adjacent systems as they will be in the future at the time of interface, and as they will be after being upgraded, which may not be the same as their current state. This parallel evolution is depicted in Figure 4.15. The colours in the figure emphasize that each of the systems may be in different states of their System Lifecycle (SLC).
- The current paradigm in any discipline is a step in the staircase of history and practitioners need to be open to considering and accepting changes that improve the discipline. This leads to the realization that some of today's commonly accepted scientific theories will be as obsolete as the Phlogiston theory[12] proposed by Johann Joachim Becher in 1667.
- The future will probably be based on technology and inventions still to be developed. Consider the buildings in central Singapore

[12] An obsolete theory that provided an explanation of why different materials burned in different ways.

Figure 4.16 Architecture in the 19th, 20th and 21st centuries

shown in Figure 4.16 as an example. The Marina Bay Sands, at the back of the picture, opened in 2010 dwarfs the Fullerton Hotel, a building opened in 1928 which in turn is taller than the earlier building at the front of the photograph. The *Temporal* perspective provides the perception that sometime in the future there may be a construction built using a to-be-developed technology which will dwarf the Marina Bay Sands in the same way in which the Marina Bay Sands dwarfs the Fullerton Hotel.

- All systems eventually come to an end, change states or fail. Figure 4.17 shows the effect of time on buildings. From this perspective you might want to think if we should care how the structures we build today will appear 2,000 years or so in the future?
- When little boys reach a certain age they start to wash the dirt off their faces. When little girls reach the same age, they start to put dirt on to their faces.

4.3.2.8. The Quantitative perspective

The *Quantitative* perspective incorporates Richmond's quantitative thinking and:

- Perceives the numbers and measurements associated with the system.
- Indicates that relative comparisons are sometimes more useful than absolute comparisons.
- Is not about the need to measure everything, *"it is more the recognition that numbers must be useful, not necessarily perfect and need not be absolute*" (Richmond, 1993).

Figure 4.17 Effect of time on buildings

- Is about quantification rather than measurement, and helps to understand relationships and leads to the values of parameters in mathematical relationships in models and simulations. An example of quantification is the Likert scale, named after its originator Rensis Likert (1903-1981). The Likert scale offers a means of determining attitudes across a continuum of choices, such as “strongly agree,” “agree”, “don’t care”, “disagree” and “strongly disagree.” A numerical value can then be allocated to each statement for further analysis. The numerical values may not necessarily be linear, namely they may be weighted.
- Provides the concept of the point of diminishing returns, where adding more effort does not produce much of anything in the way of improvement.
- Provides the concept of adding a tolerance value (± something) to a specification.
- Provides the concept that approximate numbers are appropriate in most instances. For example, the well-known value of Pi, 3.14, is just an approximation of an infinite number to two significant decimal places.
- Provides the Pareto principle named after Vilfredo Pareto (1848-1923). Pareto discovered that in many instances the little things account for the majority of the results. The commonly used 80:20 ratio just signifies the idea that much of the output comes from just a few inputs and the 80:20 ratio should not be deemed to be absolute; 80:20 might range from 70:30 to 95:5 in different instances. Examples of the principle include approximations such as:

Table 4.2 Software project outcomes (Capers Jones, 1996)

FPs	Early	On-Time	Delayed	Cancelled
1	14.68%	83.16%	1.92%	0.25%
10	11.08%	81.25%	5.67%	2.00%
100	6.06%	74.77%	11.83%	7.33%
1000	1.24%	60.76%	17.67%	20.33%
10,000	0.14%	28.03%	23.83%	48.00%
100,000	0.00%	13.67%	21.33%	65.00%

- 20% of customers account for 80% of sales.
- 20% of the products or services account for 80% of the profits.
- 20% of the sales force generates 80% of sales.
- 20% of staff causes 80% of problems.

- Leads to the question, "how will we know the proposed solution system remedies the undesirable situation or meets our needs?" The ideas generated as responses to this question lead to the quantitative acceptance criteria for the solution system and ways to measure the degree of remediation.
- Can be used to predict and prevent problems by using historical data to make predictions. For example, Table 4.2 shows data about software project outcomes as related to the number of Function Points (FP) in the software (Capers Jones, 1996). This data can be used to prevent or predict problems in future projects. For example, if the number of FPs in a project at a design review is more than 50,000 or so, then serious consideration should be given to:
  - Managing the project as one with a high probability of failure (serious cost and schedule overrun or cancellation).
  - Cancelling the project on the grounds that while you will not have the software, you will still have the funds, since if the project is cancelled in the future, you will not have the software and you will not have the funds.
  - Redesigning the software to reduce the number of FPs however, this will incur a schedule delay and some cost increment for the redesign activity.
- Examples of insight produced by perceptions from the *Quantitative* perspective include:
  - Statistical Process Control (SPC).
  - Six Sigma (Tennant, 2001).

- Miller's rule that the human brain can only handle 7±2 objects at a time (Miller, 1956).
- Brooks' mythical man month (Brooks, 1972).

4.3.2.9. The Scientific perspective

Whereas the descriptive perspectives are used to examine (and document) a system, the *Scientific* perspective:

- Incorporates Richmond's scientific thinking and is the output of the analysis process; namely, lessons learned, a statement of the problem, the design of the solution or the guess, etc.
- Is where you infer something that is not there but should be there.
- Generally contains a statement of the findings from the information in the eight descriptive perspectives stated in a manner that can be tested.

  For example Federated Aerospace has just introduced the Widget III into the marketplace. Early sales reports show that the product is not selling as well as projected. Perceptions from the *Quantitative* perspective indicate that the Widget has the same performance as its competitors but has a retail price 20% greater than its cheapest competitor. The sales director develops the hypothesis that, '*the reason for the poor sales performance is that the price of the product is too high and the price should be reduced*'. The first problem will be to determine if the hypothesis is valid. If it is (there may be other reasons for the poor sales figures: *Continuum* perspective), then the next problem will be to find a way to reduce the retail price by at least 20% and still make a profit.

  Perceptions from the *Operational* perspective indicate that there seems to be a relationship between several items in a system. The hypothesis then stated in the form of an equaton representing a causal loop by stating, "*this loop represents the relationship in the behaviour of these components*". The problem then becomes to determine if the hypothesis is valid which might be done by using the loop to predict previously unobserved behaviour and then setting up the conditions for that behaviour to occur. If the system behaves as predicted, the hypothesis is supported, if the system behaves differently, then the hypothesis is refuted and the relationships need to be re-examined. This approach is called the Scientific Method (Section 9.12.2.1).

- The statement from the *Scientific* perspective can be expressed in terms of the other perspectives. Consider the following examples

Figure 4.18 Station sign at Hiyoshi subway station

of making observations from the descriptive perspectives and formulating the *Scientific* perspective:

1) Learning to recognize Japanese Kanji characters discussed in Section 4.3.2.9.1.
2) What's missing from the picture discussed in Section 4.3.2.9.2.
3) Where's the coffee discussed in Section 4.3.2.9.3.
4) Predictions, forecasts and imagination discussed in Section 4.3.2.9.4.

4.3.2.9.1. Learning to recognize Japanese kanji characters

You are standing on a subway platform in Yokohama, Japan. While waiting for the train you notice a sign in front of you; the one shown in Figure 4.18. The sign shows the linear relationship between three stations on the Yokohama subway system, Motosumiyoshi (previous), Hiyoshi (current) and Tsunashima (subsequent). You can see the station name in four alphabets in the centre of the photograph. The top line is written in a Japanese phonetic alphabet (Hiragana) and contains three characters. The second line has the station name in English, Japanese Kanji and Korean[13]. The Kanji word uses two symbols; one character looks like a square figure 8, and a second is a more complicated character. Given that there are three syllables in 'Hi-yo-shi', and only two kanji characters, the problem is to work out the syllable represented by each Kanji character.

With two characters the combination could be 'Hiyo-shi' or 'Hi-yoshi'. Systems thinking does not help very much here as the key observation comes from the *Generic* perspective.

The names of the previous and next stations are also shown in the sign. The name of the previous station is Motosumiyoshi. The last[14] Kanji

[13] You have prior knowledge that the third alphabet is Korean, although in this example, it could be considered as an unknown alphabet and ignored since the exact alphabet is not pertinent to the problem.
[14] Domain knowledge is that the characters should be read from left to right as in English.

Figure 4.19 What is missing from the picture?

character of Motosumiyoshi is the same as the end Kanji character in Hiyoshi. The hypothesis or guess (*Scientific* perspective) is that the pronunciation of two station names ends with the same sound[15], so the syllable represented by end Kanji character in Hiyoshi is 'yoshi'. This hypothesis would then have to be tested by asking someone who could read Kanji or by looking at other bilingual signs for the same pattern.

4.3.2.9.2. What's missing from the picture?

Consider the photograph shown in Figure 4.19 and answer the question, "what is missing from the picture?" Perceptions from the *Big Picture* perspective or context indicate it is a high school.

Now perceive the system, the high school, from the *Operational* perspective. Think about the inputs and outputs. Some of the students travel to school by bus. Where do those students cross the road safely? The pedestrian crossing seems to be missing.

Or is it? Is the crossing part of the high school, part of the adjacent transportation system or is it the interface between the high school and transportation systems? In this situation what matters is that the students cross the road safely and the pedestrian crossing is missing; an issue that needs to be addressed at the Metasystem level. The photograph does illustrate the point of needing to define the correct system (and subsystem) boundaries to make sure that things are not left out; or, as often stated, "*Do not fall through the cracks*".

[15] Based on the assumption that the direction in which the word is read is the same as in English.

Figure 4.20 Which container contains coffee?

4.3.2.9.3. Where's the coffee?

You are at a conference in a foreign country; you don't speak the language but would like a cup of coffee. There are two beverage supply containers on the refreshment table, one containing hot water and one containing coffee such as those shown in Figure 4.20, an image captured at a conference in Israel. While (1) you could ask someone, or (2) let a drop of liquid out of one of the containers and taste the liquid, the point of the exercise is (3) to use the holistic thinking to infer which container contains the coffee.

From the *Operational* perspective, one perception might be the packets of powder on the right hand side of the picture.

The inference from that perception (*Scientific* perspective) is:

- The hot water is next to the packets so the beverage supply container containing the coffee is the other one.
- Based on the assumptions that:
    - Operationally the packets would be located closer to the hot water container.
    - The containers are marked correctly.

Now perceive the signs next to the beverage containers from the *Generic* perspective. One sign has one word; the other sign has two words. In English, 'coffee' is one word and 'hot water' is two words.

The inference from that perception (*Scientific* perspective) is:

- The hot water is in the container next to the sign with two words so the beverage supply container containing the coffee is the other one.
- Based on the following assumptions:
    - The same vocabulary rule as in English where 'coffee' is one word and 'hot water' is two words applies in Hebrew.
    - In this instance the reading direction is irrelevant.
    - The containers are marked correctly.

Again the hypothesis or guess would have to be tested to determine if the correct answer was inferred.

These types of assumptions are often made implicitly without conscious thought. An invalid assumption invalidates the solution. This is why it is important to document assumptions so that they can be validated at the same time as the solution is being validated.

4.3.2.9.4. Predictions, forecasts and imagination

Sometimes the test will have to wait if the statement is made as a forecast or prediction or the idea cannot be implemented and tested. For example:

- ***Movie stars are a dying breed:*** because advances in animation technology are making animated pictures so real that that the time will come when realistic artificial characters can be animated under the supervision of the director doing away with the need for, and expense of, live actors. It is also possible that the software may be set up so that the director can preload several acting styles into the software and allow the character to be played in any of them. Consider how a movie would differ if the hero were to be played by "John Wayne" or by "Charlie Chaplin's tramp". You might even get the choice built into the home distribution medium sometime in the next few years.
- ***Leonardo Da Vinci's imaginative drawings:*** some of them, such as the helicopter, could not be tested for five hundred years.

4.3.3. Building up a complete picture or linking the perspectives

Each perspective provides a partial view as shown in Figure 4.2, Figure 4.1 and Figure 4.3 respectively. Accordingly, perceptions from each perspective provide information about part of the situation. For example, consider a car as the system in the context of home family life. When the car is perceived from the HTPs, the perceptions might include:

1. ***Big picture:*** road network, cars drive the economy, etc.
2. ***Operational:*** going shopping, taking children to school, etc.
3. ***Functional:*** traveling from place to place.
4. ***Structural:*** car with doors, chassis, wheels and boot[16].
5. ***Generic:*** (four-wheeled land vehicle) trucks, vans, etc.
6. ***Continuum:*** different types of engines and vehicles (land and non-land), etc.
7. ***Temporal:*** Stanley steamer, Ford Model T, internal combustion, Ford Edsel, hybrid cars, future electric cars, etc.
8. ***Quantitative:*** miles per hour (mph), engine power, number of passengers, four doors, six wheels, cost, price, etc.
9. ***Scientific:*** depends on problem/issue.

The information needed will depend on the issue being examined, and not all information may be pertinent in any given situation.

4.3.4. Combinations of HTPs on the perspectives perimeter

Since the boundaries of the HTPs on the perspective perimeter are artificial for the benefit of holistic thinking, the understanding gained from one of the descriptive HTPs might generate an inference or insight in the *Scientific* perspective (hypothesis or solution), which is documented in a different descriptive perspective or even a combination of descriptive perspectives. Consider the following examples.

1. Hierarchies and complexity in Section 4.3.4.1.
2. Changes and improvements in Section 4.3.4.2.
3. Failure and risk analyses in Section 4.3.4.3.

4.3.4.1. Hierarchies and complexity

The concept of hierarchies is not a new concept as shown for example by the following lines from Jonathan Swift's long satirical poem "On Poetry: a Rhapsody" (Swift, 1733):

So, naturalists observe, a flea
Has smaller fleas that on him prey;
And these have smaller still to bite 'em,
And so proceed ad infinitum.

While hierarchies are thought of as a *Structural* perspective often seen in the ubiquitous organisation chart, they also have to be considered

[16] Known as a trunk in the US.

from the *Continuum* perspective as being positioned on a continuum of ever increasing complexity, where:

- The elements at any point of the hierarchy are more complex than those lower down.
- Different elements of the structure in different points on the continuum exhibit different patterns of behaviour.

The principle of hierarchies in systems (Spencer, 1862) cited by (Wilson, 2002) is one of the ways humanity has managed complexity for most of its recorded history and is defined in the following three quotations.

1. "*All complex structures and processes of a relatively stable character display hierarchical organisation regardless of whether we consider galactic systems, living organisms and their activities or social organisations" (Koestler, 1978: page 31).*
2. *"Once we adopt the general picture of the universe as a series of levels of organisation and complexity, each level having unique properties of structure and behaviour, which, though depending on the properties of the constituent elements, appear only when those are combined into the higher whole, we see that there are qualitatively different laws holding good at each level*" (Needham, 1945) cited by (Koestler, 1978: page 32).
3. Wilson (Wilson, 2002) wrote, "*The English philosopher Herbert Spencer appears to be the first to set out the general idea of increasing complexity in systems (Spencer, 1862). The term itself was first used by the English biochemist (and scholar of Chinese science) Joseph Needham (Needham, 1937). The following quotation from a Web source provides an insight into the fundamentals of the theory (ULA, 2002):*

    a. *The structure of integrative levels rests on a physical foundation. The lowest level of scientific observation would appear to be the mechanics of particles.*
    b. *Each level organizes the level below it plus one or more emergent qualities (or unpredictable novelties). The levels are therefore cumulative upwards, and the emergence of qualities marks the degree of complexity of the conditions prevailing at a given level, as well as giving to that level its relative autonomy.*
    c. *The mechanism of an organization is found at the level below, its purpose at the level above.*
    d. *Knowledge of the lower level infers an understanding of matters on the higher level; however, qualities emerging on the higher level have no direct reference to the lower-level organization.*
    e. *The higher the level, the greater its variety of characteristics, but the smaller its population.*

f. *The higher level cannot be reduced to the lower, since each level has its own characteristic structure and emergent qualities.*
g. *An organization at any level is a distortion of the level below, the higher-level organization representing the figure which emerges from the previously organized ground.*
h. *A disturbance introduced into an organization at any one level reverberates at all the levels it covers. The extent and severity of such disturbances are likely to be proportional to the degree of integration of that organization.*
i. *Every organization, at whatever level it exists, has some sensitivity and responds in kind.*"

This means that as well as exhibiting different behaviours at different levels of the hierarchy, the tools and methodologies used to examine a system at one level of the hierarchy may not be appropriate at a different level which means that as we move up the levels, new approaches have to be discovered and invented. One example is Operations Research which was developed in the UK and US during World War II to tackle problems pertaining to the loss of Allied shipping in the North Atlantic Ocean due to German submarines.

4.3.4.2. Changes and improvements

Changes and improvements are often perceived from the *Temporal* perspective yet change should also be considered from the perspective of the continuum of change discussed in Section 4.3.2.6.2.4 as well as from the *Temporal* perspective.

Perceptions from the *Quantitative* perspective can show when an innovative change must be made. For example, Federated Aerospace has been going through a cost cutting exercise by making incremental or adaptive changes and the manager in charge has summarized the situation in the graph in Figure 4.21 which shows that costs have been coming down over time but have flattened out after the seventh month so that no further reductions are being made. Note that while innovative changes may be employed anywhere along the curve, failure to innovate once the cost reduction curve flattens out tends to result in an organization going out of business.

Similarly, consider the rate of improvement over time in a different project. After seven time periods the rate of improvement has reached 8% as shown in Figure 4.22. Forecast what rate can be expected in the next time period? Supposing the organisation leadership announces an improvement target of 20% for the following year. The initial reaction of the improvement team to the forecast is that the announced target is impossible, and to send a memo back asking the leadership to stop setting

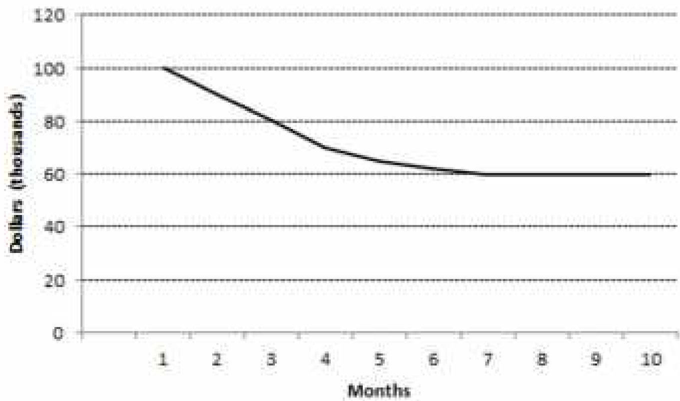

Figure 4.21 Cost reduction to point of diminishing returns

arbitrary numerical targets. However, the target may not be arbitrary. It may be that a competitor is about to announce a new product and if that numerical target is not achieved, the company will not be competitive in that product line with all the resultant negative consequences (*Big Picture* perspective). Top management may be correct in that the new target is needed and setting a numerical goal. The process improvement team may be correct in that it is an impossible goal using their forecasts based on adaptive improvements, but they need to realise that the impossibility only exists in their paradigm and they need to go beyond systems thinking and realise that alternatives exist (*Continuum* perspective) and the improvement target may be achievable if an innovative change is made[17]. When numerical targets are set that do not lie along the extrapolation of the historical curve of adaptive change, it is time to consider an innovative change.

4.3.4.3. Failure and risk analyses

The general tendency, when designing a system, is to perceive the desired modes of operation from its *Operational* and *Functional* perspectives. However, when the progressive perspectives are invoked, you are able to go beyond systems thinking and perceive the system in conceptual or even real undesired modes of working, performing risk and failure mode analyses. For example:

- ***Operational/Functional + Continuum + Temporal.*** The undesirable situations that can happen as a result of external interaction with operator, externally induced failures, misuse, etc.

[17] Such as framing the question differently as did Henry Ford, see Section 4.3.2.6.1.

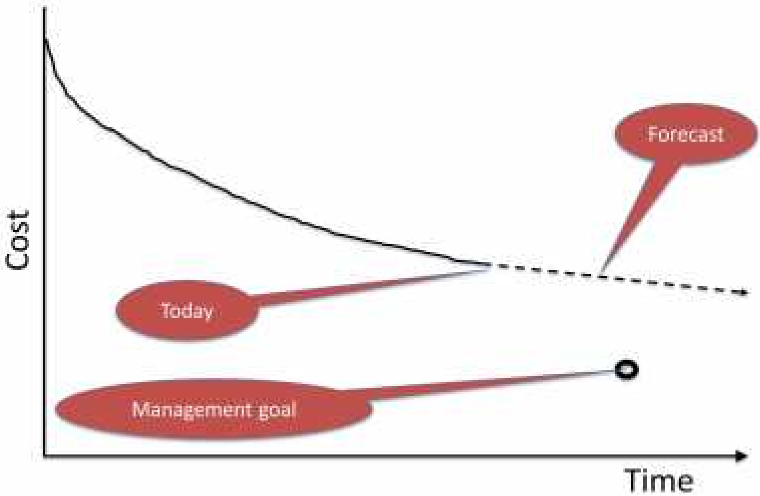

Figure 4.22 Rate of change and management's goal

These perspectives are used when performing a Fault Tree Analysis (FTA) or a Risk Analysis.

- ***Structural + Continuum + Temporal.*** The undesirable situations that can happen, for example, as a result of the internal damage due to failures in aging components. These perspectives are used when performing a Failure Effects Mode Analysis (FEMA) or a Risk Analysis.

4.4. Comparing the perspectives perimeter with systems thinking

Viewing a system from multiple perspectives is not a new concept especially in the systems engineering and software domains, e.g. (Hately and Pirbhai, 1987; Ward and Mellor, 1985; Mar and Morais, 2002). As such, the HTPs are not the only perspectives on the perspectives perimeter; however they are more comprehensive than previous sets of perspectives. For example, consider the following types of systems thinking and how they compare to the HTPs:

- The Soft Systems Methodology (SSM) discussed in Section 4.4.1.
- Causal Loops and systems dynamics discussed in Section 4.4.2.
- Lateral thinking discussed in Section 4.4.3.
- The United States Department of Defense Architecture Framework (DODAF) 1.0 discussed in Section 4.4.4.

4.4.1. The Soft Systems Methodology

The Soft Systems Methodology (SSM) (Checkland and Scholes, 1990; Checkland, 1991) is a thinking tool originating in Operations Research designed to help in investigating ill-structured undesirable situations within social activity systems. SSM contains the following seven steps (Checkland, 1991: pages 163 to 183):

1. Examining the problematic or undesirable situation by examining slow-to-change structure within the situation and elements of continuously changing processes and forming a view of how structure and process relate to each other.
2. Expressing the undesirable situation in words and Rich Pictures.
3. Developing root definitions of the relevant systems of what they are as opposed to do what they do. These definitions encapsulate the purpose of the system.
4. Creating conceptual models of the human activity systems named and defined in the root definitions. While the modelling language is English, the model may be transformed to other formats such as systems dynamics.
5. Comparing the conceptual models with the undesirable situation to identify differences (gap analysis).
6. Determining feasible desirable changes by generating a debate among the stakeholders to define possible changes to the situation which will be arguably desirable and feasible given prevailing attitudes and power structures and having regard to the history of the situation under examination. The problem then becomes to define the action to be taken to improve the situation.
7. Taking the action to improve the situation, and, having completed the action, going back to step 1.

SSM's CATWOE template seems to align with the HTPs as shown in Table 4.3[18]. CATWOE is an acronym for:

- ***Customers of the system:*** the stakeholders who interact or are affected by the systems activities.
- ***Actors within the system:*** who carry out or cause to be carried out the functions of the system.
- ***Transformation***: the process by which the inputs to the system are transformed into the outputs.

[18] The boundaries do not align directly because the elaboration of systems thinking is different.

Table 4.3 Apparent relationship between SSM's CATWOE and the HTPs

CATWOE	HTP
Client/customer	*Big Picture, Operational*
Actor	*Functional*
Transformation	*Functional and Quantitative*
Weltanschauung	*Big Picture, Operational*
Owner	*Big Picture*
Environment	*Big Picture*

- ***Weltanschauung:*** world view, perspective or paradigm (Kuhn, 1970; Churchman, 1979: page 105) from which the core purpose of the system is viewed.
- ***Owners of the system:*** who have the ultimate power to create the system or make it cease to exist.
- ***Environmental:*** constraints on the system.

The grouping of elements is a process of functional allocation, namely design. Thus SSM is not "systems thinking" per-se; rather it is a useful tool for thinking about a social system incorporating some holistic thinking concepts. See Section 10.1 for an example of applying SSM with holistic thinking enhancements.

4.4.2. Causal loops and system dynamics

As mentioned in Section 4.1.3, causal loops discussed in Senge's fifth discipline (Senge, 1990) Forrester's system dynamics (Clark, 1998) and Sherwood's seeing the forest from the trees (Sherwood, 2002) are but one of the two types of systems thinking (Section 4.1.3); the one that considers relationships between the parts of a system, for example, "*System dynamics is the study of processes through the use of systems and how they can be modeled, explored and explained*" (Clark, 1998). A process consists of activities or functions. Hence, system dynamics is a tool with which to analyse the behaviour of a system.

Causal loops are just concept maps used examine relationships between the actors or entities interacting with, or in, existing and proposed systems from the *Big Picture*, *Operational* and *Functional* perspectives. In engineering terminology they are "feedback loops".

4.4.3. Lateral thinking

Table 4.4 shows a comparison between lateral thinking discussed in Section 2.6.5 and the HTPs. Lateral thinking focuses on perceiving the problematic or undesirable situation as well as issues concerning managing the people doing the thinking about the situation while the HTPs focus on perceiving the situation.

Table 4.4 Comparison between Holistic perspectives and Lateral thinking hats

Thoughts about …	Lateral Thinking Hat	HTP
Information available and needed	White	*Temporal*, *Generic*
Intuition, feelings, and hunches	Red	*Scientific* concerning problem and solution, *Operational* concerning team doing the thinking
Cautions and difficulties, where things might go wrong	Black	*Continuum* view of *Operational/Functional/Scientific*
Values and benefits, why something might work	Yellow	*Quantitative/Operational/Functional/Scientific*
Alternatives and creative ideas	Green	*Generic*
Managing the thinking process	Blue	Holistic thinking

4.4.4. The US Department of Defense Architecture Framework 1.0

The US Department of Defense Architecture Framework 1.0 (DoDAF, 2004) was designed to provide correct and timely information to decision makers involved in future acquisitions of communications equipment to ensure communications interoperability between systems. Table 4.4 provides an approximation of the mapping between the HTPs and DODAF views and shows that the DODAF views map into the *Big Picture*, *Operational*, *Functional* and *Structural* perspectives: the DODAF embodies analysis and systems thinking. The exact mapping for any specific situation is likely to depend on how the DODAF is employed and some of the relationships may be more significant than others. The DODAF 2.2 upgrade also focused on the internal and external perspectives ignoring the progressive perspectives.

4.5. Summary

The Chapter:

1. Addressed multiple perspectives.
2. Began with a description of analysis as an internal perspective and systems thinking as an external perspective in Section 4.1.
3. Introduced the perspective perimeter to provide anchor points for discussions from a wider set of viewpoints that go beyond analysis and systems thinking in Section 4.2.

Table 4.5 Mapping between DODAF 1.0 and HTPs

	All View	Operational Views	System Views	Technical Views
Big Picture	X	-	-	X
Operational	X	X	-	X
Functional	X	X	X	X
Structural	X	-	X	X
Generic	-	-	-	-
Continuum	-	-	-	-
Temporal	-	-	-	-
Quantitative	-	-	-	-
Scientific	-	-	-	-

4. Introduced nine Holistic Thinking Perspectives (HTP) as a standard set of anchor points on the perspectives perimeter and more in Section 4.3.
5. Compared the HTPs with some other versions of systems thinking in Section 4.4.

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5. Critical thinking

This Chapter:

1. Introduces and provides an overview of critical thinking.
2. Perceives critical thinking from the perspectives perimeter in Section 5.1 and:
    1) Shows how the perspectives perimeter can be used to examine critical thinking.
    2) Uses perceptions from the *Functional* perspective to separate out the rules for thinking from the evaluation of ideas.
3. Discusses creating and analysing arguments in Section 5.2.
4. Introduces a number of ways of evaluating critical thinking in Section 5.3.

The literature on creativity and idea generation generally separates thinking up the ideas and validating the ideas. The literature on critical thinking however tends to combine the logic of thinking with validating the ideas using the terms 'smart thinking' and 'critical thinking'. The term 'critical thinking' by the way, comes from the word "criteria" not from "criticism".

There are diverse definitions of the term critical thinking including:

- *"Disciplined, self-directed thinking displaying a mastery of intellectual skills and abilities - thinking about your thinking while you're thinking to make your thinking better"* (Eichhorn, 2002).
- "*The art of thinking about thinking while thinking in order to make thinking better. It involves three tightly coupled activities: It analyses thinking; it evaluates thinking; it improves thinking*" (Paul and Elder, 2006: page xiii).
- "*Judicious reasoning about what to believe and therefore what to do*" (Tittle, 2011: page 4).
- "*The process of purposeful, self-regulatory judgement*" (Facione, 1990) cited by (Facione, 2011: page 6).

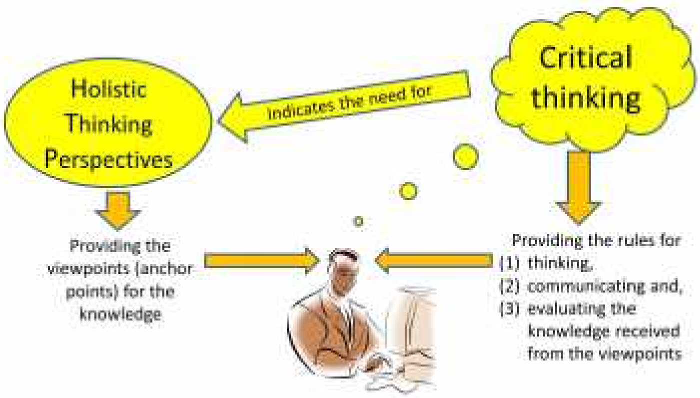

Figure 5.1 HTPs and critical thinking

- "*Purposeful, reflective judgment that manifests itself in giving reasoned and fair-minded consideration to evidence, conceptualizations, methods, contexts, and standards in order to decide what to believe or what to do*" by (Facione, 2011: page 12).

Depending on the definition, critical thinking covers:

- The thinking process.
- The means to evaluate or judge the ideas and so overlaps the *Scientific* and other HTPs.

This Chapter draws the boundaries between the HTPs and critical thinking as shown in Figure 5.1, namely

- ***The HTPs:*** manage the ideas by providing the perspectives for creating and storing the ideas.
- ***Critical thinking:***
    1) Provides the rules for
        i. Thinking about the ideas.
        ii. Communicating the ideas.
        iii. Evaluating the ideas.
    2) Indicates the need for multiple viewing perspectives.

5.1. Viewing critical thinking from the perspectives perimeter

Perceive critical thinking from the perspectives perimeter (Section 4.3) using the cognitive psychology information-processing model of the brain based on the work of (Atkinson and Shiffrin, 1968) cited by (Lutz and Huitt, 2003) shown in Figure 2.1 which likens the human mind to an information processing computer[1].

5.1.1. The Big Picture perspective

Perceptions from the *Big Picture* perspective include:

- ***Purpose:*** why the reasoning is taking place.
- ***Assumptions:*** which underpin the reasoning; consequently the assumptions must be reasonable, justifiable and clearly articulated.
- ***Beliefs***: which limit or guide the argument of the person doing the reasoning. These may be considered as cognitive filters (Section 2.1)
- ***Contextual concepts:*** the theories, principles, axioms and rules implicit in the reasoning.
- ***Point of view:*** or perspective from which the reasoning, based on the assumptions, using the information, takes place.

5.1.2. The Operational perspective

Perceptions from the *Operational* perspective provide a black box view of thinking and include the:

- ***Input to the reasoning process:*** the information may come from any number of sources (senses (sight, sound, smell taste and touch), experience, the results of a literature search, etc.) from any point on the perspectives perimeter (Section 4.2).
- ***Output, outcome or conclusion from the reasoning process:*** this could be a problem statement, a solution, or greater understanding of a situation (*Scientific* perspective).
- ***Various scenarios in which critical thinking is used:*** the literature contains a number of such scenarios including the following (Paul, 1991: page 78) cited by (Tittle, 2011: page 4):
    - Analysing or evaluating arguments, interpretations, beliefs or theories.
    - Analysing or evaluating actions or policies.
    - Assessing and evaluating solutions.
    - Avoiding oversimplifications (*Quantitative* perspective).
    - Clarifying issues, conclusions, and beliefs.
    - Comparing analogous situations: transferring insights to new contexts (*Scientific* perspective).

[1] See Section 12.6.2 for a modified psychology information-processing model.

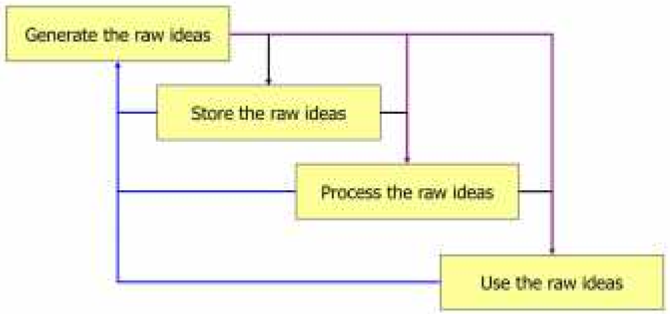

Figure 5.2 Functions of thinking

- Comparing and contrasting ideal with actual practice (*Generic* perspective).
- Creating arguments as discussed in Section 5.2.
- Developing criteria for evaluation: clarifying values and standards (*Quantitative* perspective).
- Developing one's perspective: creating or exploring beliefs, arguments, or theories.
- Distinguishing relevant from irrelevant facts (application of domain knowledge).
- Evaluating evidence and alleged facts.
- Evaluating the credibility of sources of information.
- Examining or evaluating assumptions.
- Exploring consequences (*Temporal* perspective).
- Exploring implications.
- Generating solutions (*Scientific* perspective).
- Giving reasons for something.
- Listening critically: the art of silent dialogue.
- Making interdisciplinary connections (*Generic* and *Continuum* perspectives).
- Making plausible inferences, predictions, or interpretations (*Scientific* perspective).
- Noting significant similarity and differences (*Generic* and *Continuum* perspectives).
- Practicing Socratic discussion: clarifying and questioning beliefs, theories, or perspectives.
- Questioning deeply: raising and pursuing root or significant questions.
- Reading critically: clarifying or critiquing texts.
- Reasoning dialogically: comparing perspectives, interpretations, or theories.

  - Reasoning dialectically: evaluating perspectives, interpretations, or theories.
  - Recognizing contradictions.
  - Refining generalizations.
  - Thinking precisely about thinking: using critical vocabulary.
- ***Self-analysis and evaluation of your own thinking:*** In general the initial reaction to criticism is defensive rather than reflective. People tend to defend their thinking rather than reflect and accept comments. This in turn can lead to undesired consequences when people are not willing to admit mistakes and continue in the wrong direction (Section 8.3). Self-analysis and evaluation:
  - Needs to be done to help you determine and overcome your own cognitive filters (Section 2.1).
  - Is one of the decision traps discussed in Section 8.3 when not done.

5.1.3. The Functional perspective

Perceptions from the *Functional* perspective provide an internal perspective. One of the ways the tasks performed in the process of thinking can be aggregated into four states is shown in Figure 5.2[2]. While it is convenient elaborate the process into sequential tasks for discussion purposes, it is not really a sequential process because ideas can be triggered in any state of the process, and depending on the idea generating technique employed, some states can be combined or bypassed. The tasks performed while thinking in this aggregation are:

- ***Generating the raw ideas:*** using the thinking tools described in Chapter 2 as well as Active Brainstorming discussed in Section 6.2 Ideas relate to facts, myths and values.
- ***Storing the ideas:*** using Idea Storage Templates (IST) such as those discussed in Section 6.3 or equivalent.
- ***Processing the ideas:*** commonly called 'reasoning'. The process which builds an argument to support or refute a conclusion according to a specified set of rules.
- ***Using the ideas*** to perform an activity such as providing a hypothesis or taking some action. "*Ideas range in quality from profound to ridiculous, helpful to harmful, ennobling to degrading. It is therefore appropriate to pass judgment on them. However, fairness demands that you base your judgement on thoughtful consideration of the overall strengths and weaknesses of the ideas, not on your initial impressions or feelings. Be espe-*

[2] The *Continuum* perspective points out that there might be others.

cially careful with ideas that are unfamiliar or different from your own because those are the ones you will be most inclined to deny a fair hearing" (Ruggiero, 2012). This statement leads to the second aspect of critical thinking; the judgement or evaluation of ideas discussed in Section 5.1.3.2.

5.1.3.1. Reasoning

Reasoning, often used to associate effects with causes may be deductive or inductive as discussed below.

5.1.3.1.1. Deductive reasoning

The deductive reasoning process always provides a conclusion that is either true or false. It begins with statements called 'premises' that are assumed to be true. The process then deduces what else is true if all the premises are true. The general principle is if *all* the premises are true then the conclusion is true. However, if any one of the premises is false the conclusion is false. Consider the following three examples:

- ***1:***
  - ***Premises:*** (1) All cats like fish; (2) Tabby is a cat.
  - ***Conclusion:*** Tabby likes fish.

  If the premise is true, the conclusion is true since Tabby is an instance of a class of animals called cats.

- ***2:***
  - ***Premises:*** (1) Singapore is in Asia; (2) I live in Singapore.
  - ***Conclusion:*** I live in Asia.

  The conclusion is true since Singapore is within Asia.

- ***3:***
  - ***Premises:*** (1) I live in Asia; (2) Singapore is in Asia.
  - ***Conclusion:*** I live in Singapore.

  From the perspective of deductive logic, the conclusion is false since Asia is not within Singapore. However, since Singapore is within Asia, you can infer that there is a probability that the statement might be true[3].

[3] But not how much of a probability without additional information.

5.1.3.1.2. Inductive reasoning

The inductive reasoning process infers the probability of conclusions from observations in various non-deductive ways. It is the reasoning generally used in the Scientific Method (Section 9.12.2.1) to determine the hypothesis, by detectives solving crimes and physicians diagnosing causes of illnesses. Examples of inductive reasoning include:

- ***Patterns of behaviour:*** reasoning based on observing what seems to be a pattern of behaviour by something and creating a hypothesis for the pattern. You then make a prediction pertaining to the probability of future appearances of the something based on the hypothesis. For example, you notice that there has been a rain shower at about 4 p.m. local time every day from Monday to Thursday. On Friday morning, you use those observations to infer a hypothesis that there is a high probability of a similar shower on Friday afternoon at about the same time and decide to carry an umbrella. This is the type of reasoning used to successfully infer the probable date of the drop in the price of petrol in Detroit described in Section 7.4.1.
- ***Similarity:*** generic reasoning which infers general principles or rules from specific facts. This type of generic reasoning is used with two items that are similar (having one or more common properties) to infer that properties pertaining to one item, also apply to, or can be inherited from, a similar item (*Generic* perspective). One example is the analogy from the *Structural* perspective used to infer the distributed control system in the LuZ Solar Electrical Generating System (SEGS)-1 solar array control system discussed in Section 6.4.1.
- ***Analogies:*** generic reasoning which infers a property pertaining to one item also applies to a similar item. It is used to infer a property that has yet to be observed in one item based on observations of that property in a similar item. Unlike similarities which are used to infer generic properties, analogies are used to infer a specific property. This is the reasoning discussed in Section 4.3.2.9.3 used to infer which container held the coffee.
- ***Best explanation:*** this reasoning process starts with a fact and concludes with the best explanation for this fact (Juthe, 2005). Thus, having observed a situation, you infer the best explanation of that situation and state it in the form of a guess or hypothesis. For example, you have spent the afternoon in a windowless office. When you leave the building you notice that the street is wet. You infer that the best explanation of the cause of the situation is a rain shower.

5.1.3.2. Evaluating ideas

The second function of critical thinking is the judgement of the correctness or truthfulness of the both the reasoning (process) and the outcomes or conclusions from the reasoning (products): you do this in various ways including by examining the:

- ***Relevance of the information used in the premises:*** for example, consider the following example of poor deductive logic.
  - ***Premises:*** (1) All cats like fish; (2) Brock is a dog.
  - ***Conclusion:*** Brock does not like fish.

  The validity of the conclusion cannot be determined because there is nothing in the argument that is relevant to dogs liking fish.

- ***Nature of the links between two sequential events:*** determining if the first event is indeed the cause of the second event. Correlation between events does not necessarily prove causation. See the electronic items work because they are full of smoke because they stop working after the smoke escapes anecdote on page 160 for a poor example of correlation.
- ***Validity of the argument:*** particularly in inductive reasoning. For example: I tell students in class the following anecdote. I was visiting a fruit farm in Malaysia and saw a tree with purple plastic bags hanging from the branches. Being from Europe, tropical trees were strange and so I told the students that I thought I saw a plastic bag tree for the first time. The students smiled. Why did they smile? They smiled because they knew that plastic bags don't grow on trees. But how did they know? They had enough prior knowledge about what plastic is made from to know that it does not grow on trees. The thinking sequence was:
  - ***Observation:*** plastic bags hanging on the branches.
  - ***Reasoning:*** fruit hangs on branches and grows on trees, plastic bags are growing on the trees just like fruit.
  - ***Conclusion/hypothesis:*** I am looking at a plastic bag tree.

  I illustrate the same point in an alternative way with the following question. I ask the students, "Do you know that electrical and electronic devices such as fans, air conditioners, television sets, and personal computers work because they are full of smoke?" The thinking sequence was:

- ***Observation:*** electrical and electronic devices stop functioning after the smoke comes out of them.
- ***Reasoning:*** electrical and electronic devices function until smoke comes out of them and then the devices cease to function.
- ***Conclusion/hypothesis:*** electrical and electronic devices only function when they are full of smoke.

The conclusions are wrong in both examples, but you will need different domain knowledge in each example to know that the conclusions are false and why they are false. You will need to know about plastics in the first example, and about electronics in the second example.

- ***Relationships between the premises looking for missing premises:*** Consider the following argument as an example:
  - ***Premises:*** (1) Susie is a child. (2) Electrical tools are dangerous.
  - ***Conclusion:*** Susie needs to be kept away from hammer-drills.
  - ***The missing premises*** are (3) children need to be kept away from electrical tools and (4) hammer-drills are electrical tools. The validity of the missing premises in an argument also needs to be checked.

5.1.3.2.1. The problem, solution and implementation domains

When evaluating ideas, there needs to be a reference or some prior or researchable knowledge against which to evaluate the idea as in knowing that the plastic bag tree conclusion is false because plastic bags don't grow on trees. This knowledge comes from a domain. There are three relevant domains relevant to critical thinking, namely:

1. The problem domain.
2. The solution domain.
3. The implementation domain.

It is tempting to assume that the problem domain and the solution domain are the same, but they are not necessarily so. For example, the problem domain may be urban social congestion, while the solution domain may be a form of underground transportation system to relieve that congestion. Lack of problem domain competency may lead to the identification of the wrong problem and lack of solution domain competency may lead to selection of a less than optimal, or even an unachievable, solution system. Risk management is an activity (process) that requires competency in the problem, solution and implementation domains.

5.1.3.3. Process used in critical thinking

Arons provided the following illustrative list of thinking and reasoning processes used in critical thinking that underlie analysis and inquiry (Arons, 1990: pages 314 to 319)[4]:

1. Consciously raising the following questions when studying some body of material or approaching a problem:
   - "What do we know …?"
   - "How do we know …?"
   - "Why do we accept or believe …?"
   - "What is the evidence for …?"
2. Being clearly and explicitly aware of gaps in available information. Recognizing when a conclusion is reached or a decision made in absence of complete information and being able to tolerate ambiguity and uncertainty. Recognizing when one is taking something on faith without having examined the "How do we know …?" and "Why do we believe …?" questions.
3. Discriminating between observation and interference, between established fact and subjective conjecture.
4. Recognizing that words are symbols for ideas and not the ideas themselves. Recognizing the necessity of using only words of prior definition, rooted in shared experience, in forming a new definition and in avoiding being misled by technical jargon.
5. Probing for assumptions (particularly the implicit, unarticulated assumptions) behind a line of reasoning.
6. Drawing inferences from data, observations, or other evidence and recognizing when firm inferences cannot be drawn. This subsumes a number of processes such as elementary syllogistic reasoning (e.g., dealing with basic prepositional, "if … then" statements), correlational reasoning, recognizing when relevant variables have or have not been controlled.
7. Performing hypothetico-deductive reasoning; that is, given a particular situation, applying relevant knowledge of principles and constraints and visualizing, in the abstract, the plausible outcomes that might result from various changes one can imagine to be imposed on the system.

[4] Arons stated that the list is meant to be illustrative; it is neither exhaustive nor prescriptive.

8. Discriminating between inductive and deductive reasoning; that is being aware when an argument is being made from the particular to the general or from the general to the particular.
9. Testing one's own line of reasoning and conclusions for internal consistency and thus developing intellectual self-reliance.
10. Developing self-consciousness concerning one's own thinking and reasoning processes.

5.1.4. The Continuum perspective

Perceptions from the *Continuum* perspective provide the following concepts:

- ***Multiple solutions:*** the *Continuum* perspective provides for inductive reasoning to produce multiple outcomes of the thinking process, each with different probabilities of occurrence. These are useful when thinking about risks and opportunities.
- ***Potential for errors or defects:*** every part of the reasoning process is open to error such as incorrect theories, myths and assumptions, faulty input data, poor logic, etc., all of which lead to false or incorrect outcomes and the need to prevent, detect and compensate for these defects.
- ***Breadth:*** the degree to which the reasoning recognises or employs arguments from several different perspectives.

5.1.5. The Temporal perspective

Perceptions from the *Temporal* perspective indicate the:

- ***Need to consider history:*** the issues that have created the situation are still present and need to be considered in the reasoning.
- ***Further implications and consequences:*** there will always be further implications and consequences from any act of reasoning. These need some consideration.

5.1.6. The Structural perspective

Perceptions from the *Structural* perspective indicate the need for:

- ***Clarity*** of the purpose, information, arguments and outcomes.

The *Structural* perspective is also used to identify the premises and conclusions in an argument by the words used in the statement. For example, words relating to:

- ***Premises:*** include 'according to', 'after all', 'as', 'assume', 'because', 'by', 'considering', 'for', 'given', 'if', 'implied', 'in fact', 'premise', 'reason', 'seeing that', 'since', 'suppose', and 'whereas'.

- ***Conclusions:*** include 'accordingly', 'as a result', 'conclude', 'conclusion', 'consequently', 'deduce', 'follows', 'for that reason', 'hence', 'implied', 'indicates', 'infer', 'means', 'probably', 'proven', 'result', 'seem', 'shown', 'so', 'supports', 'therefore', 'then', and 'thus'.

You should always check the context in which the identification words are used to determine whether or not they are used in premises or conclusions because words have multiple meanings and some words such as 'evidence' can be used to identify both premises and conclusions.

Sometimes the identification words are implied and not articulated. For example, a statement such as, "X's book on systems thinking is a load of rubbish, don't buy it" should be written with identification words such as "*since* X's book on systems thinking is a load of rubbish, *the recommendation is* don't buy it" or something with similar identification words.

5.1.7. The Quantitative perspective

When performing critical thinking, perceptions from the *Quantitative* perspective indicates the need for:

- ***Accuracy:*** for example consider statements such as, "four out of five people surveyed" and, "most people like …" used in inductive reasoning. Taken on their own, there is no way to determine the accuracy of the statements. Citing the source of such information may be one way to show the accuracy of the information.
- ***Precision:*** the need to use:
  - ***Numbers instead of adjectives:*** for example, instead of the non-precise word 'large' use the appropriate number.
  - ***The appropriate degree of precision:*** sometimes the number 3.14 is all that is required when the calculator displays 3.1415926535. Sometimes "approximately 3" will be enough.
  - ***Tolerances on values:*** Instead of describing the voltage needed to recharge your personal computer as 18 Volts, you should use 18±v Volts or whatever the voltage and actual range (v) is.
- ***Depth:*** the degree to which the argument reflects the degree of complexity of the issue.
- ***Sufficiency:*** the number of premises and amount of information in the argument to support the conclusion.

When evaluating critical thinking, the *Quantitative* perspective provides the metrics used to evaluate a person's critical thinking ability as discussed in Section 5.3.

5.1.8. The Scientific perspective

The *Scientific* perspective is the idea contained in the conclusion, statement of the hypothesis or guess that is stated after having thought about the situation.

5.2. Creating or analysing arguments

One way of using critical thinking to create or analyse an argument is to use the following process adapted from Tittle (Tittle, 2011: page 17)[5]:

1. Determine the point of the argument (claim/opinion /conclusion).
2. Identify the reasons and the evidence.
3. Articulate all unstated premises and connections in the reasoning (assumptions)[6].
4. Define the terms used in the argument.
5. Clarify all imprecise language (*Quantitative* perspective).
6. Differentiate between facts and opinions.
7. Eliminate or replace "loaded" language and other manipulations[7].
8. Assess the reasoning/evidence:
    - If deductive, check for truth (factual), acceptability and validity.
    - If inductive, check for truth (factual), acceptability, relevance and sufficiency.
9. Determine ways to strengthen the argument[8] by:
    - Providing and incorporating additional reasons and/or evidence.
    - Anticipating objections and providing adequate responses to the objections.
10. Determine ways to weaken the argument[9] by:

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[5] This process, based can be used to examine an argument or to create one (*Continuum* perspective)

[6] Or at least as many as you can

[7] Words which have emotional significance or contain implied judgments.

[8] And do so

[9] If writing the paper and ways are found, then strengthen the argument to remove those weaknesses.

- Considering and assessing counterexamples, counterevidence and counterarguments.
- Determining if the argument should be modified or rejected because of the counterarguments.
- If appropriate, identify and provide any additional information required before the argument could be accepted or rejected.

Perceived from the *Continuum* perspective, this process can be used both to examine an argument as well as to create one.

5.3. Evaluating critical thinking

Since there are diverse opinions on the nature of critical thinking, perceptions of the skills and abilities used to evaluate critical thinking can also provide insights as to the nature of critical thinking, and so are discussed in this Section.

Faced with the problem of evaluating the degree of critical the first step in developing the solution was to ask the question, "*has anyone already done it?*" in accordance with the problem-solving process shown in Figure 9.14. A literature review showed that the problem of assessing the degree of critical thinking in students seemed to have already been solved (Facione, et al., 2000; Eichhorn, 2002; Wolcott and Gray, 2003; Allen, 2004; Paul and Elder, 2006; Perry, 1981). Consider the following approaches:

1. Wolcott and Gray's five levels discussed in Section 5.3.1.
2. Paul and Elder's student profiles discussed in Section 5.3.2.
3. Facione and Facione's four levels discussed in Section 5.3.3.
4. Perry's nine-level approach discussed in Section 5.3.4.
5. Similarities and differences discussed in Section 5.3.5.

5.3.1. Wolcott and Gray's five levels

Wolcott and Gray aggregated lists of critical thinking abilities by defining five levels of critical thinking by students based on the words they used in written assignments (Wolcott and Gray, 2003). In evaluating the findings, perceptions from the *Generic* perspective noted that Wolcott's method for assessing a critical thinking level was very similar to that used by Biggs for assessing deep learning in the education domain (Biggs, 1999). Wolcott's five levels (from lowest to highest) are:

1. Confused fact finder.
2. Biased jumper.
3. Perpetual analyzer.
4. Pragmatic performer.

5. Strategic revisioner.

Consider each of them.

5.3.1.1. Confused fact finder

A confused fact finder is a person who is characterised by the following:

- Looks for the “only” answer.
- Doesn’t seem to “get it”.
- Quotes inappropriately from textbooks.
- Provides illogical/contradictory arguments.
- Insists professor, the textbook, or other experts provide “correct” answers even to open-ended problems.

5.3.1.2. Biased jumper

A biased jumper is a person whose opinions are not influenced by facts. This person is characterised by the following:

- Jumps to conclusions.
- Does not recognise own biases; accuses others of being biased.
- Stacks up evidence for own position; ignores contradictory evidence.
- Uses arguments for own position.
- Uses arguments against others.
- Equates unsupported personal opinion with other forms of evidence.
- Acknowledges multiple viewpoints but cannot adequately address a problem from viewpoint other than own.

5.3.1.3. Perpetual analyzer

A perpetual analyser is a person who can easily end up in “analysis paralysis”. This person is characterised by the following:

- Does not reach or adequately defend a solution.
- Exhibits strong analysis skill, but appears to be “wishy-washy”.
- Write papers that are too long and seem to ramble.
- Doesn’t want to stop analysing.

5.3.1.4. Pragmatic performer

A pragmatic performer is a person who is characterised by the following:

- Objectively considers alternatives before reaching conclusions.
- Focuses on pragmatic solutions.

Table 5.1 Evaluation of critical thinking by Paul and Elder

Skill	**Exemplary**	**High-performing**	**Mixed-quality**	**Low-performing**
Raises important questions and issues (formulating them clearly and precisely)	Regularly	Often	Sometimes	Rarely
Analyses key questions and problems (logically)	Regularly	Most	Sometimes	Superficially
Distinguishes accurate from inaccurate, relevant from irrelevant information	Regularly	Often	Sometimes	Rarely
Recognizes questionable assumptions	Regularly	Most	Some	Does not recognise their own assumptions
Clarifies key concepts	Regularly	Often	Clarifies some concepts	Clarifies concepts only partially
Uses language in keeping with educated usage	Regularly	Typically	Sometimes	Rarely
Identifies relevant competing points of view	Regularly	Commonly	Sometimes	Rarely
Displays sensitivity to important implications and consequences	Regularly	Many	Inconsistently sensitive	Insensitive
Reasons	Regularly	Often	Sometimes	Rarely

Skill	Exemplary	High-performing	Mixed-quality	Low-performing
carefully from clearly stated, well-justified premises in a subject				

- Incorporates others in the decision process and/or implementation.
- Views task as finished when a solution/decision is reached.
- Gives insufficient attention to limitations, changing conditions, and strategic issues.
- Sometimes comes across as a "biased jumper", but reveals more complex thinking when prompted.

5.3.1.5. Strategic revisioner

A strategic revisioner is a person who is characterised by the following:

- Seeks continuous improvement/lifelong learning.
- More likely than others to think "out of the box".
- Anticipates change.
- Works toward construction knowledge over time.

5.3.2. Paul and Elder's student profiles

Paul and Elder also assessed student performances in four levels but in a different manner (Paul and Elder, 2006: pages 74 to 77), namely:

- ***Exemplary Students:*** (grade of A) who display excellent reasoning and problem-solving skills.
- ***High-performing students:*** (grade of B) who display sound reasoning and problem-solving skills.
- ***Mixed-quality students:*** (grade of C) who display inconsistent reasoning and problem-solving skills.
- ***Low-performing students:*** (grades of D or F) who display poor reasoning and problem-solving skills.

The skills and abilities pertaining to each type of student and level of critical thinking are summarized in Table 5.1.

5.3.3. Facione and Facione's four levels

Peter A. Facione and Noreen C. Facione also provide a holistic critical thinking scoring rubric in four levels according to the treatment of the skills and abilities shown in Table 5.2 (Facione, et al., 2000), where:

- ***Level 4:*** consistently does all or almost of the actions in the "Strong" column.
- ***Level 3:*** does most or many of the actions in the "Acceptable" column.
- ***Level 2:*** does most or many of the actions in the "Unacceptable" column.
- ***Level 1:*** consistently does all or almost all of the actions in the "Weak" column.

Table 5.2 Facione and Facione's holistic critical thinking scoring rubric

Treatment of:	Strong	Acceptable	Unacceptable	Weak
Evidence, statements, graphics, questions, etc.	Interprets accurately	Interprets accurately	Misinterprets	Offers biased interpretations
Arguments (reasons and claims) for and against	Identifies salient arguments	Identifies relevant arguments	Fails to identify strong relevant counterarguments	Fails to identify or hastily dismisses strong, relevant counterarguments
Alternative points of view	Thoughtful analysis and evaluation of major alternatives	Offers analysis and evaluations of obvious alternatives	Ignores or superficially evaluates obvious alternatives	Ignores or superficially evaluates obvious alternatives
Results	Justifies key results	Justifies some results	Justifies few results	Does not justify results
Procedures	Justifies key procedures	Justifies some procedures	Justifies few procedures	Does not justify procedures
Assumptions	Explains assumptions	-	-	-

Treatment of:	Strong	Acceptable	Unacceptable	Weak
Reasons	Explains reasons	Explains reasons	Seldom explains reasons	Does not explain reasons
Way of reaching conclusions	Draws warranted, judicious, non-fallacious conclusions	Draws warranted, non-fallacious conclusions	Draws unwarranted, or fallacious conclusions	Argues using fallacious or irrelevant reasons and unwarranted claims
Judiciousness	Fair-mindedly follows where evidence and reasons lead	Fair-mindedly follows where evidence and reasons lead	Regardless of evidence or reasons, maintains or defends views based on self-interest or preconceptions	Regardless of evidence or reasons, maintains or defends views based on self-interest or preconceptions. Exhibits close-mindedness or hostility to reason

5.3.4. Perry's nine-level approach

Perry evaluated student's cognitive capabilities in nine levels of increasing ability to see multiple potentially correct solutions and the degree of self-learning as opposed to seeing single correct solutions and being spoon-fed with knowledge by the instructor (Perry, 1981) where students:

- Progressed through nine-stages of critical thinking starting from viewing truth in absolute terms of right and wrong (obtained from "good" or "bad" authorities) to recognizing multiple, conflicting versions of "truth" representing legitimate alternatives; namely using the *Continuum* perspective.
- Improved the way they understood their own thinking.

5.3.5. Similarities and differences

Gordon et al. provided a way to identify the difference in cognitive skills between innovators, problem formulators, problem solvers and imitators (Gordon G. et al., 1974). The difference is based on:

Table 5.3 Factors conducive to innovation (Gordon G. et al., 1974))

Ability to find **similarities** among objects which seem to be **different**	HIGH	Problem solvers	Innovators
	LOW	Imitators/Doers	Problem Formulators
		LOW	HIGH
		Ability to find **differences** among objects which seem to be **similar**	

- Ability to find ***differences*** among objects which seem to be ***similar.***
- Ability to find ***similarities*** among objects which seem to be ***different.***

The differences in the '*ability to find …*' leads to the different type of personalities shown in Table 5.3 (Gordon G. et al., 1974). For example:

- ***Problem formulators:*** score high in ability to find differences among objects which seem to be similar, namely they are good at using the *Continuum* perspective.
- ***Problem solvers:*** score high in ability to find similarities among objects which seem to be different, namely they are good at using the *Generic* perspective.

From a slightly different perspective, Gharajedaghi discussed four personality types based on the same abilities in the context of separating the problem from the solution (Gharajedaghi, 1999: pages 116 to 117) where:

- ***Leaders and pathfinders:*** (innovators in Table 5.3) have a holistic orientation to seeing the bigger picture and putting issues in the proper perspective.
- ***Problem solvers:*** are scientifically oriented with a tendency to find similarities in things that are different. They are concerned with immediate results.
- ***Problem formulators:*** are artistically oriented having a tendency to find differences in things that are similar. They are concerned with the consequences.
- ***Doers*** are practitioners producing tangible results.

Both Gordon et al. and Gharajedaghi discuss the same abilities in the context of separating the problem from the solution, however they do not provide a way to evaluate a person's skills in those areas which overlap with the *Generic* and *Continuum* perspectives.

5.3.6. Integrating evaluation approaches

Paul and Elder, Facione and Facione, and Wolcott and Gray conflate several different aspects of critical thinking into a number of single digit levels, Perry evaluates critical thinking based on conflating the ability to see multiple solutions to problems namely the ability to use the *Continuum* perspective with the degree of self-learning ability. Using a single number for multi-dimensional attributes is not a good measurement approach. While it is simple, it conflates attributes that often need to be considered separately. For example, the traditional US Department of Defense (DOD) approach to risk management is to calculate the probability of occurrence of a risk event and the severity of the consequences of that event should it occur, multiply the two values together and deal with the risks that have the highest numbers (DOD, 1993). The consequences are that risks with low probabilities of occurrence but with high severity consequences tend to be ignored because they get low numbers. Instead if using a single number or level, we need to develop a way to evaluate each skill aspect of critical thinking separately and present the result as a set of evaluations perhaps in a manner similar to the way key performance parameters are evaluated.

5.4. Summary

This Chapter:

1. Introduced and provided an overview of critical thinking.
2. Perceived critical thinking from the perspectives perimeter in Section 5.1 and:
   - Showed how the perspectives perimeter can be used to examine critical thinking.
   - Used perceptions from the *Functional* perspective to separate out the rules for thinking from the evaluation of ideas.
3. Discussed creating and analysing arguments in Section 5.2.
4. Introduced a number of ways of evaluating critical thinking in Section 5.3.

For further information, consult the referenced works cited in the text.

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Part II
Problem-solving

6. Holistic thinking

This Chapter:

1. Summarises holistic thinking as the combination of the use of the HTPs and critical thinking (the evaluation of ideas).
2. Begins with an introduction to how to use the HTPs to store information about Case Studies and real world situations in Section 6.1.
3. Introduces Active Brainstorming in Section 6.2 as a way to increase the number of ideas generated by brainstorming using the HTPs coupled with the Kipling questions "who, what, where, when, why and how" (Kipling, 1912).
4. Introduces three problem-solving Idea Storage Templates (IST) in Section 6.3 for storing the ideas produced in the Active Brainstorming session.
5. Contains three examples of using the HTPs and ISTs in Section 6.4.
6. Contains suggestions for using the perspectives perimeter in creating innovative solutions to provide a context for the examples in Section 6.5 and those that follow in the remainder of the book.

Holistic thinking goes beyond systems thinking by not only thinking about a system as a whole but also by doing the thinking in a systemic and systematic manner embodying both types of systems thinking discussed in Section 4.1.3. It does this by perceiving issues from the perspectives perimeter using the HTPs coupled with Active Brainstorming to think in a systemic and systematic manner about a system (ideation)[1], coupled with critical thinking (ideation and idea evaluation) as shown in Figure 6.1 (*Structural* perspective) and Figure 6.2 (*Functional* perspective). The elements of holistic thinking include:

1. Making perceptions from the HTPs discussed in Section 4.3.

[1] Using the internal, external, progressive, *Quantitative* and *Scientific* perspectives from nine different viewpoints on the perspectives perimeter.

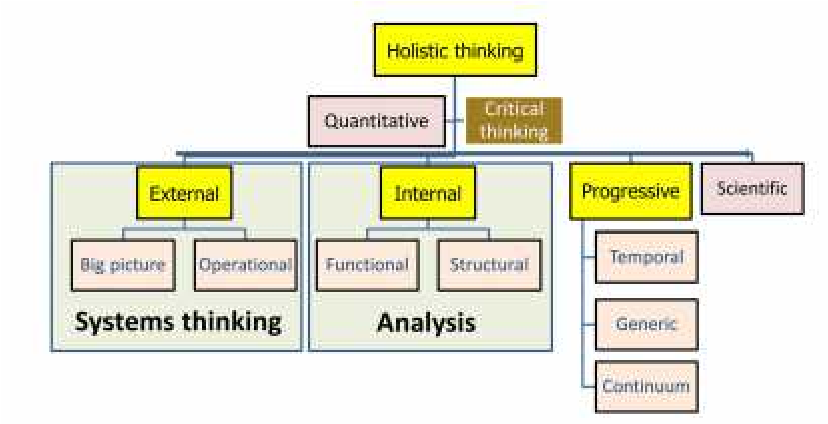

Figure 6.1 *Structural* perspective of holistic thinking

2. Documenting the information from those perceptions in the HTPs discussed in Section 6.1.
3. Triggering ideas about remedying undesirable situations, and identifying problems using Active Brainstorming discussed in Section 6.1.3.

6.1. Documenting observations using the HTPs

This Section discusses how to use the HTPs to:

1. Document Case Studies discussed in Section 6.1.1.
2. Document Organizations discussed in Section 6.1.2.
3. Store information discussed in Section 6.1.3.

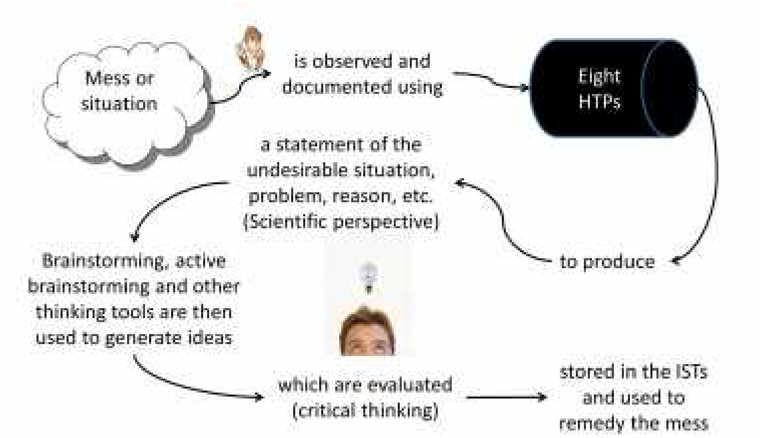

Figure 6.2 Rich Picture *Functional* perspective of holistic thinking

6.1.1. Documenting Case Studies and real-world situations

The HTPs may be used to document perceptions from the various perspectives when writing situational summaries and reports as well as working with Case Studies. For example, consider:

1. Developing Case Studies discussed in Section 6.1.1.
2. Analysing Case Studies discussed in Section 6.1.1.2.
3. Documenting real-world situations discussed in Section 6.1.3.

6.1.1.1. Developing Case Studies

McNamara provides the following five-step process for developing a Case Study (McNamara, 1999):

1. Gather data about the case.
2. Organise the data to highlight the focus of the study.
3. Develop the narrative.
4. Validate the narrative.
5. Compare the study with appropriate others to identify areas of improvement.

You can organise the data by HTP in the same way as the information about the situations described in Section 6.4 was organised. You can then extract the pertinent information for the case when developing the narrative. See Chapter 11 for examples of such narratives.

6.1.1.2. Analysing Case Studies

When analysing Case Studies, the suggested process to follow, based on Mauffette-Leenders' short process (Mauffette-Leenders, et al., 2007: pages 33 to 35)[2] is:

1. Understand the purpose of the assignment using the case.
2. Read the first and last few paragraphs of the documentation.
3. Stop and think about the 'who', 'what',' where', 'when', 'why' and 'how'.
4. Skim the rest of the material.
5. Stop and think about the relationships between items in the material.
6. Read the material in detail, extracting and storing the information in the appropriate HTP. Distinguish between the product or system and the anecdote. In general, the anecdote or timeline describing what happened belongs in the *Temporal* perspective.

[2] Note the similarity to the suggestions for how to read this book in Section 1.1 (*Generic* perspective).

7. Review the sorted material for consistency and if necessary move information to another perspective if that seems to be a more appropriate place.
8. Distinguish between fact and the author's opinion.
9. Store the facts in the descriptive perspectives and the author's opinion in the *Scientific* perspective.

6.1.1.3. Documenting real-world situations

If you are dealing with a real world situation rather than a Case Study and writing a situational analysis, use the *Generic* perspective and think of yourself as living a Case Study. The process becomes:

1. Understand the purpose of what you are doing (why you are doing it, and what outcome you hope to achieve).
2. Try to look at the big picture often called a bird's eye or helicopter view.
3. Think about the 'who', 'what',' where', 'when', 'why' and 'how' as perceived in Active Brainstorming (Section 6.2).
4. Collect pertinent material.
5. Stop and think about the relationships between items in the material.
6. Make notes, sorting and storing the information in the appropriate HTPs discussed in Section 6.1.

6.1.2. Documenting organizations

When studying an organisation either to gain an understanding of it or in response to an undesirable situation such as falling sales, or some uncertainty about launching a new product, the descriptive HTPs may be used to store perceptions about an organization from the various viewpoints and the *Scientific* perspective may be used to contain the analysis and recommendations which separates facts from opinions. For example, when observing and analysing a business, the:

- ***Big Picture perspective:*** is the place to store information about the mission, strategy and goal of the business, the industry, products, competitors, partners, country, etc.
- ***Operational perspective:*** is the place to store information about the way the business interacts with customers and suppliers. For example, scenarios describing how sales take place and how raw material is ordered and received.
- ***Functional perspective:*** is the place to store information about what the business does and how it does it. Some of this information is often in the form of process descriptions. For example

in purchasing, a low inventory triggers a purchase request which initiates a purchasing process.

- ***Structural perspective:*** is the place to store information about how the business is organised. This information tends to show up in hierarchical organisation charts.
- ***Generic perspective:*** is the place to store information about how the business compares with similar organizations.
- ***Continuum perspective:*** is the place to store information about:
  - How the organization differs from similar organisations
  - Alternatives to customers, suppliers and potential markets etc.
- ***Temporal perspective:*** is the place to store information about the past, present and future of the business.
- ***Quantitative perspective:*** is the place to store numeric and other quantitative information associated with the business. For example, number of employees, sales, profits, and other financial information.
- ***Scientific perspective:*** is the place to store the hypothesis for (the reason), or cause of, the symptoms that generated the study and recommendations for further action.

6.1.3. Storing the information

Looking at it from another perspective, in general, with respect to the system or situation, descriptions of:

- ***"Who …"*** belong in the:
  - *Operational* perspective if pertinent to who is performing in a scenario, vignette or use case.
  - *Big Picture* perspective if pertinent to an adjacent system or systems.
- ***"What …"*** belong in the:
  - *Big Picture* perspective if it is pertinent to the purpose of the system.
  - *Operational* perspective if pertinent to a scenario, vignette or use case.
  - *Structural* perspective if pertinent to a physical element of the situation.
- ***"Where …"*** belong in the *Big Picture* perspective or the *Structural* perspective.
- ***"When …"*** belong in the:

  - *Operational* perspective if pertinent to a scenario, vignette or use case.
  - *Temporal* perspective if pertinent to the timeline in the anecdote leading up to the situation.
- ***"Why …"*** belong in the *Big Picture* perspective but can be used as explanations in the other descriptive perspectives or as inferences in the *Scientific* perspective.
- ***"How …"*** belong in the:
  - *Functional* perspective or the *Structural* perspective (how it works).
  - *Operational* perspective (how it is used).

In addition if the system went through different states and there were major differences in its attributes in the different states as time passed, then you'll need a different set of HTPs for each state.

For more examples of the use of the HTPs in this manner see:

- Section 6.4.1 for an example of using the elements of holistic thinking in the design of the LuZ SEGS-1 system.
- Section 6.4.2 for an example of designing an Unmanned Aerial Vehicle (UAV) and as a generic template for perceiving a system.
- Section 6.4.3 for a view of the Royal Air Force (RAF) Battle of Britain Air Defence System (RAFBADS).
- Section 5.1.3.2 for an example of perceiving critical thinking.

6.2. Active Brainstorming

Active Brainstorming:

- Is one way of increasing the number of ideas produced in brainstorming.
- Sessions are organised in the same way as brainstorming sessions discussed in Session 2.6.2.
- Should only be used after the initial flow of ideas from brainstorming dry up.
- Produces additional ideas relating to the problem or issue in a systemic and systematic manner. Table 6.1 contains data from seven teams in the first postgraduate classroom brainstorming/Active Brainstorming exercise showing the increase in the number of ideas. Later exercises provided similar results[3].

[3] The actual number depended on how well the students understood the concept of Active Brainstorming. The 'to many to count' is probably 'too lazy to count'

Table 6.1 Improvement in number of ideas generated

Team	Total number of ideas after Brainstorming	Total number of ideas after Active Brainstorming	Improvement (%)
1	20	40	100
2	9	89	889
3	22	66	200
4	31	64	106
5	39	79	103
6	28	89	218
7	20	"Too many to count"	Large

- Achieves these increases in the number of ideas generated by examining the issue from each of the HTPs and triggering ideas by asking the Kipling questions "who, what, where, when, why and how" (Kipling, 1912) in a systemic and systematic manner.

6.2.1. Using Active Brainstorming

Before the session begins, identify who needs to be present, invite them with a reason for them to attend and tell them what issue or problem the session will be discussing to give them time to think up ideas before attending.

When the session begins, there will be a natural tendency to generate spontaneous ideas in an unstructured brainstorming manner, particularly in a session containing newcomers to the technique. The ideas will include answers, further questions, names of people to contact for more information, and the need for further analysis. The facilitator should:

- Not attempt to stem the flow of ideas and ask the participants to wait for the appropriate question[4].
- Just make sure the ideas are recorded in whatever media is being used for the purpose (white board, flip charts, mind mapping software etc.)

Once the initial flow of ideas stops, the facilitator starts the true Active Brainstorming process using the Active Brainstorming idea-triggering template shown in Table 6.2 to perceive the situation from the perspectives perimeter starting by posing questions from the *Big Picture* perspective. The initial cues for the Active Brainstorming questions can come from the ideas generated from the regular brainstorming session

[4] Which is one reason the ideas are not documented in the idea triggering template shown in Table 6.2.

Table 6.2 Active Brainstorming idea triggering template

	Who?	What?	Where?	When?	Why?	How?
Big Picture						
Operational						
Functional						
Structural						
Generic						
Continuum						
Temporal						
Quantitative						
Scientific						

performed just prior to the commencing the Active Brainstorming session. For example, if one of the ideas produced by regular brainstorming was 'she plays the flute', then Active Brainstorming can focus on that idea and expand it beginning with questions such as:

- Why is she playing the flute?
- Who is she playing with?
- Where is she playing it?

Store the ideas in the same place that the initial flow of ideas are stored. Do not store the responses in the Active Brainstorming idea triggering template shown in Table 6.2 during the session since doing so tends to divert the session into a discussion (dispute) as to the area in which to store the idea, and interferes with the flow of ideas.

After posing a question, when the ideas stop flowing, the facilitator moves on to pose the next question in the row. The second row should often be the *Operational* perspective. It often helps to draw a flow chart of the scenarios or a similar concept map (Section 2.5) when starting the questioning sequence for the *Operational* perspective to provide a focus for questioning.

At the end of the flow of ideas from the last question in a row, the facilitator moves down to the first column in the subsequent row. Expect a question posed one area of Table 6.2 to sometimes generate ideas that pertain to other areas. If no ideas come forth immediately, and sometimes they don't because not all areas are pertinent to every issue, the facilitator should skip to the next question or even the next row or column. Examples of typical questions posed from the HTPs are provided below in Section 6.2.2. The facilitator should ensure that the discussions triggered by each question are terminated when the flow dries up or starts generating redundant ideas.

6.2.2. Typical Active Brainstorming questions

The following questions based on laws of association (Section 2.6.2) are intended as a starting point for you to add your own follow-on thoughts and questions. The list is not intended to be complete and not all questions may be appropriate to specific situations. In addition, the questions posed in lateral thinking (Section 2.6.5) can also be used in Active Brainstorming.

6.2.2.1. Typical questions from the Big Picture perspective

1. What is the purpose of the…?
2. Why this system is there in the first place?
3. Why is it performing these activities?
4. What problem is this system remedying?
5. Where is this system in the context of things?
6. What is this next to?
7. Why is this next to...?
8. What are the assumptions underlying the system?

6.2.2.2. Typical questions from the Operational perspective

9. What are the operational scenarios? (Open system view).
10. Who is going to operate/administer it?
11. What do they need to operate/administer it?
12. Under what conditions will it be operated/administer?
13. Where will they operate/administer it?
14. When will they operate/administer it? (Redundant to *Temporal* perspective).
15. Why will they operate/administer it?
16. How will they operate/administer it?
17. How will they gain access to it?

6.2.2.3. Typical questions from the Functional perspective

18. What activities does/will it perform? (Closed system view).
19. How does it perform those activities?

6.2.2.4. Typical questions from the Structural perspective

20. What parts does it have?
21. What are they interchangeable with?
22. What can the parts be replaced with?

6.2.2.5. Typical questions from the Generic perspective

23. What does this remind you of?
24. What functions does this system inherit from its class of systems?

Table 6.3 Attribute mapped to HTP

Change	HTP
Cheaper	*Quantitative*
Stronger	*Structural*
Easier to use	*Operational*
Lighter	*Structural*
Safer	*Operational, Functional* and *Structural*

25. What does it have in common with...?
26. Who has had a similar problem?
27. What is this similar to?
28. What applies to both situations?
29. Where can I find a similar situation?
30. When was there a similar situation?
31. When will there be a similar situation?
32. Why is this similar?
33. How is this similar?

6.2.2.6. *Typical questions from the Continuum perspective*

34. What is an alternative way of…?
35. What is the opposite of?
36. Why is this different?
37. How is this different?
38. In what way can we change … – it depends, see Table 6.3.
39. Should we try to change … – it depends, see Table 6.3.
40. How could we reduce the…?
41. How could we increase the…?
42. What happens if … breaks or fails?

6.2.2.7. *Typical questions from the Temporal perspective*

43. What happens before, after, at the same time?
44. What part of the … limits the useable lifetime?

6.2.2.8. *Typical questions from the Quantitative perspective*

45. How well does it work?
46. Why is this larger/smaller than…?
47. What is the cost of…?
48. How can this be made cheaper?
49. What part is the most expensive and why?
50. How much money do we have to spend?

6.2.2.9. *Typical questions from the Scientific perspective*

51. What could we use…?

52. What kind of vehicle could we use to…?
53. How will you know when the problem no longer exists or is remedied?

More examples of questions can be found in the:

- Description of the Luz SEGS-1 system in Section 6.4.1.
- Example addressing the problem of vertically integrating Small and Medium Enterprises (SME) in Taiwan in Section 11.4.

6.2.3. Key questions

As you gain experience in holistic thinking and Active Brainstorming, you will learn which type of questions from the areas provide the pertinent insight to the various types of issues being discussed and focus on those areas. These questions are known as key questions. The answers to the key questions provide the pertinent information and insight to achieve the goal such as defining the correct problem and identifying the correct feasible solution. Key questions will depend on the situation.

6.2.4. Questions to focus on problems and situations

You can frame questions to focus on problems and situations with the appropriate wording (Ruggiero, 2012: page 129). For example:

- "How can …?" tend to lead to problems.
- "Is …?", "Does …?" or "Should …?" tend to lead to situations.

6.3. Idea Storage Templates

This Section presents templates for organizing and storing the ideas generated in the Active Brainstorming sessions performed to examine situations and issues to identify undesirable situations, problems and solutions. The section begins with an overview of the Strengths, Weaknesses, Opportunities, and Threats (SWOT) template (Learned, et al., 1969), a well-known Idea Storage Template (IST) in the business domain and then introduces three new ISTs for use in problem-solving.

6.3.1. The SWOT idea storage template

SWOT is a:

- Planning tool used to help think about a project or product (Learned, et al., 1969).
- Piece of paper or whiteboard divided into four areas corresponding to the letters in the acronym SWOT used as a blackboard-style multiple-access working memory (Nii, 1986) as

Table 6.4 SWOT idea storage template

Strengths	Weaknesses
Opportunities	Threats

shown in Table 6.4. For example, in marketing, a SWOT analysis of a product would be used to consider:

- ***Strengths:*** characteristics of the product that gives it an advantage over similar products.
- ***Weaknesses (or Limitations):*** characteristics of the product that places it at a disadvantage relative to other products.
- ***Opportunities:*** things to take advantage of, to improve performance or sales of the product.
- ***Threats:*** things that could cause trouble or problems for the product.

The SWOT thinking process focuses on each area of the SWOT in turn. Typical questions asked in a SWOT analysis might start with the questions:

- What are …?
- Why are …?
- Where …?

From the *Generic-Continuum* perspectives[5], SWOT is a type of Active Brainstorming from just four perspectives. However, unlike Active Brainstorming, where the ideas are sorted after the session, in a SWOT analysis, the ideas are generally stored in the appropriate area as they are generated because the answers to the questions lie in the same areas as the questions.

6.3.2. Three new idea storage templates

This Section introduces the following three blackboard-style, multiple person access, parallel working memory, problem and remedy ISTs for storing the ideas generated by brainstorming and Active Brainstorming and used as shown in Figure 6.3:

1. ***OARP:*** for ideas or concepts pertaining to the problem.

---

[5] Perceptions from the *Generic* perspective perceive the process as being similar to Active Brainstorming; perceptions from *Continuum* perspective recognizes the four different viewpoints are different to those in the HTPs. SWOT are characteristics of the perspective, for example, at the strategic level, SWOT is used within the *Big Picture* perspective. SWOT can also be used in the other perspectives.

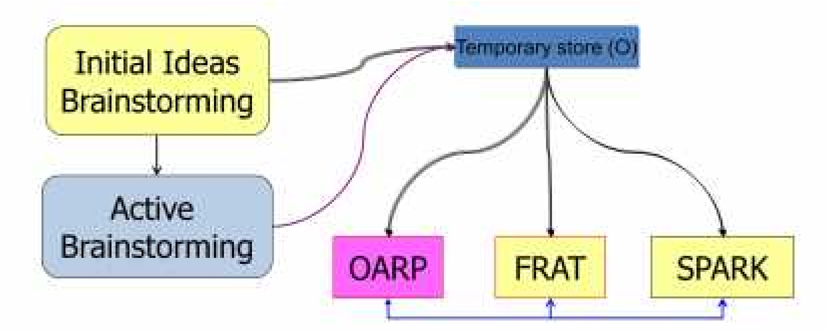

Figure 6.3 Relationship between OARP, FRAT and SPARK

2. ***FRAT:*** for ideas or concepts pertaining to the solution (product).
3. ***SPARK:*** for ideas or concepts pertaining to implementing the solution (process).

6.3.2.1. OARP

Observations, Assumptions Risks and Problems (OARP) is a four-area template for storing ideas related to the underlying cause or real problem consisting of:

1. ***Observations:*** ideas concerning perceptions relating to the need, problem and symptoms. This part of the template:
   - Helps to develop understanding of a situation by containing questions, answers, analyses and other relevant information.
   - May also contain analyses of ideas.
   - Begins as the initial repository of ideas from the brainstorming and Active Brainstorming sessions.
   - Ends up as the repository for the left over ideas that remain after moving the other ideas into the other areas of the three ISTs.
2. ***Assumptions:*** the assumptions implicit in the thinking. A critical area, since undocumented assumptions may be incorrect and may cause the wrong solution to be realized.
3. ***Risks:*** ideas about reasons the activity to remedy the problem could fail. During the discussion of the problem, there are bound to be ideas or concepts generated that incorporate solutions since we often use solution language instead of problem language, namely we say, "we need a car" when we should be saying, "we need transportation". By identifying risks associated with realizing the car solution we can more readily identify solu-

tion related concepts and transform them to problem related concepts and focus on the underlying cause or real problem.

- ***Real Problem:*** ideas concerning the cause or problem. The ideas from this part of the template often eventually produce a clear and concise statement of what has to be done to change the situation. The problem statement is generally developed after considerable discussion.

6.3.2.2. FRAT

Functions Requirements Answers and Test (FRAT)[6] is a four-area template based on the FRAT views of a system (Mar, 1994; Mar and Morais, 2002). However, in this instance FRAT has been adapted as an IST to store:

1. ***Functions:*** ideas concerning the normal and contingency mode mission and support functions or activities the solution system performs or needs to perform (mainly ideas from the *Functional* perspective).
2. ***Requirements:*** ideas concerning how well each function must be performed (Mar, 1994) (mainly ideas from the *Quantitative* perspective)[7].
3. ***Answers:***[8] ideas concerning (feasible and non-feasible[9]) candidate answers or solutions.
4. ***Tests:*** ideas:
    - Concerning the selection criteria for evaluating or selecting the answers or solutions.
    - Pertaining to how and what will be done to determine how well the answers or solutions perform the needed functions.

---

[6] The late Brian Mar seems to have had a sense of humour. Perceive the acronym from the *Continuum* perspective and transpose the letters R and A.

[7] Some systems and software engineers equate requirements with needs. These persons are working in the 'B' paradigm. The systems engineers who use requirements to quantify functions are working in the 'A' paradigm (Kasser, 2012).

[8] The word "answer" is used instead of "solution" in the template because (1) it keeps the original Mar acronym and (2) it prevents confusion because the "S" character is used in the SPARK template for schedules rather than solutions.

[9] Non-feasible ideas may also be generated during brainstorming and Active Brainstorming. There ideas need to be stored until they can be processed. None-feasible ideas may be useful as goals as triggers for alternatives.

6.3.2.3. SPARK

Schedules, Products, Activities, Resources and risKs (SPARK) is a five-area template for containing ideas pertaining to the implementation of the answer or solution namely information used in project management, where:

1. ***Schedules:*** ideas concerning the time to be taken by the activities.
2. ***Products:*** ideas concerning the products to be produced.
3. ***Activities:*** ideas concerning the activities which produce the products.
4. ***Resources:*** ideas concerning resources used in or by the activities to produce the products
5. ***risKs:*** ideas concerning anything that could prevent, delay, or increase the costs of, the production of the products. These ideas may be product or process related.

6.3.2.4. Discussion

The three ISTs are temporary or working memories used to store and share information between people working on an issue. The ideas are to be used in the later activities that realize the solution. At the time the issue is being examined, the focus will be on filling in OARP. However, during this process, ideas pertaining to the solution and its implementation will be generated and discussed and stored in FRAT and SPARK. Some of these ideas will reflect on the feasibility of answers or on the understanding of the underlying real problem.

During each phase of the solution system realization process often called the System Development Process (SDP), various tools are used to generate ideas and information depending on the domain and the problem being faced. OARP, FRAT and SPARK can provide temporary storage of those ideas which are then used to realize the solution system.

6.4. HTPs and ISTs

The key to success in applying the HTPs is the domain knowledge also known as subject matter expertise either present in the team or acquired when researching the answers to the questions posed in the Active Brainstorming sessions. This Section provides the following three examples of the use of Active Brainstorming, the HTPs, ISTs and identifying key questions:

1. The Luz SEGS-1 solar array control and electronics system in Section 6.4.1.

Figure 6.4 Part of the LuZ SEGS-1 Solar Array

2. Designing an Unmanned Aerial Vehicle (UAV) in Section 6.4.2.
3. The Royal Air Force Battle of Britain Air Defence System (RAFBADS) in Section 6.4.3.

Chapter 11 contains additional examples.

6.4.1. Luz SEGS-1 solar array control and electronics system

This Section uses the Luz SEGS-1 project to provide an example of sorting information about a system into the HTPs, identifying an undesirable situation, using Active Brainstorming to remedy the situation (design the system), the key questions in Active Brainstorming and the use of the ISTs to store the ideas generated in the Active Brainstorming session.

The LuZ Group, a start-up joint Israel-American venture defined, designed, developed, installed and operated the world's first commercial Solar Electrical Generating System (SEGS)-1 in 1981-1983 (Kasser, 1984). At the design time, as the first of a kind, SEGS-1 initially only existed as a concept. A photograph of part of the system during its construction is shown in Figure 6.4.

Perceive the solar array Control and Electronics System (CES) from the HTPs at system design time.

6.4.1.1. The Big Picture perspective

Perceptions from the *Big Picture* perspective include:

- SEGS-1 is the containing or Metasystem.

- The system under consideration/discussion is limited to the CES for the array of solar collectors within SEGS-1.
- The CES is a system in itself, and at the same time is a subsystem of SEGS-1.
- The oil pumping and heat transfer elements of the solar field, and the array of mirrors, are outside the CES. They interface to the CES electronically via the oil temperature sensors and mechanically via the motors.
- The solar collection array of mirrors is to be located in an area the size of a football field.
- There is an adjacent totally decoupled system, an experimental heliostat solar power-generating field which may at sometimes provide a false sun via the reflection from the central tower and the Local Controllers (LOCs) may lock on to it and fail to follow the sun.
- There is no space in the development facility to build and test a large array of LOCs prior to deployment half way around the world. The design and test programs will have to compensate for this constraint.

6.4.1.2. The Operational perspective

Perceptions from the *Operational* perspective include:

- The CES operates automatically daily, seven days a week, as long as there is no major cloud cover.
- Manual operation takes place in certain scenarios.
- While SEGS-1 can be maintained after hours, it is undesirable (extra operating cost), and the identification and replacement of a failed component should be quick.
- It is desirable that the CES be able to predict failing vacuums in the heat flow elements containing the oil pipes so that replacements could be scheduled proactively.

6.4.1.3. The Functional perspective

Perceptions from the *Functional* perspective include:

- The mirrors deploy to track the sun in the morning as soon as the sun is high enough to generate positive power, track the sun during the day and stow in the evening.
- The CES performs or initiates the following functions:
    - ***Resting or stowed:*** the mirrors are at rest in an upside down position. This minimises dirt collection and wind-

Table 6.5 Transitions between LOC states

Resting	X (Cmd.)				
	Deploying	X (Auto)		X (Cmd.)	X (Cmd.)
		Tracking	X (Auto)	X (Cmd.)	X (Cmd.)
	X (Cmd.)	X (Auto)	Idling	X (Auto)	X (Cmd.)
	X (Cmd.)			Waiting	X (Cmd.)
X (Auto)					Stowing

born sand abrasion of their surfaces which reduce the reflection coefficient and hence the efficiency of the system. Since the mirrors also act as radiators when not acting as heaters, stowing the mirror minimises heat loss to outer space.

- ***Deploying:*** the mirrors are moving up from the stowed position to begin to track (follow) the sun.
- ***Tracking:*** the mirrors follow the sun across the sky keeping the oil pipe at the focus, allowing the sun to heat the oil.
- ***Stowing:*** the mirrors are returning to the stow position at the end of the day.
- ***Manually commanded movement:*** the mirrors are moving as commanded by the operator.
- ***Idle:*** the mirrors are stationary.
- ***Data collection, storage and reporting:*** the system generates, stores and reports information about the positions of the mirrors, and temperatures of the oil at their foci.

Transitions between the states take place manually or automatically as shown in the N^2 chart in Table 6.5. In this instance of the N^2 chart, the link between the input and output contains the information about how the change of state is triggered.

6.4.1.4. The Structural perspective

Perceptions from the *Structural* perspective include:

- Each and every mirror can only move in one axis – elevation.
- The azimuth is fixed approximately north-south.
- The oil pipe is inside a glass tube assemble called a heat flow element. The air in the heat flow element has been pumped out of the glass tube after assembly to leave a vacuum to cut down on conducted heat loss.

- Even though there are about six hundred LOCs, since each LOC will be identical to the others, there are really only four subsystems. These are:

    1) The Central Station.
    2) The LOCs.
    3) The interconnecting command and control network between the Central Station and the LOCs.
    4) The power distribution system.

6.4.1.5. The Generic perspective

Perceptions from the *Generic* perspective include the following insights[10]:

- The CES architecture is similar to a constellation of Low Earth Orbiting (LEO) satellites and a control station. This allows spacecraft Telemetry Tracking and Control (TT&C) techniques to be considered as design options.
- The mirror positioning function is similar to a satellite ground station positioning function.
- Short duration loss of insolation due to intermittent clouds is similar to the loss of synchronizing pulses in an analogue television (TV) signal, so a flywheel technique could be employed to compensate.
- The CES will perform similar functions to the equivalent CES of the adjacent experimental heliostat solar power-generating field so we need to learn from their experiences[11].

6.4.1.6. The Continuum perspective

Perceptions from the *Continuum* perspective include the following insight:

- There are at least three design choices positioned in different points of the system solution implementation continuum discussed in Section 4.3.2.6.2.2 including:

    - At one end of the continuum, a smart Central Station manages the entire array as well as collecting and storing information about the CES.
    - At the other end of the continuum, a dumb Central Station collects and stores information about the system while the LOCs perform the mirror management functions.

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[10] Note how the first three insights require knowledge from other domains.

[11] This is the principle that someone has faced the problem before and we can learn from their experiences.

  - Somewhere along the continuum namely a mixture of the previous two options.

6.4.1.7. The Temporal perspective

Perceptions from the *Temporal* perspective indicate:

- This is the first system of its kind.
- We do not know everything about how the system will be operated.
- Our design is based on assumptions.
- We will learn more about how the operators actually use the controls as time goes by. This information should be used to upgrade the Central Station software.
- The efficiency of SEGS-1 is expected to reduce over time due to physical effects in subsystems adjacent to the CES (such as loss of vacuum in the heat flow elements).

6.4.1.8. The Quantitative perspective

Perceptions from the *Qualitative* perspective raise the following issues.

- Feasibility study calculations have shown that each 40 Meter long mirror must be pointed at the sun with an accuracy of ±0.2 degrees.
- The CES uses alternating current electrical power to move the mirrors and power the LOCs. To be practical, SEGS-1 must put more power into the electrical power grid than it takes out.
- The more power it can produce, the greater the revenue to the investors who will own SEGS-1.

6.4.1.9. The Scientific perspective

This perspective is where the design options are stored. Decisions to be made included:

- Deciding between the alternative minicomputer- or microcomputer-based candidate solutions for the Central Station.
- Deciding on the number of mirrors controlled by a single LOC.
- Deciding on the electrical power distribution voltage (110V, 220V, or 440V).
- Deciding on the type of mirror position sensor (relative, absolute, analogue or digital).

The early state control system engineering had developed a common vision of the system based on a Central Station minicomputer containing all the intelligence in the system and dumb LOCs interfacing the minicomputer to the mirror assembly. Communications would be by the then new high-speed communications technology known as Ethernet. This concept created several undesirable situations including:

- ***Lack of experience:*** there was minimal experience in using minicomputers and Ethernet in the team. This put the minicomputer solution in the high-risk category.
- ***Cost:*** minicomputers were expensive. One system would cost at least $300,000 for the basic hardware and software. At least three Central Station systems would be required[12], an operational unit and a spare on site in case of a failure as well as a software maintenance development unit. LuZ was a start-up company and cash-strapped.
- ***Mirror control:*** the Central Station would have to perform a loop repeating the command and control algorithm for each mirror; monitoring the position of the mirror and temperature of the oil in the pipes, and moving the mirror to keep the sun in the focus position. This would be complex, and the design would have to be validated by estimating the software cycle time for each mirror control loop based on an estimate of the number of instructions. The complete loop plus all the other computations associated with the loop (such as communications) would have to be performed in less time than it would take the sun to move 0.1 degrees.

Had active brainstorming been used in this situation, the facilitator would pose questions during the Active Brainstorming session and ensure that the resulting ideas in the answers were written on the whiteboard. The facilitator should also note the questions for future use. Once the session had ended the information could be stored as shown in Table 6.6. After the ideas are examined and stored they would be moved to the appropriate IST. A few of the questions and responses that were posed as if the questions had been posed during an Active Brainstorming session in the design process are shown in in Table 6.6.

Note the empty areas in Table 6.7, Table 6.8 and Table 6.9 have been labelled with the word 'None' to both:

- Record that no ideas ended up in those areas.
- Verify that the ideas in those areas were not lost in the transfer process.

[12] If the spare was deemed unaffordable, then the downtime would have to be accepted with the consensus of the customer and an appropriate on-site maintenance contract with the vendor or manufacturer be put into place for the operational unit.

Table 6.6 Extract from summary of typical Active Brainstorming session idea processing idea archive

HTP	Question	Answer	To be stored in IST	
Operational	What initiates the deployment?	Manual and automatic	A	FRAT
Big Picture	What can inhibit energy production?	Clouds, rain, dirt on mirrors, loss of vacuum in heat flow elements	O	OARP
Big Picture	What is the electromagnetic interference situation?	Don't know. It is a large field with long cables.	R	OARP
		Use shielded cables and bury them in the ground. Track as a risk.	A	FRAT
Functional	What functions are the LOCs performing?	Deploying, tracking, stowing, idle and resting.	A	FRAT
Functional	What stops the system locking onto the neighbouring Heliostat tower instead of the sun?	Functionality to calculate the position of sun at that time of the day, compare it with the actual pointing angle of the mirrors and make sure they are within ±0.2 degrees?	R	FRAT
			R	OARP
Structural	What are the conceptual subsystems?	LOCs, central processor, power distribution units	A	FRAT
Generic	***What is this similar to?*** [KEY QUESTION]	(1) A constellation of satellites and their central control station. (2) The neighbouring Heliostat system which could provide ideas for control displays	A	FRAT
		Action item: arrange visit to Heliostat control centre.	A	SPARK
Continuum	What are the alter-	Central processing -	A	FRAT

HTP	**Question**	**Answer**	**To be stored in IST**	
	native conceptual solutions?	minicomputer and dumb LOCs, distributed processing - microcomputer and intelligence in the LOCs.		
Temporal	When does it need to operate?	Daily when the sun shines.	A	FRAT
Temporal	When does it have to be installed?	In two years	S	SPARK
Quantitative	How accurate must the mirror pointing be?	±0.2 degrees (based on prior calculations)	A	FRAT
Quantitative	What is the spec on the vibration of the mirror, given the sun sensor has to be mounted on it (track ±0.2 degrees)?	Don't know, track as a risk.	R	OARP
Quantitative	***How fast do things happen?*** [KEY QUESTION]	Not very, the mirror moves very slowly, as does the oil.	R	OARP

The ideas[13] stored in:

- ***SPARK*** are shown in Table 6.7 Note that the only two relevant ideas ended up in the S area.
- ***OARP*** are shown in Table 6.8. Note that none of the ideas ended up in the A or P areas.
- ***FRAT*** are shown in Table 6.9. Note that none of the ideas ended up in the R or T areas.

The key questions

The two key questions that contributed to the success of the project were from the progressive perspectives beyond systems thinking, namely:

1. "What is this system similar to? (*Generic* perspective) discussed in Section 6.4.1.9.1.

[13] Although the questions have been copied in the example tables, they do not have to be in a real world session. The focus is on the ideas.

Table 6.7 Ideas moved to SPARK

Area	Question	Answer
S	When does it have to be installed?	In two years
	What is this similar to? [KEY QUESTION]	Action item: arrange visit to Heliostat control centre.
P	None	None
A	None	None
R	None	None
K	None	None

Table 6.8 Ideas moved to OARP

Area	Question	Answer
O	What can inhibit energy production?	Clouds, rain, dirt on mirrors, loss of vacuum in heat flow elements
A	None	None
R	What is the electromagnetic interference situation?	Don't know. It is a large field with long cables. Track as a risk.
		Use shielded cables and bury them in the ground. Track as a risk.
	What stops the system locking onto the neighbouring Heliostat tower instead of the sun?	Functionality to calculate the position of sun at that time of the day, compare it with the actual pointing angle of the mirrors and make sure they are within ±0.2 degrees?
	What is the spec on the vibration of the mirror, given the sun sensor has to be mounted on it (track ±0.2 degrees)?	Don't know, track as a risk.
	How fast do things happen? [KEY QUESTION]	Not very, the mirror moves very slowly, as does the oil.
P	None	None

2. "How fast do things happen?" (*Quantitative* perspective) discussed in Section 6.4.1.9.2.

Table 6.9 Ideas moved to FRAT

Area	Question	Answer
F	None	None
R	None	None
A	What initiates the deployment?	Manual and automatic
	What is the electromagnetic interference situation?	Don't know. Use shielded cables and bury them in the ground. Track as a risk.
	What functions are the LOCs performing?	Deploying, tracking, stowing, idle and resting.
	What stops the system locking onto the neighbouring Heliostat tower instead of the sun?	Functionality to calculate the position of sun at that time of the day, compare it with the actual pointing angle of the mirrors and make sure they are within ±0.2 degrees?
	What are the conceptual subsystems?	LOCs, central processor, power distribution units
	What is this similar to? [KEY QUESTION]	(1) A constellation of satellites and their central control station. (2) The neighbouring Heliostat system which could provide ideas for control displays
		Action item: arrange visit to Heliostat control centre.
	What are the alternative conceptual solutions?	Central processing - minicomputer and dumb LOCs, distributed processing - microcomputer and intelligence in the LOCs.
	When does it need to operate?	Daily when the sun shines.
	How accurate must the mirror pointing be?	±0.2 degrees (based on prior calculations)
T	None	None

6.4.1.9.1. What is this system similar to?

The first key question came from an insight from the *Generic* perspective and was, "*what is this system similar to?"* The out-of-the-box answer was 'a constellation of Low Earth Orbiting (LEO) satellites!' The similarity was based on the *Structural* perspective; the "architecture" being similar to a central command station handling a network of remote satellite units via command and control links. Each remote unit would perform its own on-board station keeping (positioning and telemetry generation).

The insight gained from the key question resulted in an object-oriented approach using a self-regulating or homeostatic LOC (Section 7.4.2). The intelligence was shared between the Central Station and the LOC such that:

- The Central Station computed the mirror-pointing angle.
- The Central Station commanded the LOCs to deploy their mirrors to just below the calculated sun angle.
- The LOC deployed their mirrors, acquired and tracked the sun.
- The LOC sent back status information to the Central Station.
- The Central Station performed the operator interface functions.
- The Central Station software was designed to be implemented in sequential releases using the cataract approach (Kasser, 2002a) to advance along the system implementation continuum (Section 4.3.2.6.2.2), where the first release contained the:
  - System architecture.
  - Operator interface.
  - Manual control functions.

  Successive software Builds or iterations were designed to move the system off the manual end of the continuum slowly adding automation as we learnt more about how the operators interacted with the system.

6.4.1.9.2. How fast do things happen?

The second key question came from an insight from the *Quantitative* perspective and was, "*how fast do things happen*?" The answer was not very fast. The massive mirrors deployed slowly, the oil heated slowly, so there was no need for a requirement for high-speed command and control links between the Central Station and the LOCs. This insight eliminated the need for the risky Ethernet and allowed the use of a low cost 1200 Baud American Standard Code for Information Interchange (ASCII) asynchronous polled communications protocol using shielded twisted pair cables.

6.4.1.10. The innovative approach

The innovative approach considerably reduced the development and financial risks and allowed the Central Station to be downsized to a $2,000 Z-80 based 8-bit S-100 bus microcomputer. As a consequence, not only was the hardware cost reduced by $900,000, the control system for the solar field was installed within budget and schedule.

6.4.2. Designing an unmanned aerial vehicle

This Section is an example of the use of the HTPs to develop the initial set of necessary functions and properties for the design of the Mark 1 Unmanned Aerial Vehicle (UAV). The approach can also be used as a template when thinking about the design of any type of system.

6.4.2.1. The Big Picture perspective

Perceptions from this perspective include:

- The purposes for which the Mark 1 will be developed and deployed.
- The assumptions.
- The context or containing system in which the Mark 1 is being used. Examples are the specific environment (desert, arctic, littoral, tropical rain forest, etc.), military organization, unit designations, locations, and units supported by the information gathered by the Mark 1.

6.4.2.2. The Operational perspective

This perspective is the black box view. Perceptions from this perspective include:

- The normal and contingency mission scenarios. Examples include specific types of photoreconnaissance missions, search and rescue missions, and specific search and destroy missions, etc.
- The normal and contingency support scenarios to be performed by and on the Mark 1. Examples include refuelling, maintenance, damage repair, etc.

6.4.2.3. The Generic perspective

Perceived from the *Generic* perspective, any system is an instance of a class or type of system. Thus the Mark 1 is an instance of a class of systems known as UAVs, which are in turn an instance of a class of systems known as powered aerial vehicles. Consequently the Mark 1 can potentially inherit all the functions and properties of generic UAVs and powered aerial vehicles.

6.4.2.4. The Functional perspective

This perspective is the closed system or white box view. Perceptions from this perspective include:

- The specific, or sub-set, of the internal functions performed by the Mark 1. These can be inherited from the full generic set of functions of a UAV. Examples are navigation, transmitting a radio signal, receiving commands from the ground, etc.
- The relationships between these functions.

6.4.2.5. The Structural perspective

Perceptions from this perspective include details of the physical structure or architecture of the Mark 1. Examples are fuselage, wings, engine, etc. The physical assembly diagrams come from this perspective.

6.4.2.6. The Quantitative perspective

Perceptions from this perspective include quantitative numbers associated with the *Operational* and *Functional* perspectives such as reliability, costs, etc. Examples are the maximum weight of the vehicle, minimum and maximum time aloft, maximum amount of payload, the range of operating and storage temperatures, vibration specifications, mean time between failures, Mean Time To Repair (MTTR), etc.

6.4.2.7. The Temporal perspective

Perceptions from this perspective indicate that the missions may change; parts may wear out and need to be replaced (reliability and maintainability). These ideas contribute to the mission and support functions of the UAV. For example, the UAV will use the Federated Aerospace F-1000 jet engine. The engine contains a lift bearing that freezes after about 16 hours of operation but is also ten times lighter than any alternative. This temporal information will be used when designing the mission and support scenarios to determine the maintenance policy for the F-1000 lift bearing.

6.4.2.8. The Continuum perspective

Perceptions from this perspective:

- Indicate that there may be more than one way to perform a specific mission and leads to the concept of developing several operational scenarios.
- Lead to the consideration of how specific partial failures might affect the structural design and operational performance of the UAV.
- Provide the insight used in the contingency planning associated with the mission and support scenarios in the *Operational* perspective.

6.4.2.9. The Scientific perspective

This perspective includes:

- The actual design of the Mark 1. This is because until the UAV has actually flown and successfully performed its mission, the UAV is a conceptual or hypothetical solution to a problem.
- Hypothesizing the effect of failures and other contingencies generated by perceptions from the *Continuum* perspective when developing the mission and support scenarios in the *Operational* perspective.
- Hypothesizing effects of the failures in the physical structure when performing failure and risk analyses.

6.4.2.10. Comments

Going beyond systems thinking, holistic thinking could provide the generic functions and properties that the UAV would inherit from its class of systems. The domain knowledge relating to the UAV and the specific missions it would be performing in the specific environment would be a critical element in designing or otherwise acquiring an acceptable UAV for the problem. This comment applies to any type of design problem, just replace the UAV knowledge with the knowledge of the system you have to design and start brainstorming and Active Brainstorming the design issues.

6.4.3. The Royal Air Force Battle of Britain Air Defence System

As an example of a different use of the HTPs in system analysis at various points in the design process, consider the Royal Air Force (RAF) Battle of Britain Air Defence System (RAFBADS) that was used to foil the Luftwaffe's attempt to gain control of the sky over southern England in 1940. The RAFBADS was designed in the late 1930's and deployed in time to meet the Luftwaffe threat. Travel back in time to the period in which the RAFBADS was being designed and view the problem of providing an air defence system from the HTPs.

> *"Work on the system began in 1937 and it was still being refined in 1940… … It was a remarkable creation. It brilliantly solved the problems of dealing with massive amounts of data from a wide range of sources in a very short time and using it to exercise control over the fighting. It was a system for managing chaos. Its intelligence gathering capability extended to the period after an engagement, enabling Dowding and his generals to blow away the fog of war very quickly. It possessed a Defence Teleprinter Network (DTN) connecting all RAF stations and Headquarters. After*

> *raids, the DTN was full of information gathered from returning pilots in de-briefs as well as from those who stayed on the ground. As a result 'loss details, combat reports, ground damage reports, casualties, aircraft and equipment requirements were easily disseminated throughout the whole system'. Its fundamental excellence and its ultimate success in practice can be attributed to a number of features.*
>
> *Firstly, its operational structure was simple and roles were very clear. Everyone knew what they had to do. It was not parsimonious with information: plot data was shared widely and passed simultaneously to several levels at once. Bentley Priory gave out information simultaneously to groups and sectors and sectors could plug into local Observer Groups once they knew something was up in their area. It was in effect an analogue intranet. Whilst it was used to transmit orders down the chain of command, it was also designed to allow anybody in the system to find out what they wanted when they wanted it from anybody else. It was a network organization based on telephone lines rather than e-mail" (Bungay, 2000: page 64)".*

However, in operation, when the parts of the system went down, a window was opened up in the air defence system that could have allowed unimpeded entry to the enemy aircraft. The two preventable (perhaps) failures were:

1. The radar sites and operations rooms were dependent on externally generated electricity from the Power Grid. When the Power Grid connections were destroyed by enemy action, parts of the system went off-line until repairs were affected and power was restored. Standby power generators should and could have been deployed as part of the installations.
2. The operations rooms were co-sited with airfields for convenience. On occasions when the airfields were bombed, the operations rooms were damaged and taken off line for short periods of time.

It should be pointed out that the effects of these failings were minor due to the tactics employed by the Luftwaffe in the battle. However, an alternative set of tactics (Bungay, 2000) would have exploited these defects to cause much more and serious damage to the RAF infrastructure. Modern systems engineering needs to be able to develop systems in the same manner as the RAF developed this system without overlooking similar types of defects.

The following discussion is not intended to be a complete application of the HTPs to the problem of providing an air defence system. Rather, the discussion highlights aspects brought out by the HTPs.

6.4.3.1. The Big Picture perspective

Perceptions from the *Big Picture* perspective described below include:

1. The purpose of the RAFBADS discussed in Section 6.4.3.1.1.
2. The context or environment of the RAFBADS discussed in Section 6.4.3.1.2.
3. The assumptions in the design of the RAFBADS discussed in Section 6.4.3.1.3.
4. The adjacent systems discussed in Section 6.4.3.1.4.

6.4.3.1.1. Purpose

The purpose of the RAFBADS is to protect the United Kingdom, particularly England, from invasion.

6.4.3.1.2. Context

The context consists of containing systems as follows:

- ***The situational context:*** a war in which England is facing an enemy intent in invading and conquering it. The RAFBADS is the first line of defence responding to enemy attempts to open a breech in the defences.
- ***The organizational context:*** the RAF with its traditions, procedures and organizational structure.
- ***The Metasystem view:*** let the battle be the system and the RAF and Luftwaffe be the two major subsystems. In the Metasystem view, the subsystem partitioning was as follows:
    - The RAF subsystem comprised the organizational structure, the logistics and support systems that supply aircraft, pilots, fuel, ordnance, etc. to the fighter airfields. The airfields are not part of the RAF subsystem.
    - The Luftwaffe subsystem performed similar functions supporting their fighter and bomber aircraft but included their airfields.
    - The RAFBADS subsystem comprised a complex well-structured interface between the RAF and Luftwaffe subsystems. The RAFBADS contained the RAF fighter airfields and aircraft, and the sensors and command and control links that vectored the fighters to meet the Luftwaffe intruders (Checkland and Holwell, 1998).

6.4.3.1.3. Assumptions

The assumptions upon which the RAFBADS are based seem to be as follows:

- The resources needed to operate the RAFBADS, namely, pilots, fuel, aircraft and electrical power are outside the boundary of the RAFBADS and provided to it.
- Weather is an important factor. The state of technology is such that enemy attacks are to be expected only in good weather[14]. This assumption, if validated, allows the down time due to bad weather to be applied to maintaining the system (preventative aircraft maintenance, pilot rest time, etc.).
- The function of rescuing of downed pilots is outside the system. However, this was changed in 1941 after having learned of the need to bring the function inside the system (Bungay, 2000: page 68).

6.4.3.1.4. Adjacent systems

The adjacent systems perform the other functions of fighting a war. The immediate adjacent (tightly coupled) RAF system provides the inputs, namely fuel, ordnance, pilots, aircraft and other supplies to the RAF-BADS. Identifying these systems outside the boundary of the RAFBADS pointed out a need for a Metasystem in which the RAFBADS and the systems producing the resources for the RAFBADS are subsystems of the Metasystem. When implemented, the need for pilots, ordnance, replacement aircraft and fuel was identified and appropriate adjacent systems instituted. However, the reliance on external power seems to have contributed to at least two holes in the defence radar system, when:

- An attack on 16 August 1940 put the radar (radio direction finding) station at Ventor out of action for three days by cutting the power supply and a mobile generator had to be brought in to restore operation (Bungay, 2000: page 206).
- Enemy action severed the main electricity Power Grid and put the whole of the Kent radar system off the air on 30 August 1940 (Bungay, 2000: page 276).

Early identification of this reliance on external power should have led to a requirement for emergency standby power generators.

Other loosely coupled adjacent systems perform functions such as:

[14] The term needs a more precise definition with respect to visibility, cloud, etc.

- Prevention of attacks by destroying the resources needed by the Luftwaffe to mount attacks.
- Damaging the enemy's ability to wage war.
- Contributing to ending the war in England's favour.

6.4.3.2. The Operational perspective

The purpose of the RAFBADS is defence; it will be a reactive system responding to stimuli. A CONOPS in the form of a set of detailed operational scenarios would be developed to describe anticipated responses to specific and generic enemy threats in terms of the way the RAFBADS makes use of people and the technology.

The system inputs are information, pilots, aircraft, ordnance, fuel, other supplies and mains generated electrical power.

The system outputs (the products it produces) are damaged and destroyed enemy aircraft.

The feedback function or relationship between outputs and inputs is that pilots and aircraft lost to enemy action, ordnance and fuel consumed must be replaced. From a homeostatic or self-regulating perspective the system strives to maintain a steady state of operational readiness in terms of the number of operational aircraft (the combination of mission-ready aircraft and trained pilots).

6.4.3.3. The Functional perspective

This perspective is employed in traditional systems engineering. Thus, a functional analysis would be performed showing what functions the RAFBADS performs (in terms of information flows, vectoring of RAF aircraft, etc.) so as to gain and maintain control of the air. The functional view would show that information about the location of the enemy is generated by the audio and visual observers and radar sites and sent to Fighter Command HQ. HQ sends the information on to the Groups and finally it is disseminated to the appropriate airfields. Information about the state of readiness of the airfields and squadrons and the results of air engagements are sent back from the airfields to Fighter Command HQ.

6.4.3.4. The Structural perspective

The *Structural* perspective in this case is very much a physical and organizational view of the airfields, radar sites, the observers, the communications links, etc.

6.4.3.5. The Generic perspective

From the *Generic* perspective the RAFBADS is operating in a siege situation. Historically, sieges have ended either when the enemy gives up and departs, or when the enemy breaks through the defences and slaughters the defenders. Thus the purpose of the RAFBADS is to prevent the enemy attacks from succeeding until the enemy decides to go away or is defeated by one of the loosely coupled adjacent systems mentioned in the *Big Picture* perspective.

In traditional city sieges, the pivotal situation is when the enemy breaks though the defences and enters the city usually through a hole in the defences. The *Generic* perspective indicates that the analogy to a hole in the defences in this situation would be the control of the air over the south coast of England by the Luftwaffe. Factors contributing to this situation would be[15]:

- ***Loss of airfields:*** since the interceptor aircraft cannot be launched (scrambled).
- ***Loss of radar information:*** since the point of attack cannot be determined and defenders scrambled and vectored to meet them.

This information is made use of in the operational scenarios. This perspective predicted that the airfields would be primary targets for destruction by the enemy by likening the situation to the need by a besieger to destroy the guns that deterred attackers from approaching too close to the city to create and utilize a breech in the defences. This perspective should also provide the insight that if the airfields are prime bombing targets, then any physical structures adjacent to the airfield would be likely to suffer collateral bomb damage.

6.4.3.6. The Continuum perspective

Perceptions from this perspective indicate the need for an ability to operate with damage, the ‘fail-soft’ concept discussed above. This should produce requirements for the architecture of the system. The design process would use the *Scientific* perspective to postulate causes of failures and mitigation approaches which would then be incorporated in failure scenarios (*Operational* perspective) and corresponding requirements.

6.4.3.7. The Temporal perspective

The RAFBADS was optimized to vector RAF fighter aircraft to the vicinity of the Luftwaffe invaders to provide the maximum amount of en-

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[15] Remember the war is still in the future at the time this analysis is being performed.

gagement time while conserving RAF fighter resources (Bungay, 2000). The RAFBADS contains both people and technology. It can be expected to get better in time. Consequently, there will be several learning curves including:

- Pilots learning tactics of air combat.
- Ground to air communications.

Perceptions from this perspective also:

- Illuminate the:
    - Training needs.
    - The logistics needs for ensuring operational availability.
- Provide insights leading to the adoption of a maintenance concept.
- Recognize the need to make use of lessons learned from similar conflicts. At that time the only aspects of conflicts in the air which could have provided some lessons learned would most likely have been bombing and strafing of ground facilities in the First World War[16] and the Spanish Civil War.

6.4.3.8. The Quantitative perspective

Perceptions from the *Quantitative* perspective relate to quantifying aspects of the *Big Picture* and to the *Operational* and *Functional* perspectives. Perceptions from the *Big Picture* perspective identify the need for quantitative information about:

- Number of RAF aircraft and pilots ready to fly.
- Number of losses on both sides.
- Number, type, location, speed and direction, of Luftwaffe aircraft approaching, or over England.
- Ratio of losses between the RAF and the Luftwaffe to provide a sense of how the battle is progressing; such as using the attrition rates to predict when the RAF would run out of aircraft.
- The accuracy and timeliness of the information.

Perceptions from the *Operational* and *Functional* perspectives describe the response of the system to the detection of enemy aircraft heading towards the English coast. This description provides the basis for determining quantitative factors such as:

- Range of aircraft (time in the air).

[16] Zeppelin attacks as per the First World War would be very unlikely.

- Response time to deploy fighters.

The initial availability requirements would be seven days a week during daylight to cope with anticipated day attacks. However the degree of availability might be different for night than for day. The designers of the Metasystem would have to commission an analysis to determine if the need for a night-time defence could and would be met by night fighters or by anti-aircraft guns and searchlights, or a combination thereof. That study would provide the information pertaining to the night-time availability requirements.

The information leads to trade-off studies between candidate solutions (designs) provided by the *Scientific* perspective which determines the performance requirements for the subsystems. For example, the closeness to the coast of the initial time of detection of an enemy incursion, and the locations of the RAF airfields determines the response time to deploy the fighters from each airfield to meet the incoming bombers.

This perspective also indicates that the enemy could infer some measure of the degree of "the holes in the defences" if they were to have a way of measuring the number of RAF fighter aircraft responding to incursions.

6.4.3.9. The Scientific perspective

The *Scientific* perspective:

- Goes beyond systems thinking and produces the initial conceptual Concept of Operations (CONOPS) for the RAFBADS based on the perceptions from the set of descriptive perspectives. The CONOPS also describes how the RAFBADS would be tested in operation.
- Works out ways of defending or hiding radar sites, repairing bomb damage to airports and other critical installations, providing back up power generators in the event of damage to the utility lines outside the system and ways of providing back up capability for other functions to minimize down time. These activities are then incorporated into the *Operational* perspective as the scenarios which minimize and quickly repair "holes in the defences".

6.4.3.10. Summary

The RAFBADS example has shown:

- The need to go beyond systems thinking.
- How each perspective provides information about the system

- How information from one perspective is used to augment information in one or more of the other perspectives.
- Has illustrated that the perspectives are interdependent, namely:
    - Information gained from one-perspective influences other perspectives.
    - Information gained from one perspective can be used to generate ideas in other perspectives.
    - An insight may be obtained from the combination of perspectives.
- That the approach is holistic since the definition of each perspective and the corresponding allocation of content to each of the perspective is for the convenience of the user, and is not a mirror of the real world[17].

6.5. Using the perspectives perimeter in creating innovative solutions

This Section summarises one way to use the perceptions from the perspectives perimeter in creating innovative solutions to provide a context for the examples in Section 6.4 and those that follow in the remainder of the book.

6.5.1. When trying to understand a situation

Do as applicable:

1. Collect data about the situation.
2. Store the data by the eight descriptive perspectives to provide a template framework for locating and using the information.
3. Analyse the relationships from the *Operational* and *Functional* perspectives.
    - Start by making a list of the factors involved.
    - Determine any relationships between the factors. For example:
        - If factor 'X' increases, what happens to factors 'Y' and 'Z'?
        - If factor 'Y' increases, what happens to factors 'X' and 'Z'?
        - If factor 'Z' increases, what happens to factors 'X' and 'Y'?

[17] Just like any other system representation.

- Draw causal or feedback loops showing the factors and their relationships.
- Determine the relative influences or importance of the factors using perceptions from the *Quantitative* perspective and modify the loops if necessary.

4. Store the ideas in the appropriate ISTs where.
   - The ideas stored in the HTPs will help document the situation in a systemic and systematic manner.
   - The ideas stored in OARP will help identify the problem: the cause of the undesirable situation.
   - The ideas stored in FRAT will help conceive the solution.
   - The ideas stored in SPARK will help to turn the solution into reality.
5. Evaluate the ideas using critical thinking, identifying those that are unsuitable.

6.5.2. When trying to determine a course of action

Do as applicable:

1. Use Active Brainstorming to create ideas about the situation, problem and solution.
2. Store the ideas in the ISTs.
   - The ideas stored in OARP will help identify the problem: the cause of the undesirable situation or the process that needs to take place to create the Feasible Conceptual Future Desired Situation (FCFDS) (Section 9.11).
   - The ideas stored in FRAT will help identify aspects of the solution that need further consideration.
   - The ideas stored in SPARK will end up forming the beginning of the project plan to realise the solution.
3. Evaluate the ideas using critical thinking, identifying those that are unsuitable.

6.6. Summary

This Chapter:

1. Summarised holistic thinking as the combination of the use of the HTPs and critical thinking (the evaluation of ideas).
2. Began with an introduction to how to use the HTPs to store information about Case Studies and real world situations in Section 6.1.
3. Introduced Active Brainstorming in Section 6.2 as a way to increase the number of ideas generated by brainstorming using the

HTPs coupled with the Kipling questions "who, what, where, when, why and how" (Kipling, 1912).

4. Introduced three problem-solving Idea Storage Templates (IST) in Section 6.3 for storing the ideas produced in the Active Brainstorming session.
5. Contained three examples of using the HTPs and ISTs in Section 6.4.
6. Provided suggestions for using the perspectives perimeter in creating innovative solutions to provide a context for the examples in Section 6.5 and those that follow in the remainder of the book.

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7. The nature of systems

This Chapter:

1. Discusses the nature of systems because:
    1) Undesirable situations, desirable situations, problems and solutions tend to manifest themselves in systems.
    2) The process to change from an undesirable situation to a desirable situation incorporates the problem-solving process which often includes or overlays the System Development Process (SDP).
    3) The process is itself a system.
2. Begins with a list of definitions of a system in Section 7.1
3. Perceives the nature of systems from the different HTPs in Section 7.2.
4. Introduces yet another definition of a system in Section 7.3.
5. Discusses basic system behaviour in Section 7.4
6. Discusses the properties of systems in Section 7.5.
7. Introduces a standard functional template for a system from which it should be possible to develop a set of reference functions for any class of system in Section 7.6.
8. Discusses complex systems in Section 7.7.
9. Discusses ways of reducing complexity in Section 7.8 including examples of how to optimise systems based on the interactions at the interfaces of the subsystems.

7.1. Various definitions of the word "system"

The word "system" means different things to different people. For example, Webster's dictionary contains 51 different entries for the word "system" (Webster, 2004). Consider the following representative sample of definitions of the term taken from various sources from the last forty years:

- "*An array of components designed to accomplish a particular objective according to a plan*" (Johnson, et al., 1963).

- "*A set of concepts and/or elements used to satisfy a need or requirement*" (Miles, 1973: page 2).
- "*An assemblage or combination of components or parts forming a complex or unitary whole*" (Blanchard and Fabrycky, 1981).
- "*A number of elements and the relationships between the elements*" (Flood and Jackson, 1991).
- "*A set of different elements so connected or related as to perform a unique function not performed by the elements alone*" (Rechtin, 1991).
- "*Consists of three related sets, a set of elements, a set of interactions between the elements, and a set of boundary conditions*" (Aslaksen and Belcher, 1992).
- "*Any process or product that accepts and delivers outputs*" (Chapman, et al., 1992).
- "*The model of a whole entity; when applied to human activity, the model is characterized fundamentally in terms of a hierarchical structure, emergent properties, communication and control. An observer may choose to relate this model to real-world activity. When applied to natural or man-made entities, the crucial characteristic is the emergent properties of the whole*" (Checkland, 1991).
- "*A network of interdependent components that work together to try to accomplish the aim of the system*" (Deming, 1993).
- "*A group of elements dynamically related in time according to some coherent pattern. Both the nature and purpose of the System are recognized by an observer within his perception of what the system does. Using this approach, models may be constructed to represent the System being studied*" (Beer, 1994: page 7).
- "*The object of study, what we want to discuss, define, analyze, think about, write about and so forth*" (Kline, 1995).
- "*Any organized assembly of resources and procedures united and regulated by interaction or interdependence to accomplish a set of specific functions*" (FS-1037C, 1996).
- "*A collection of personnel, equipment, and methods organized to accomplish a set of specific functions*" (FS-1037C, 1996).
- "*A set of **related components** that **work together** in a particular **environment** to perform whatever **functions** are required to achieve the system's **objective***" (Dewitz, 1996: page 5).
- "*A set of integrated end products and their enabling products*" (Martin, 1997: page 17).
- "*A collection of interrelated components that work together to achieve some objective*" (Sommerville, 1998: page 24).

- "*An interdependent group of people, objects, and procedures constituted to achieve defined objectives or some Operational role by performing specified functions. A complete system includes all of the associated equipment, facilities, material, computer programs, firmware, technical documentation, services, and personnel required for operations and support to the degree necessary for self-sufficient use in its intended environment*" (IEEE 1220, 1998).
- "*An entity designed to function so as to achieve an objective*" (Westerman, 2001: page 5).
- "*An integrated set of elements that accomplish a defined objective*" (INCOSE, 2002). The International Council on Systems Engineering (INCOSE) definition then adds, "*People from different engineering disciplines have different perspectives of what a "system" is*".
- "*A combination of interacting elements organized to achieve one or more stated purposes*" (Arnold, 2002).
- "*A complex whole the functioning of which depends on its parts and the interactions between those parts*" (Jackson, 2003: page 3).
- "*A bounded object which is capable of responding to external stimuli, and in response to external stimuli a system's internal components interact with each other to produce internal and external effects*" (Scuderi, 2004).

The various definitions of the word 'system' reflect views of problems through different cognitive filters by the creators of the definitions, namely systems engineering in the manner of Wymore (Wymore, 1993: page 2) who writes that systems engineers are problem solvers.

7.2. The nature of systems

Using perceptions from the perspectives perimeter, the nature of systems can be summarized as follows:

7.2.1. The Temporal perspective

Perceptions from the *Temporal* perspective include:

- The definitions of a system have changed over the last 40 years and are still changing as shown in the examples in Section 7.1.
- Systems evolve over time.

7.2.2. The Big Picture perspective

Perceptions from the *Big Picture* perspective include:

- Systems have external observer(s).
- Systems exist within containing systems.

7.2.3. The Operational perspective

Perceptions from the *Operational* perspective indicate that systems:

- Exhibit different types of behaviour (Section 7.4).
- Have different properties (Section 7.5).

7.2.4. The Functional perspective

A generic functional view of a system is pictured in Figure 7.1 as a jigsaw piece because systems can be represented by a number of functions (components or subsystems) fitted together to perform the function of the system. Generically a function converts inputs to outputs using resources. Hitchins grouped the complete set of functions performed by any system into the following two classes (Hitchins, 2007: pages 128 to 129):

1. ***Mission:*** the functions which the system is designed to perform to remedy the undesirable situation in its operational context under normal and contingency conditions, as, and when required.
2. ***Support:*** the functions the system needs to perform in order to be able to perform the mission under normal and contingency conditions, as, and when required. Support functions can further be grouped into:

    - ***Resource management:*** the functions that acquire, store, distribute, convert and discard excess resources that are utilized in performing the mission.
    - ***Viability management:*** the functions that maintain and contribute to the survival of the system in storage, standby and in operation performing the mission.

7.2.5. The Structural perspective

Perceptions from the *Structural* perspective include a system:

- Can be almost anything including products, objects, things, processes, methodologies, and ways of doing something such as a betting system.
- Contains the following minimum set of common elements (based on the commonality in the definitions in section 7.1):

    - An external boundary.
    - Internal components or subsystems.
    - Interactions between the internal components.
    - Inputs.
    - Outputs.

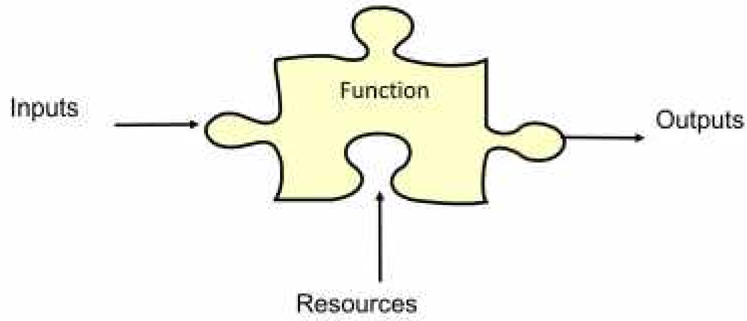

Figure 7.1 Generic functional view of a system

7.2.6. The Generic perspective

Perceptions from the *Generic* perspective indicate that the definitions of a system and a subsystem are identical.

7.2.7. The Continuum perspective

Perceptions from the *Continuum* perspective indicate that

- Systems can be classified in different ways (Section 7.2.8.1).
- Some of the initial minimum set of common elements (Section 7.2.8.2) may be incorrect or unknown especially at the time the system boundary is first drawn.

7.2.8. The Quantitative perspective

Perceptions from the *Quantitative* perspective include:

- Classification of systems.
- Common elements.

Consider each of them.

7.2.8.1. Classification of systems

A number of authors classify systems by levels of complexity and types of system. From the *Generic* perspective, these approaches seem to be paralleling the development of theories of motivation in Psychology. For example, Murray identified separate kinds of behaviour and developed an exhaustive list of 39 psychogenic or social needs (Murray, 1938). However, the list is so long that there is almost a separate need for each kind of behaviour that people demonstrate (Hall and Lindzey, 1957). While this list has been very influential in the field of psychology, it has not been applied directly to the study of motivation in organizations. This is probably because the length of the list makes it impractical to use. One could expect that classifying systems by complexity and types would result in similar lengthy lists.

Maslow's hierarchical classification of needs (Maslow, 1954; 1968; 1970) on the other hand, has been by far the most widely used classification system in the study of motivation in organizations. Maslow differs from Murray in two important ways, his list is hierarchical, commonly drawn as a pyramid, and is short; it only contains five categories. While levels of complexity and types of system can also be expected to be influential in systems engineering, the research applying holistic thinking to the problem of classifying system focused on locating or developing the shorter broad-based classification based on problem-solving discussed in Section 9.13.

7.2.8.2. Common elements

Perceptions from the *Structural* perspective (Section 7.2.5) indicate that the minimum set of common elements in a system can be represented by the generic diagram shown in Figure 7.2 (Flood and Jackson, 1991) which represents the creation of the system by taking an area of interest and drawing a boundary around that area such that anything inside the boundary becomes part of the system and partitioning the area inside the boundary into subsystems or components.

Figure 7.2 however, is only a simple representation of the area of interest. Each component may in itself consist of components; hence the components tend to be known as subsystems. Furthermore, the representation in Figure 7.2 assumes that external elements can be ignored for the purpose for which the system was constructed. This assumption is not necessarily true as we continue to discover sometimes to our detri-

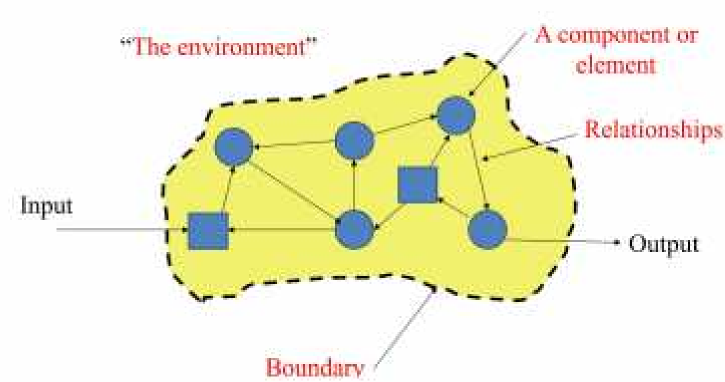

Figure 7.2 Common elements of a system (Flood and Jackson, 1991)

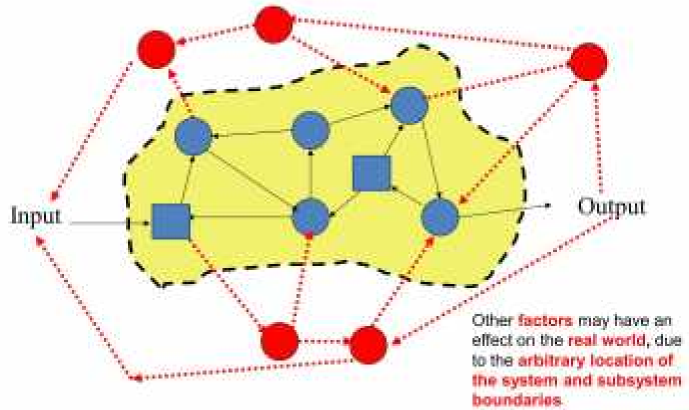

Figure 7.3 A more generic and more complex representation of a system which takes external effects into account

ment as indicated by perspectives from the *Continuum* perspective mentioned above. For example, in some land areas, the irrigation cycle was initially assumed to be pump water up from the underground aquifer to irrigate the land. This would lower the level of the underground aquifer. Rainwater would then seep down and restore the water in the aquifer. However it was subsequently found that pumping subsurface water to the surface did indeed lower the level of the underground aquifer. However the aquifer was not replenished by surface water seeping down after rainfall as was initially postulated (hypothesized or assumed), but instead was replenished by salt water from a nearby ocean seeping sideways into the aquifer to maintain the level. What's more, as the *Temporal* perspective shows, in similar situations these external effects may show up with various time delays ranging from fractions of seconds to longer than centuries as discussed in Section 4.3.2.7. Thus as we learn more about what needs to be considered in our situations, we change the boundaries of the system to incorporate external elements, initially considered as not having an effect on the system of interest (SOI), as and when we discover that they do in fact have an effect. However, the more we add to the system the more complex the system becomes.

Figure 7.2 and Figure 7.3 also introduce artificial complexity (Section 7.7.2).because they contain both the block box open systems view and the white box closed system view in the same figure. The holistic thinking approach uses two separate figures, one for each view.

A more generic and more complex representation of a system which includes the effects of components in or adjacent to the area of interest that affect the system is shown in Figure 7.3 which reminds us of Kline's dictum that the system is only a representation of the real world (Kline, 1995), or in today's object-oriented parlance, an abstraction or a view of the real world. Kline uses the term Sysrep to reflect this situation and reserves the term 'system' to describe the area of interest from which the Sysrep is created[1].

7.3. Yet another definition of the term "system"

This Section proposes a semantically loaded teaching definition of the term 'system' that incorporates the hypotheses of this chapter, namely:

> *A system is an abstraction from the real world of a set of objects, each at some level of decomposition, at some period of time, in an arbitrary boundary, crafted for a purpose.*

Consider the implications of the terminology used in the definition.

- ***Abstraction:*** used in its object-oriented meaning to remind us that a system is not the real world, but is Kline's Sysrep and must always be viewed in that context.
- ***A set of objects:*** the *Structural* perspective: the components of the system.
- ***Each at some level of decomposition:*** the hierarchical view within the *Structural* perspective: each component may itself be an aggregate of components.
- ***At some period of time:*** the *Temporal* perspective: not only do the system and its components have to be considered at the same period of time (Beer, 1994), but consideration has to be taken into account that the area of interest represented by the system may change over time.
- ***In an arbitrary boundary***: the *Big Picture* perspective: the boundary is crafted by the observer to enclose a section of the real world (Jackson and Keys, 1984; Churchman, 1979: page 91);(Beer, 1994: page 7). The word arbitrary is used because the boundary may appear arbitrary to other entities until the purpose for drawing the boundary is understood. The act of drawing an external boundary implies a containing or meta-system, so the concept of hierarchies is built into the definition. The act of drawing internal boundaries or partitioning the system defines the components or subsystems. The choice of partitioning is a major factor in the efficacy of any system description (Aslaksen and Belcher, 1992).

[1] And human nature being what it is, ignored the word 'Sysrep' and continued to use the word 'system' for both concepts.

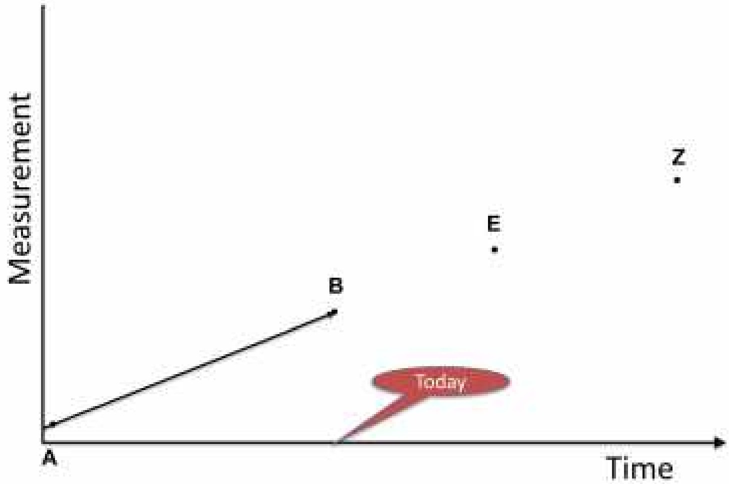

Figure 7.4 Predicting the behaviour of a system over time

- ***Crafted for a purpose:*** this is the part of the definition that really changes things. The system does not have to have a purpose. The boundary is defined by the purpose for which it is drawn in the mind of the observer (Jackson and Keys, 1984; Churchman, 1979: page 91);(Beer, 1994: page 7).

7.4. Basic system behaviour

System behaviour over time is often plotted in graphs. Perceive the behaviour of a system between points A and B in Figure 7.4 from the *Temporal* perspective and draw a line joining points B and E and then extend it to Z. Most people will draw a straight linear line from B to E to join the points and then draw another straight line joining E and Z. Apply some critical thinking and ask why straight lines and why not curves? In general, the lines drawn joining points A, B and E represent the known (observed) behaviour over time. When asked to extrapolate the line beyond point E to point Z, most people continue the line in the same direction. This action is based upon the assumption that the conditions that resulted in the behaviour of the system between points A and B will not change in the near future. This is the assumption people use to predict future behaviour with various degrees of accuracy.

Depending on the type of system, the types of system behaviour include:

1. Cyclic discussed in Section 7.4.1.
2. Homeostatic discussed in Section 7.4.2.
3. Exponential growth discussed in Section 7.4.3.

4. Goal seeking discussed in Section 7.4.4.
5. S-shaped growth discussed in Section 7.4.5.

7.4.1. Cyclic

The system exhibits repetitive patterns of behaviour or cycles when perceived from the *Temporal* perspective. Examples of such cycles include the annual seasons (spring, summer, autumn and winter) and the 11-year sunspot cycle.

One example was identified in 1970 when I noted that the average price of gasoline in the North West suburbs of Detroit seemed to vary between 18 and 32 cents in a cyclic manner. When I plotted the price daily, I saw that the price rose at a rate of about 1 cent every two days until it reached about 32 cents then dropped overnight to 18 cents. Then, after a day or so, the price started to rise again. The cycle repeated for at least thirteen more iterations[2]; the graph showed a perfect sawtooth pattern. Knowledge of the cycle allowed the fall in price to be predicted and taken advantage of by waiting for the price to fall to 18 cents a gallon and filling the tank the day before the price rose to 32 cents.

7.4.2. Homeostatic

The system tends to maintain a stable condition with some small variation about a mean value generally caused by negative feedback in the system responding to a change. Heating and cooling systems exhibit this behaviour when functioning correctly. The LOCs in the Luz SEGS-1 project discussed in Section 6.4.1 were designed to operate in a homeostatic manner.

7.4.3. Exponential growth

The system grows by a fixed percentage at regular intervals of time. Exponential growth is generally caused by positive feedback in the system.

7.4.4. Goal seeking

The system moves from a starting position to a goal or target value over a period of time. When shown as a graph, the starting position may be above or below the goal. Depending on the rate of change, the system may overshoot the goal and oscillate a few times until a stable state is reached. From the *Generic* perspective the problem-solving process can be considered as goal-seeking behaviour in which the system is moved from being in an undesirable situation to achieve the goal of being in the Feasible Conceptual Future Desired Situation (FCFDS) (Section 9.11) when the FCFDS becomes a reality.

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[2] I moved out of the area and stopped plotting the chart.

7.4.5. S-shaped growth

The system grows exponentially for a period of time then flattens out at the top of the curve in the manner of goal seeking behaviour. This curve is often used to describe market penetration of new products where the top of the curve represents a saturated market.

7.5. Properties of systems

Systems have various properties made up of the (1) properties of the subsystems and (2) the properties of the interactions between the subsystems. These properties include:

1. States discussed in Section 7.5.1.
2. Emergence discussed in Section 7.5.2.
3. Failures discussed in Section 7.5.3.
4. Components discussed in Section 7.5.4.
5. Subsystems discussed in Section 7.5.5.

7.5.1. States

Systems in general exhibit their behaviour in stable states until a state transition takes place. The system then changes to a new stable state. Examples of various changes in system states include:

- ***Ice, water, steam:*** if the system (molecules of water) begins at a temperature below zero degrees centigrade and is heated, the behaviour of the ice is homeostatic until the melting point of ice is reached and the system goes through a transition phase changing state to water. As the liquid is heated further, the water then exhibits homeostatic behaviour until the temperature reaches the boiling point and a further state change to steam takes place.
- ***Ship, storm, ship':***[3] a ship is sailing the ocean and experiences a major storm. A state change takes place during the storm due to storm related damage. When the storm is over the ship continues its journey but in a damaged state.
- ***Government, election/revolution, government':*** a country has a government, the state change takes place and the country continues with a new government.
- ***Family, baby, family':*** a family exists in one state, a new baby comes along and the family then exists in a changed state.
- ***Country, natural disaster, country':*** a country exists in one state, a natural disaster such as an earthquake, volcanic eruption,

[3] The ' character is used to identify that while the new state may have the same name, it is different.

Figure 7.5 Section of urban drainage system

tsunami or combination of any of the above occurs, and the country goes through a transition. The country then continues in another state.

- ***Situation, policy, situation':*** a government perceives an undesirable situation and issues and implements a policy to change the state into a desirable situation. The country then exists in a new state which may or may not be the one the government desired.
- ***System, failure, system':*** An operational system suffers a failure and changes state to a new system. If the failure is total then the system changes from an operational to a non-operational state. If the failure is partial, then the system changes from an operational state to a partially failed state.
- ***System, upgrade, system':*** a system is changed from one state to an upgraded state.
- ***Amplifier, transient, oscillator:*** an amplifier is working in one state and suffers a transient which makes it oscillate. It then remains oscillating until some other action is taken.

Some system states are known due to experience and can be shown in a graph of system behaviour. Others may be unknown until the system moves beyond point B in Figure 7.4 and an unanticipated state change takes place and the lesson is learnt the hard way. For example, consider the section of an urban drainage system shown in Figure 7.5. During fine

Figure 7.6 Section of urban drainage system after a rain shower

weather there is a trickle of water in the centre of the channel. Since most of the time the weather is fine, you might think that the side sections could be used as a bicycle path or running track when it is not raining.

Now take a look at the same section just after a rain shower shown in Figure 7.6. The water is travelling quickly and level is well above the side sections. When this happens in a similar situation in nature it is called a flash flood. So before deciding on converting the drainage channel to a bicycle or running path, you need to perform a study on how quickly the water levels change during a rain shower, how many staircases would be needed to allow people to climb out of the channel when it begins to rain, and if people would exit the channel in a timely manner. After the study, you'd probably decide not to convert the drainage channel to a bicycle or running path. These pictures describe a situation at the micro level. However from the *Generic* perspective the situation at the macro level is that same as when settlers moving west in North America built towns along the riverbank not realising that they were building in the flood plain. When a flood came along, the river changed state and the settlers learnt about flood plains the hard way. In the drainage channel the flood plain is the paved section that is only flooded when it rains.

7.5.2. Emergence

Rechtin and Maier wrote, "*systems are collections of different things which together produce results unachievable by the elements alone*" (Rechtin and Maier, 1997: page 10). This statement dealing with emergence is but one property of the principle of integrative levels governing increasing complexity in systems discussed in Section 4.3.4.1. One definition of emergence is, "*the process of coming forth, issuing from concealment, obscurity, or confinement*"[4], namely the functionality of the system emerges from the components **and the interactions** between the components. For example, when wires, a transparent container, and an inert gas or vacuum are combined in the right way they form an incandescent electric light bulb. When the incandescent light bulb is connected to a working power source the resulting system produces electric light and heat which are properties of the system as a whole, not of any single component.

There seem to be three types of emergent properties (Kasser and Palmer, 2005):

1. Desired.
2. Undesired.
3. Serendipitous.

The three types of emergent properties are split as follows between:

- Known emergent properties at design time.
- Unknown emergent properties at design time.

7.5.2.1. Known emergent properties

These being the known emergent properties provided by the solution system that are:

- ***Desired:*** being the purpose of the system as described in the incandescent electric light bulb example in section 7.5.2.
- ***Undesired:*** a property of the system known from experience and compensated for, or prevented from occurring, in the design of the system. Examples include heat in an incandescent light bulb, resonance in suspension bridges, oscillations in high gain amplifiers and medicinal drug side effects, etc. For example:
    - Antibiotics commonly used to treat bacterial infections have a side effect of causing diarrhoea because they also kill the beneficial bacteria in the human digestive system. Adding an anti-diarrhoea agent to the antibiotic medication could compensate for this undesired emergent property.
    - The incandescent electric light bulb generates heat as well as light. The heat, or rather ways of dissipating the

[4] Oxford English Dictionary

heat, has to be taken into consideration when designing light fixtures, handling and operating light bulbs.

7.5.2.2. Unknown emergent properties

These being unknown emergent properties provided by the solution system that are:

- ***Undesired:*** which have the opposite effect to those intended, or make the solution undesirable or even unable to remedy the problem. For example, Thalidomide was sold from 1957 to 1961 as a solution to the problem of mitigating the undesirable situation of morning sickness in pregnant women. Unfortunately the drug was found to cause severe birth defects in some situations and had to be withdrawn from the market.
- ***Serendipitous:*** beneficial and desired once discovered, but not part of the original specifications. These tend to be accidental discoveries.

7.5.3. Failures

Sooner or later systems will fail or break down and exhibit abnormal behaviour. Failures may be total in which the system stops working, or partial in which some functionality is lost while the system can still operate. Failures due to wear and tear on parts can be predicted and can often be prevented by a combination of proper maintenance and design for reliability. Contingency plans for dealing with failures and breakdowns should be prepared and periodically updated.

7.5.4. Components

Man-made systems contain three kinds of components (Ramo, 1973: page 24), namely:

1. ***Technology:*** the equipment and materiel within the system boundary, often organized into subsystems.
2. ***People:*** trained to operate, maintain and interact with the system.
3. ***Information:*** acquired, processed, stored and disseminated to internal and external users. This information tells the people and technology what to do and when and where to do it, all of which makes the system operate properly in its designed context.

7.5.5. Subsystems

Systems are made up from subsystems. When thinking about systems as a rule of thumb, you need to think about your system and one level up and one level down in the hierarchy (Machol and Miles Jnr, 1973: page 48).

7.6. A standard functional template for a system

Ensuring that a design for the solution system is complete constitutes a significant problem. From the *Generic* perspective, the use of a standard or reference set of functions in the form of a template that can be tailored to describe a specific system can ensure a greater probability of design completeness as described in this Section.

7.6.1. Some advantages of the use of functions

The use of functions has a number of advantages including the following:

1. Supports abstract thinking by encouraging problem solvers to think in abstract terms in the early stages of identifying a problem and providing a solution discussed in Section 7.6.1.1.
2. Maximises completeness of a system by allowing for the inheritance of generic functions for the class of system discussed in Section 7.6.1.2.
3. Provides for the use of standard functional templates for various types of systems which can help maximize completeness of the resulting system discussed in Section 7.6.1.3.
4. Improves probability of completeness by making it easier to identify missing functions in system functional descriptions than in implementation (physical) descriptions discussed in Section 7.6.1.4.
5. Allows the system to be modelled in its functional form at design time to determine how well the solution functionality appears to remedy the problem discussed in Section 7.6.1.5.

7.6.1.1. Supports abstract thinking

People tend to use solution language to describe functions. For example, we often use the phrase “need a car” when we should be saying, “need transportation”. Using implementation language in the early stages of problem-solving tends to produce results that may not be the best solution to the problem even if it is a complete solution, as well as generally not being an innovative solution. This is because solution language tends to turn examples into solutions with little exploration of alternative solutions. For example if the need is stated as, “we need a car”, the problem-solving process tends to focus on selecting the car to meet the need. A need should be stated from the *Operational* and *Quantitative* perspectives as, “provide a transportation function to move N people with B (pounds/cubic feet) of baggage M miles in H hours over terrain of type

T with an operational availability of O". Creating the solution concept in the form of capability or functionality is in accordance with Arthur D. Hall who stated that if a problem can be stated as a function, then the total solution is the needed functionality as well as the process to produce that functionality (Hall, 1989). In holistic thinking terms, state the need using functional or problem language not structural or solution language. Using the language of functions in the early stages of problem-solving will nudge the stakeholders into abstract thinking rather than fixating on an implementation. For example, they might stop saying, "I need a car" and start saying, "I need transportation".

7.6.1.2. Maximises completeness of a system

From the *Generic* perspective, any system is an instance of a class of systems and once the first one has been built, subsequent systems can inherit properties and functions. Consequently, any system can have two types of mission and support functions:

1. ***Generic:*** to that class of system.
2. ***Specific:*** to that instance of the system.

For example, when building a spacecraft the necessary thermal-vacuum properties and functions needed to survive the launch and operate in space can be inherited from previous spacecraft of that type. Once inherited the properties need to be examined to determine if they are applicable with or without modification. Other specific properties and functions for that spacecraft must then be examined to determine if they conflict with the generic ones.

7.6.1.3. The use of a standard functional template for a system

Figure 7.7 shows a template for a system in which the functionality has been grouped into mission and support functions. Note how Figure 7.7 does not show details of the mission and support functions because these details have been abstracted out since they belong in lower level drawings. An immediate advantage of the Figure 7.7 *Functional* perspective template is that one can see that there are two system outputs, the desired output labelled 'output' and another output labelled 'waste'. If applied to the incandescent light bulb, the desired output is light; the undesired or waste output is heat.

Process improvement and cost reductions efforts tend to focus on the effectiveness of producing the desired output, namely the mission functions. The template shows that there is also a need to focus on reducing the amount of waste or exploring ways in which 'waste' can be used or treated as a desired output and sold to someone who wants the

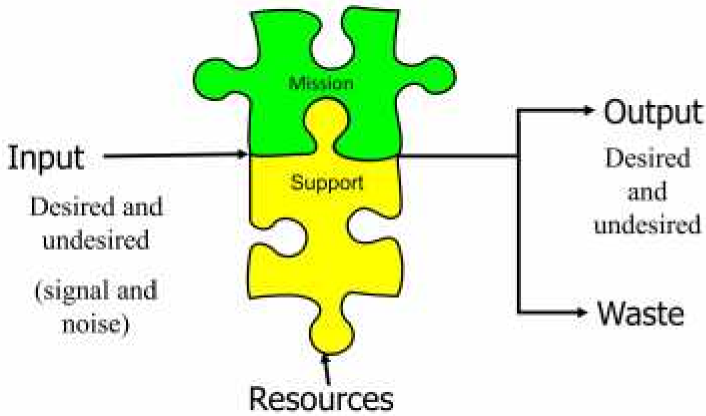

Figure 7.7 Functional template for system

waste For example waste heat might be sold or used; waste food in a restaurant might be used for fertiliser or animal food and so on.

By using the inheritance concept, it should be possible to inherit functions from the set of reference functions for the class of system being developed. This seems to be the concept behind Hitchins' Generic Reference Model of any system (Hitchins, 2007: pages 124 to 142). Problem solvers and application domain experts working together[5] would assemble the detailed functions to be performed by the solution system from the set of reference functions for the class of system being developed, tailoring the functions appropriately. For example, if the solution is a:

- ***Spacecraft:*** the support functions for surviving launch and the out-of-atmosphere environment would be among those inherited.
- ***Information system:*** the functions displaying information to ensure that data is not hidden due to colour blindness in the operators would be among those functions inherited. In addition, a typical template for data processing system might look like that shown in Figure 7.8. This method for developing a system design should decrease the number of missing functions.

7.6.1.4. Improves probability of completeness at design time

This method for developing a solution system design should decrease the number of missing functions and allow innovative designs as shown in the following examples:

[5] In an integrated team

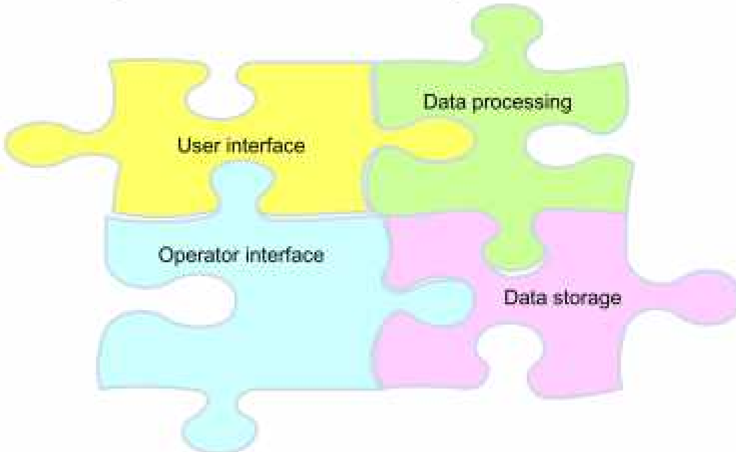

Figure 7.8 Functional template of a data processing system

1. An Automatic bank Teller Machine (ATM) discussed in Section 7.6.1.4.1.
2. The Wright Brothers' heavier-than-air flying machine discussed in Section 7.6.1.4.2.

7.6.1.4.1. An Automatic bank Teller Machine (ATM)

An ATM is a simple system to which most people can relate, having had some interaction with such machines. The mission functions for which the ATM was designed include:

- Withdrawing funds.
- Depositing funds.
- Checking the balance in the user's accounts.

The support functions for the ATM include:

- Removing and replenishing bank notes.
- Deterring theft.
- Countering attempted theft.
- Servicing the electromechanical components to keep them operational.

By considering the CONOPS for each of the functions of the ATM and how the functions can be implemented, alternative innovative design approaches may be identified for implementation sometime in the future. For example the physical realization of the ATM uses 1980's technology and is based on the use of a plastic card containing a magnetic memory and a Personal Identification Number (PIN). Thirty years since the initial

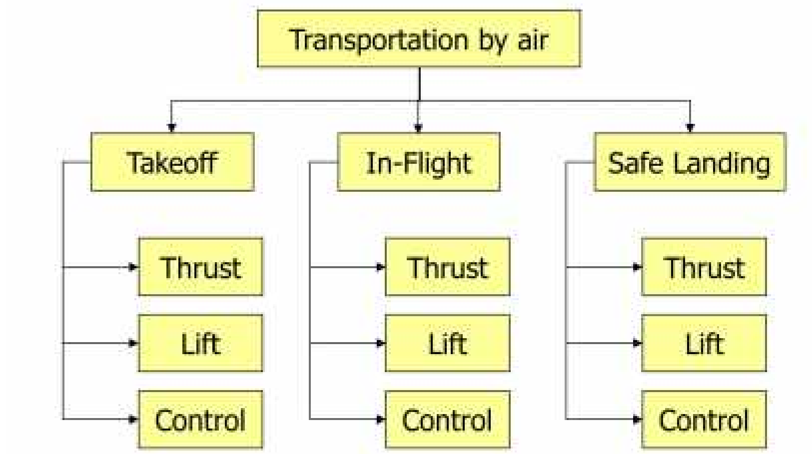

Figure 7.9. Wright Brothers' heavier-than-air flying machine functions

implementation alternative implementations have become possible based on thumb prints, laser retina scans, cell phones and other techniques to ensure security without the need for the plastic card. The functional approach allows the holistic thinker to pose the following question, "*Is the financial industry trading off the costs of developing and deploying newer more secure ATMS against the cost of the losses incurred from the current generation of ATMs*?"

7.6.1.4.2. The Wright Brothers' heavier-than-air flying machine

The *Structural* perspective of the functional representation shown in Figure 7.9 elaborates the transportation function into three sub-functions. Each of the sub-functions is further elaborated into three sub-functions. The thrust function applies to horizontal motion, the lift function applies to vertical motion and the control function applies to the control of thrust and lift. When thinking about how the vehicle behaves, it is easy to notice the lack of a function that moves the vehicle sideways in the figure[6]. If the transportation by air problem is expanded to include travel from Point A to Point B, where some distance separates points A and B, the *Structural* perspective of the functional representation might look like that shown in Figure 7.10. During the discussion of the Concept of Operations (CONOPS) for the transportation function, the lack of a function performing communications with the ground should become apparent.

[6] However to be fair, that function may not have been needed. The Wright Brother's heavier-than-air flying machine was a solution to the problem of flying *per sé* for a short distance using a heavier-than-air flying machine. No intentional sideways movement was needed; in the air, the function was not required, and on the ground the function was provided by human effort expended in moving the machine.

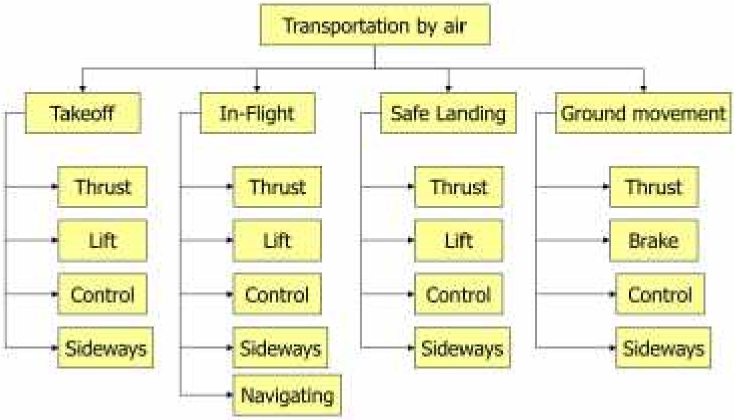

Figure 7.10 Including additional functions necessary to travel some distance

7.6.1.5. Modelling systems at design time

Since a function by definition transforms an input to an output while consuming resources and generating waste, functions can be expressed mathematically which allows them to be used in models and simulations. If the set of functions is complete, and the mathematical representations truly represent the functions, then calculations can be made to determine how well the proposed solution system will meet the need at design time before the functions are allocated to the components in the implemented version of the system. When the model underlying the calculations is developed, variable and parameters that are not understood or are vague become candidates for risks to be monitored during the development.

Perceptions from the *Continuum* perspective indicate that there is a need to distinguish between operational and functional models and simulations since reliance on functional models and simulations to save the costs of testing and evaluation can be dangerous. There is a major difference between operational and functional models and simulations.

- ***Operational models and simulations:*** focus on actual and conceptual views of a system where:
    - Actual views include models of what the system is doing.
    - Conceptual models include models of what the system:
        - Could do.
        - Should do.
        - Needs to do.

These models can be used to gain consensus on the 'what' aspect of a system.

- ***Functional models and simulations:*** focus on the 'how' it is being done. These are useful when the underlying mechanisms are well-understood and the functionality can be expressed mathematically. However, when the underlying mechanisms in an unprecedented system such as a flying system (an experimental aircraft) are unknown, then using simulations as training tools can be downright dangerous. The model and simulation is only as good as its underlying assumptions, and when they are wrong, people can be killed.

7.7. Complex systems

Is the world more complex today than in previous times, or is there just a perception that it is so due to unnecessary complexity? Perceive complexity from the following perspectives on the perspectives perimeter:

1. The *Quantitative* perspective discussed in Section 7.7.1.
2. The *Continuum* perspective discussed in Section 7.7.2.
3. The *Scientific* perspective discussed in Section 7.7.3.

7.7.1. The Quantitative perspective

Looking at the literature, the subject of complexity seems to be subjective since:

- "*The classification of a system as complex or simple will depend upon the observer of the system and upon the purpose he has for constructing the system*" (Jackson and Keys, 1984).
- "*A simple system will be perceived to consist of a small number of elements, and the interaction between these elements will be few, or at least regular. A complex system will, on the other hand, be seen as being composed of a large number of elements, and these will be highly interrelated*" (Jackson and Keys, 1984).
- "*A complex system is an assembly of interacting members that is difficult to understand as a whole*" (Allison, 2004: page 2).

When applying critical thinking to these definitions the words 'small', 'few', 'large', 'simple' and 'difficult to understand' have no objective values.

7.7.2. The Continuum perspective

Perceptions from the *Continuum* perspective indicate differences between:

1. Subjective and objective complexity discussed in Section 7.7.2.1.
2. The different types of objective complexity discussed in Section 7.7.2.2.
3. How to manage complex systems discussed in Section 7.7.2.3.

7.7.2.1. Subjective and objective complexity

There do not appear to be words that uniquely define the concepts of subjective complexity and objective complexity in the English language. The words 'complex' and 'complicated' have been used for both concepts because their meanings overlap and contain both a subjective and objective meaning. For example consider the following definitions (Dictionary.com, 2013):

- "***Complex***
    a. Composed of many interconnected parts; compound; composite: [e.g.] a complex highway system.
    b. Characterized by a very complicated or involved arrangement of parts, units, etc.: [e.g.] complex machinery.
    c. So complicated or intricate as to be hard to understand or deal with: [e.g.] a complex problem.
- ***Complicated***
    a. Composed of elaborately interconnected parts; complex: [e.g.] complicated apparatus for measuring brain functions.
    b. Difficult to analyse, understand, explain, etc.: [e.g.] a complicated problem".

Hence the literature accordingly uses the words 'complicated' and 'complex' as synonyms to mean both subjective and objective complexity.

Sillitto distinguished between subjective and objective complexity (Sillitto, 2009) as:

- "***subjective complexity***[7] *– which means that people don't understand it and can't get their heads round it – and*
- ***objective complexity*** *– which means that the problem situation or the solution has an intrinsic and measurable degree of complexity* ".

7.7.2.2. The different types of objective complexity

[7] This author highlighted the words 'subjective complexity' and 'objective complexity'.

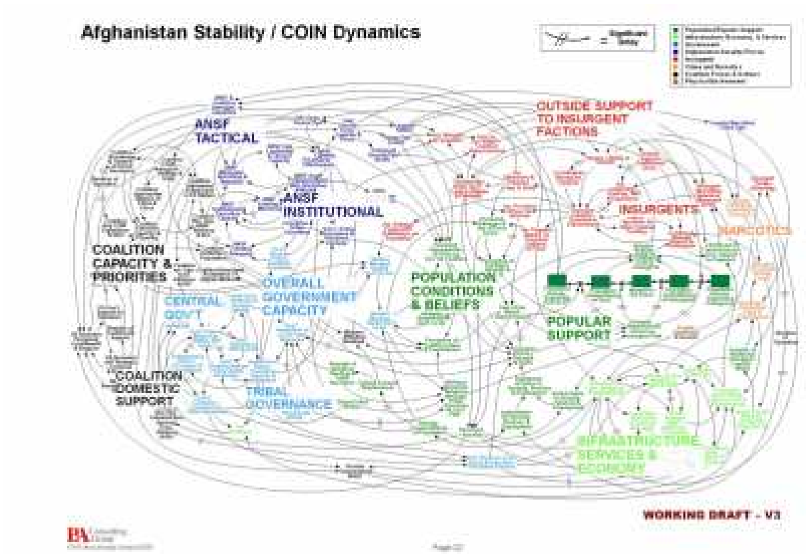

Figure 7.11 Example of artificial complexity

The various definitions of objective complexity in the literature can be aggregated into two types of objective complexity as follows:

- ***Real world complexity:*** in which elements of the real world are related in some fashion, and made up of components. This complexity is not reduced by appropriate abstraction it is only hidden.
- ***Artificial complexity:*** arising from either poor aggregation or failure to abstract out elements of the real world that, in most instances, should have been abstracted out when drawing the internal and external system boundaries, since they are not relevant to the purpose for which the system was created. It is this artificial complexity that gives rise to complexity in the manner of Rube Goldberg or W. Heath Robinson. For example, in today's paradigm, complex drawings are generated that contain lots of information[8] and the observer is supposed to abstract information as necessary from the drawings. The natural complexity of the area of interest is included in the drawings; hence the system is thought to be complex. One example is shown in Figure 7.11 When shown this drawing in a briefing, General McChrystal

[8] The DODAF Operational View (OV) diagrams can be wonderful examples of artificial complexity.

was reported to have said to an aid, "*When we understand that slide, we'll have won the war*"[9].

7.7.2.3. How to manage complex systems

There seems to be a dichotomy on the subject of how to manage complex systems. On one hand there is literature on the need to develop new tools and techniques to manage them and on the other hand, there is literature on techniques such as aggregation which mask the underlying complexity to ensure that only the pertinent details for the particular situation to deal with the issues are considered.

Examples from the 'need to develop new tools and techniques' side of the dichotomy found in a literature review of complexity in the systems engineering field include:

- Shinner who stated that the problems posed by complexity seem to be unmanageable, (Shinner, 1976).
- Bar-Yam (Bar-Yam, 2003) who:
  - Proposed that, "*complex engineering projects should be managed as evolutionary processes that undergo continuous rapid improvement through iterative incremental changes performed in parallel and thus is linked to diverse small subsystems of various sizes and relationships. Constraints and dependencies increase complexity and should be imposed only when necessary. This context must establish necessary security for task performance and for the system that is performing the tasks. In the evolutionary context, people and technology are agents that are involved in design, implementation and function. Management's basic oversight (meta) tasks are to create a context and design the process of innovation, and to shorten the natural feedback loops through extended measures of performance*"
  - Quoted the Chaos study suggesting that the systemic reason for the challenged projects was their inherent complexity (CHAOS, 1995).
  - Cited his own prior work, "*for all practical purposes adequate testing of complex engineered systems is impossible*" and suggested an evolutionary process for engineering large complex systems.

Examples from the 'just get on and deal with it' side of the dichotomy include:

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[9] http://www.nytimes.com/2010/04/27/world/27powerpoint.html, accessed 11 September 2011.

- Jenkins who defined systems engineering as, "*the science of designing complex systems in their totality to ensure that the component subsystems making up the system are designed, fitted together, checked and operated in the most efficient way*" (Jenkins, 1969).
- Maier and Rechtin who recommend that the way to deal with high levels of complexity is to abstract the system at as high a level as possible and then progressively reduce the level of abstraction (Maier and Rechtin, 2000).
- Section 7.8 and Section 9.18.

7.7.3. The Scientific perspective

Perceived from the *Scientific* perspective, Bar-Yam seems to drawing the wrong conclusion from the Chaos study. The general finding from the Chaos study that the systemic reason for the challenged projects is poor management not complexity! Bar-Yam may be correct in writing, "*that for all practical purposes adequate testing of complex engineered systems is impossible*". However perceptions from the:

- *Temporal* perspective indicates that Bar Yam's statement only applies to the architectures in use today.
- *Continuum* perspective indicates that there should be other architectures that <u>would</u> allow adequate testing.
- *Generic* perspective indicates that Bar Yam's suggestion for an evolutionary process is nothing new; it is just the concept of establishing baselines and then using a "build a little, test a little" approach which is well established in all areas of engineering.

7.8. Reducing complexity

The basic underlying complexity of the real world cannot be reduced. "*The concept that a complex system can be decomposed into smaller and simpler units - and hence into simpler problems - omits an inherent characteristic of complexity, the interrelationships among the components*" (Rechtin and Maier, 1997: page 8) (i.e. real-world complexity) however, it can be managed successfully. This Section now suggests a process for creating a system to be used in the early states of the SDP to help to manage complexity at the time the system is created by optimizing the interfaces. The process follows Maier and Rechtin's recommendation that the way to deal with high levels of complexity is to abstract the system at a high a level as possible and then progressively reduce the level of abstraction (Maier and Rechtin, 2000: page 6) and contains the following activities:

1. Examining the undesirable situation from several different perspectives discussed in Section 7.8.1.

2. Developing an understanding of the situation discussed in Section 7.8.2.
3. Create the FCFDS containing the System of Interest (SOI) discussed in Section 7.8.3.
4. Using the principle of hierarchies to abstract out the complexity discussed in Section 7.8.4.
5. Abstracting out the parts of the situation that are not pertinent to the problem discussed in Section 7.8.5.
6. Partitioning the FCFDS into the SOI and adjacent systems discussed in Section 7.8.6.
7. Optimizing the interfaces discussed in Section 7.8.7.
8. Partitioning the SOI into subsystems discussed in Section 7.8.8.

Note:

- The activities should be performed in an iterative sequential parallel manner not in a sequential manner.
- The FCFDS will evolve to the actual or created situation during the time taken to plan the SDP as well as the time taken to perform the SDP.

7.8.1. Examining the undesirable situation from several perspectives

Traditional systems enquiry creates dynamic views of the behaviour of a SOI using tools such as causal loops (Senge, 1990), system dynamics (Clark, 1998; Wolstenholme, 1990), queuing theory, linear programming and other tools used in operations research. Other approaches include building models or applying sets of equations suitable to the class of situation. However, while modelling the behaviour of a SOI does provide a wealth of information, using this single behavioural perspective does not

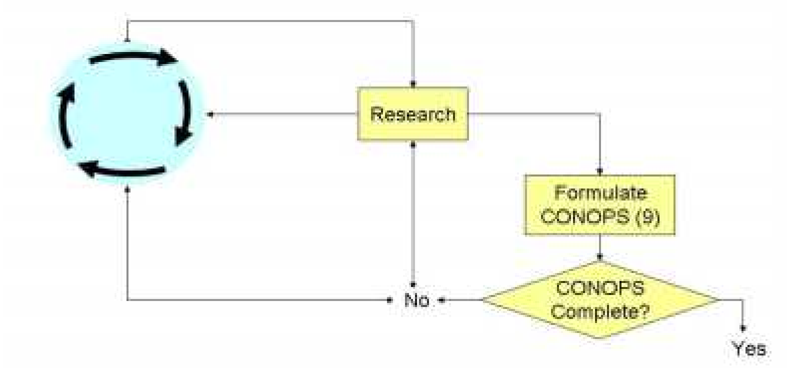

Figure 7.12 Holistic approach to formulating a CONOPS

provide a full understanding of the SOI and may even lead to a misunderstanding, identification of the wrong cause of the undesirability and a definition of the wrong problem. Thus use of these traditional systems thinking tools must be considered as only a part of the process of examining the situation to gain an understanding of the situation since one needs to go beyond systems thinking and employ perceptions from the *Generic* and *Continuum* perspectives to identify the right problems and some acceptable solutions.

7.8.2. Developing an understanding of the situation

Figure 7.12 shows the holistic approach to gaining an understanding of the situation and documenting it in a CONOPS. The situation is perceived from the eight descriptive HTPs (Section 4.3) and the understanding of the situation and the operation of the SOI in the situation is documented in the CONOPS or equivalent (*Scientific* perspective). After examining the situation from the eight descriptive perspectives, the systems engineer should develop an understanding of the situation. For example:

- The entities involved in the situation should have been identified. These entities include those directly involved and the indirect stakeholders (Kasser, 2015: pages 270 to 285).
- The behaviour of the SOI can be understood from the information obtained from the relationships in the *Operational* and *Functional* perspectives. This information is often used to build a behavioural model.
- The undesirable aspects tend to show up in the *Structural*, *Operational* and *Functional* perspectives and should have been identified by discussions with the stakeholder and by analysis.
- The cause or causes of the undesirability and a conceptual approach to remedying the undesirability should then have been

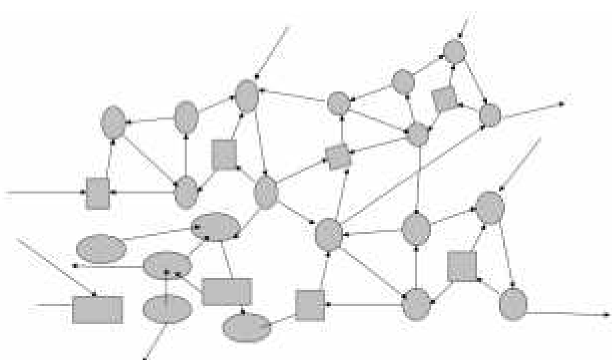

Figure 7.13 The FCFDS

inferred (*Scientific* perspective).

7.8.3. Creating the FCFDS

The FCFDS is a modified existing situation. Even in in situations where the stakeholders cannot agree on the causes of the undesirability, they should be able to agree on the nature of the undesirability and a situation in which the desirability is no longer present. As such, the initial version of the FCFDS is the existing situation with the undesirability removed, and often with suggested improvements added. The FCFDS will contain a number of elements coupled together as shown in Figure 7.13.

7.8.4. Using the principle of hierarchies to abstract out the complexity

The principle of hierarchies in systems (Section 4.3.4.1) is one of the ways humanity has managed complexity for most of its recorded history. It includes:

- Keeping the systems and subsystems at the same level in the hierarchy of systems.
- Abstracting out or hiding the internal components of systems and subsystems. For example, Maier and Rechtin recommend that the way to deal with high levels of complexity is to abstract the system at a high a level as possible and then progressively reduce the level of abstraction (Maier and Rechtin, 2000: page 6).
- The concept that one systems engineer's subsystem is another systems engineer's SOI.

A situation is a system which contains a number of systems. Each system in turn may contain a number of subsystems. Each subsystem may be further elaborated into a number of components (subsystems of the subsystem). This concept is often shown in the traditional hierarchical structure such as in organisation charts, Work Breakdown Structures (WBS) and product breakdown structures.

7.8.5. Abstracting out the parts of the situation that are not pertinent to the problem

Consider the complex and complicated concept map shown in Figure 7.11. However, if you look closely at the figure, you will see that there does seem to be a hierarchy expressed by the distinction between items in upper and lower case words. The drawing could have been made more understandable by presenting it as a series of hierarchical drawings, starting with a high level version containing just the items in uppercase, and a series of lower level drawings elaborating each element in the high level version. This is the approach used to reduce the complexity of the struc-

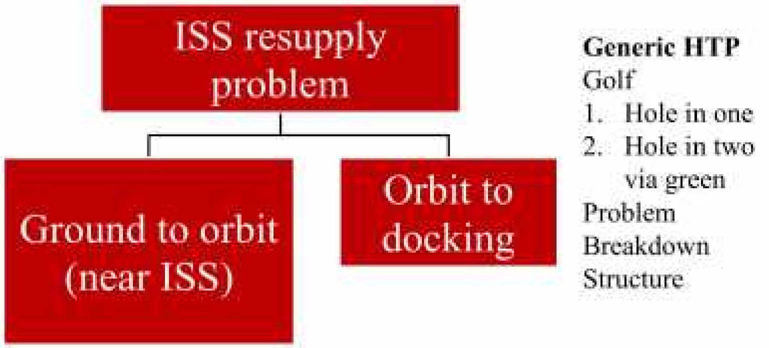

Figure 7.14 Spacecraft docking Problem Breakdown Structure (PBS)

ture of the components involved in making a cup of instant coffee from the relatively complicated drawing shown in Figure 2.6 to the two simpler drawings shown in Figure 2.4 and Figure 2.7. The abstraction technique uses elaboration (Hitchins, 2003: pages 93 to 95) coupled with domain knowledge to develop an understanding of the situation, namely the interrelationships among the parts of the system and to determine which parts of the system are pertinent to the situation and which parts can be safely ignored.

Dealing with issues in any specific situation will probably only need a subset of the information perceived from the different HTPs.

Instead of a single system view, there are a number of views, each of them dealing with some aspect of the SOI. So, it is the systems engineer's role to determine which elements are pertinent to the problem and abstract out the remainder[10]. Consider examples of:

1. Docking two spacecraft discussed in Section 7.8.5.1.
2. A rock discussed in Section 7.8.5.2.
3. A camera discussed in Section 7.8.5.3.
4. A human being discussed in Section 7.8.5.4.

7.8.5.1. Docking two spacecraft

When considering the problem of docking two spacecraft, once the spacecraft are close, the problem is simplified by creating a closed system view to only consider the:

[10] When dealing with existing systems or systems that have already been realized in other places, this information will be generally be available using the *Generic* perspective. When dealing with unprecedented systems, good systems engineers will immerse themselves in the situation to identify which elements are important, the underlying assumptions that may cause problems, etc.

- Relative positions of the spacecraft.
- Relative velocity of the spacecraft.
- Relative alignment in X, Y and Z orientation of the spacecraft.

The problem is then set up to produce a relative docking velocity close to zero with the docking collars on both spacecraft properly aligned. Positioning the spacecraft for commencing the docking maneuverer is a separate problem which takes into account their starting and target locations and velocities. Moreover, determining which factors are pertinent and which are not requires domain expertise and a correct understanding of the situation.

The problem of docking two spacecraft at this time is generally a sub-problem of transferring supplies from the earth to the spacecraft as shown in the Problem Breakdown Structure (PBS) in Figure 7.14 which depicts the problem of docking a resupply spacecraft to the International Space Station (ISS). The problem could be treated as a complex problem, but perceptions from the *Generic* perspective indicate a similarity between trying to get a hole in one in golf, and a single step docking solution. Splitting the problem into to sub-problems simplifies the effort where:

- The first problem is to get the ball on the green in golf, or get the resupply vehicle close to the spacecraft being resupplied.
- The second problem is to get the ball into the cup in golf, and docked to the second spacecraft in the resupply situation.

7.8.5.2. A rock

A rock is a very simple system made up of chemical molecules[a]. The system boundary is drawn at the surface. While determining the nature of the rock, various views can be used including:

- ***Sight:*** one looks at its colours.
- ***Taste:*** taste might give us some information about the chemicals in the rock.
- ***Weight/mass:*** might tell us something about its composition.
- ***Touch:*** the surface texture might be of interest.
- ***Chemical analysis:*** the components might be of interest.
- ***Radiation:*** could tell us something.

Each view provides information that the others do not, helping to build up a complete understanding of the nature of the rock. Which view we use depends on what issue we are dealing with.

[a] If it contains more than one element and the properties of the rock are due to the elements and their interactions.

7.8.5.3. A camera

Perceive a camera. As discussed in Section 4.3.2.6.9, when considering:

- The device that takes the photograph or creates the image, the system boundary is drawn around the camera.
- The act of taking the photograph, the system boundary is drawn to include the photographer.
- Transporting the camera from one place to another, the system boundary is drawn to include the transportation elements including the carrying case.

Developing one representation that includes all the elements for photographing and transportation and then requiring the elements under consideration for a specific situation to be abstracted out of the representation, creates unnecessary complexity. The three separate simpler views, abstracted out of the real world are simpler for understanding the various aspects of the use of a camera in photography.

7.8.5.4. A human being

Some areas of the real world can only be fully understood by a combination of:

- Examining the internal components of the system.
- Observing the system in action in its environment.

Consider a human being, a biological system. To learn about:

- The interaction between the system and its adjacent systems we observe the sample in action in specific situations and either observe or infer the interaction.
- The internal subsystems we have to dissect a sample of the system. However, once dissected, an individual sample cannot usually be restored to full functionality. However we have learnt something about the class of systems it represents which can be applied to other instances (human beings); the assumption being that the internal components of human beings are almost identical so that what is learnt about one instance of the system applies to the entire class of that system.

7.8.6. Partitioning the FCFDS into the SOI and adjacent systems

It is the act of drawing the system boundary that creates the system (Jackson and Keys, 1984; Beer, 1994; Churchman, 1979: page 91). When the undesirable situation already contains a SOI, such as in an upgrade or replacement situation, then the existing SOI tends to be the starting point for creating a new SOI. However, the systems engineer should not assume that the boundaries of the existing and new (replacement) SOIs are identical and keep in mind that the boundaries of the SOI may need to change to remedy the undesirable situation as described below.

The entities in the FCFDS should be aggregated into the SOI and adjacent systems by some common denominator such as function, mission or physical commonality according to the rules for performing the aggregation described below.

7.8.6.1. Rules for performing the aggregation

The FCFDS is partitioned into the SOI and adjacent systems using the following three rules for performing aggregation:

1. ***Keep number of subsystems at any level to less than 7±2:*** in accordance with Miller's rule to facilitate human understanding of the SOI (Miller, 1956).
2. ***Configure each subsystem for the maximum degree of homeostasis:*** this rule which is widely used in human systems as well as in technological systems provides risk management and interface simplification since a subsystem configured according to this rule:
    - Ensures that the subsystem can continue to operate if the command and control link is lost.
    - Often requires a simple interface that passes relatively low-speed high-level commands and status information rather than high-speed real-time control commands.
3. ***Maximize the cohesion of the individual subsystems and minimize the coupling between subsystems*** (Ward and Mellor, 1985).

There are various types of cohesion and coupling.

7.8.6.1.1. Continuum of coupling

When perceiving coupling and cohesion from the *Continuum* perspective, the degree of coupling and cohesion can be seen as lying on a continuum as follows:

- ***Independent:*** the end of the continuum where the elements are not coupled at all.
- ***Interdependent:*** the middle sections of the continuum where the coupling of the elements ranges from loosely-coupled to tightly-coupled.

- ***Inseparable:*** the other end of the continuum where the elements are so tightly coupled that they cannot be separated.

7.8.6.1.2. Relating or joining the elements together

Cohesion and coupling also define how the elements relate or join together, where:

- ***Cohesion:*** the term used with respect to the closed system view seen from an external perspective looking into a <u>single</u> system or subsystem.
- ***Coupling:*** the term used with respect to the open system view seen from an external perspective looking at <u>more than a single</u> subsystem or subsystem.

Sommerville provided the following list of types of cohesion in the software domain (Sommerville, 1998):

- ***Coincidental:*** the elements have no relationship.
- ***Logical:*** the elements are performing similar functions.
- ***Temporal:*** the elements that are activated at a single (the same) time.
- ***Procedural:*** the elements that make up a single control sequence.
- ***Communicational:*** the elements that operate on the same input data or produce the same output data.
- ***Sequential:*** the output from one element in the component serves as input for some other element.
- ***Functional:*** each element is necessary for the execution of a single higher-level function.

Other types of coupling from the software domain include:

- ***Content coupling (high):*** one element modifies or relies on the internal workings of another element, e.g. accessing local data of another element.
- ***Common coupling:*** two elements share the same global data, e.g. a global variable.
- ***External coupling:*** two elements share an externally imposed data format, communication protocol, or device interface.
- ***Control coupling:*** one element controls the logic of another, by passing it information on what to do.
- ***Stamp coupling (data-structured coupling):*** the elements share a composite data structure and use only a part of it, possi-

bly a different part, e.g. passing a whole record to a function which only needs one field.

- ***Data coupling:*** the elements share data, e.g., through parameters.
- ***Message coupling (low):*** the elements are not dependent on each other; instead they use a public interface to exchange parameter-less messages.
- ***No coupling:*** the elements do not communicate with one another.

In the physical realm, one can add other forms of coupling including:

- ***Mechanical coupling:*** the elements are coupled together by mechanical means, e.g. rivets, nuts and bolts, nails, joints, glue, welds, hook and loop fasteners, etc.
- ***Gravitic coupling:*** the elements are coupled together by gravity, e.g. one element rests on top of another. This type of coupling is common on planetary surfaces.
- ***Magnetic coupling:*** the elements are coupled together by magnetic means, e.g. intruder alarms, magnetic locks and items on refrigerator doors.
- ***Electrostatic coupling:*** the elements are coupled together by electrostatic charges.

Each type of coupling has advantages and disadvantages. The role of the systems engineer is to examine the different ways components can be aggregated into subsystems and use a design approach that maximizes cohesion and minimizes coupling which contributes to optimizing the interaction between the interfaces of the subsystems. A useful tool to perform this activity is the N^2 chart (Lano, 1977) (Section 2.7.5.5) or the Design Structure Matrix (Eppinger and Browning, 2012).

7.8.6.1.3. Variations on a theme

However, in practice, maximizing cohesion and minimizing coupling is not always the rule in systems engineering. Consider the two subsystems A and B shown in Figure 7.15. There are three interfaces between the two subsystems. Note that element B4 in subsystem B does not have any connection with the remaining elements in subsystem B. From the software perspective the coupling is coincidental and if the rules are followed, element B4 should be moved to subsystem A to become element A5 and reduce the number of interfaces to a single interface as shown in Figure 7.16. The systems engineering rules are slightly different and depend on the situation. For example:

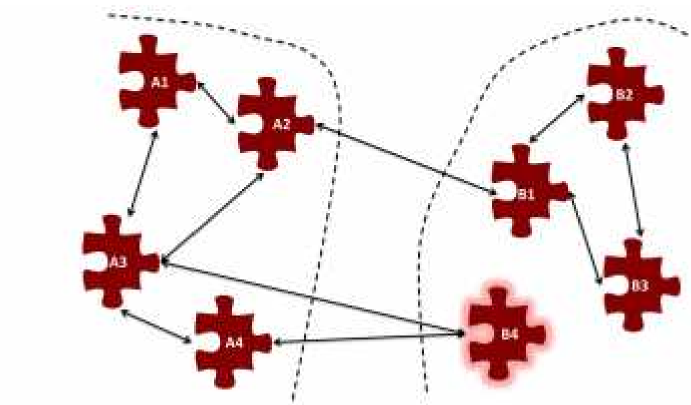

Figure 7.15 Cohesion and coupling

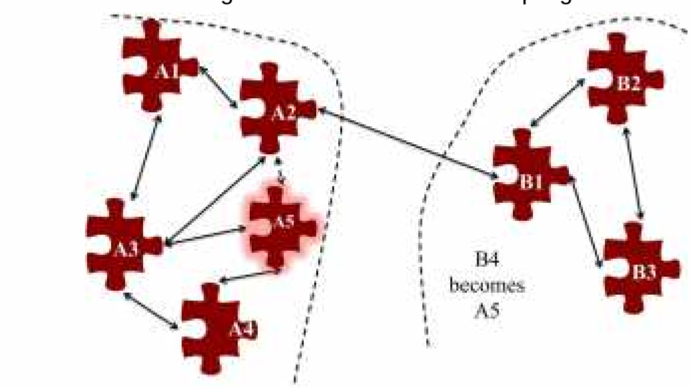

Figure 7.16 Better coupling and cohesion

- If subsystem A is the flight subsystem of a UAV and subsystem B is the ground control subsystem, then B4 may be located in the ground subsystem because it may consume too much power or be too heavy to fly. In such a situation, it is the role of the systems engineer to monitor the rate of change in technology maturity to determine that if in the future, should the system be upgraded, element B4 is a candidate for replacement with a different technology that would allow it to be moved to subsystem A4.
- Element B4 could also represent a function performed by the operator in the ground subsystem in the initial release of the operational software. This approach allows for an incremental software delivery approach where the function is intended to be migrated to the flight subsystem in subsequent software upgrades.

7.8.7. Optimizing the interfaces

Optimizing complex systems represents a challenge for reasons that include:

- There will usually be different viewpoints on what should be optimized.
- Traditional approaches to complex systems development either ignore the issue or optimize subsystems.
- The system optimization paradox which was stated by Machol and Miles who wrote, "*the principle of suboptimization states that optimization of each subsystem independently will not lead in general to a system optimum, and that improvement of a particular subsystem actually may worsen the overall system. Since every system is merely a subsystem of some larger system, this principle presents a difficult if not insoluble problem, - one that is always present in any major systems design*" (Machol and Miles Jnr, 1973: page 39).

The system optimization paradox can be dissolved. System optimization at any level optimizes the interactions between the subsystems at that system level within the constraints imposed by the systems engineer of the metasystem, via:

- "*The proper allocation of the system requirements to the subsystems*" (Wymore, 1997).
- The rules for performing the aggregation discussed in Section 7.8.6.1.

This Section now examines the following range of systems from a perspective in which the subsystem boundaries are redrawn to show that the SOI can be considered as having been optimised for the interactions between the subsystems:

1. Optimizing your sex life discussed in Section 7.8.7.1.
2. Weapons systems discussed in Section 7.8.7.2.
3. Logistics systems discussed in Section 7.8.7.3.
4. The Apollo Program discussed in Section 7.8.7.4.
5. Resupplying the MIR space station discussed in Section 7.8.7.5.
6. The human cardiovascular system discussed in Section 7.8.7.6.
7. A distance-learning classroom discussed in Section 7.8.7.7.
8. The library discussed in Section 7.8.7.8.
9. Forming the INCOSE Australia Chapter discussed in Section 7.8.7.9.

7.8.7.1. Optimizing your sex life

Optimizing your sex life raises several issues mostly not addressed. For example, in this situation, is each of the participants a system on their own, or are they subsystems of a greater whole? Traditional subsystem optimization approaches would result in an optimization of either the male experience or the female experience[12], while a holistic approach to optimization would seek to optimize the mutual experience by applying holistic thinking to the problem.

In such a situation, you would seek to understand the situation using perceptions from the eight descriptive HTPs (Section 4.3) as a starting point. This is an iterative research situation in the manner of Hall's methodology for systems engineering (Hall, 1962) where you have to research the application domain to gain an understanding of the situation but is generally shown as a sequential process such as the one in Figure 9.1. The only practical difference is that the product of the Scientific Method (Section 9.12.2.1) is a supported hypothesis, while the product produced here is a CONOPS. Consider the process steps.

1. Observe discussed in Section 7.8.7.1.1.
2. Research discussed in Section 7.8.7.1.2.
3. Understand the situation discussed in Section 7.8.7.1.3.
4. Formulate the hypothesis for the solution discussed in Section 7.8.7.1.4.
5. Test the solution performance to verify it meets the need discussed in Section 7.8.7.1.5.

7.8.7.1.1. Observe

You first seek perceive the situation starting from the eight descriptive HTPs on the perspectives perimeter shown in Figure 4.4 and then using Active Brainstorming with cognizant stakeholder personnel to generate ideas. In this instance some of the typical starter questions from the *Functional*, *Operational* and *Generic* perspectives in Section 6.2.2 would be good starting points.

7.8.7.1.2. Research

You would then perform some research by immersing yourself in the situation or by means of a literature review or by holding discussions with domain experts to clarify issues or answer questions that came up during the Active Brainstorming sessions. You might also undertake some prototyping experiments to clarify aspects of the situation. The results of the prototyping experiments would be analysed and further research under-

[12] Assuming heterosexual activity in keeping with the traditional view.

taken if necessary. The research findings might determine that some of the factors are subjective and depend on the person (the subsystem), the time and place (the environment), a function of age, length of relationship or other factors. In such a situation you would list these factors as solution selection criteria and determine ways to identify and weight these factors. It should be noted that this step is often overlooked, and when it is overlooked, tends to result in the formulation of the wrong problem statement.

7.8.7.1.3. Understand the situation

The next step is to gain an understanding of the situation as discussed in Section 7.8.2.

7.8.7.1.4. Formulate the hypothesis for the solution

The next step, assuming a linear sequence, is to formulate the problem statement in the form of a hypothesis (the *Scientific* perspective). "*A problem well stated is a problem half solved*" (Dewey, 1933). If the problem can be stated as a function, then the solution system is one that provides the needed functionality (Hall, 1989) which can be described in a CONOPS. The first version of a CONOPS constitutes a hypothesis for the operation of the solution system in its FCFDS. In this instance, you would determine the factors that make your sex life enjoyable and what signals need to be exchanged between you and your partner[13] on all interfaces (tactile, audible, visual, etc.) at all times. You (and your partner, if available) would develop a CONOPS containing scenarios for the mission and support[14] functions performed in different aspects of your sex life.

7.8.7.1.5. Test the solution performance to verify it meets the need

The linear sequence approach teaches that once the hypothesis for the functionality of the solution has been developed in the form of the CONOPS, the hypothesis would be tested against solution selection criteria. In reality, this is not a linear process; it is a continual process of observation, brainstorming, research and hypothesis formulation and in-process hypothesis formulation and testing as shown in Figure 7.12 so that when completed, the CONOPS represents the system operating in a FCFDS.

7.8.7.1.6. Comments

Traditional subsystem optimization would tend to result in an optimization of either the male experience or the female experience. The tradi-

[13] Before, during and after the actual sex act

[14] In this instance, the support functions might be concerned with creating the appropriate environment, and ensuring that appropriate consumable supplies are available as and when needed (logistics).

tional approach might begin by considering one of the parties and optimizing the system to provide maximum pleasure for that party. The holistic approach on the other hand considers both parties as parts of a larger system and optimizes the interactions at the interface for maximum pleasure to both parties. In a really complex system, there may be a number of interfaces such that the individual interfaces may be grouped into a third high-level subsystem. Notice that there may be different subsystem boundaries in the traditional and holistic approaches as shown in the examples that follow.

7.8.7.2. Weapons systems

Weapons systems are initially designed to perform specific missions. The general goal of a weapons system is to deliver the required amount of something, usually, but not necessarily, explosive ordnance, to the target in a timely manner. The ‘required’ amount depends on the mission. For example, tanks were originally designed as part of a system that would enable troops to pass safely through territory swept by hostile machine gun fire, specifically the trenches in World War I. From the holistic thinking perspective, let the battlefield be the system and the allied forces and enemy forces be the two major subsystems (friend and foe), then the tank can be considered as an element of the interface between the friend and foe subsystems. The subsystem partitioning is reasonably traditional.

With hindsight, what actually happened can be discussed as if holistic thinking had been employed starting with framing the problem as:

- ***The undesirable situation:*** the inability to break through the enemy front line trenches (swept by machine gun fire which, according to lessons learned from experience, precluded the traditional infantry or cavalry charge from performing the function) so that infantry and cavalry could then be used in their traditional manner to route the enemy after a breakthrough.
- ***The FCFDS:*** a break through into the enemy front line trenches by the application of yet-to-be-developed technology.
- ***The problem:*** to create the FCFDS.
- ***The solution:*** unknown at the time the problem was formulated.

Various scenarios would have been conceptualized and rejected. Research would have been carried out to see if there was anything appropriate that could be employed. Concepts such as shields (hand-held or motorized) and land ships (tanks) would have been prototyped and various types of tanks evolved together with the tactics for their use. In fact, the lack of holistic thinking meant that the tank was not effectively integrated into the British forces until the Battle of Amiens which began on 8 August 1918. This was the battle that led to the end of World War I. However, by then the Germans had learned to deal with tanks. Consequently, 72% of the Allied Tank Corps was destroyed in the first days of the battle, 41.4% of all British tanks had been destroyed by the 64th day and on 5 November the British only had eight tanks left. Luckily, the tank was not the deciding factor in ending the war. The holistic approach might have produced a better system (integration of tanks, infantry and doctrine) and fewer casualties.

Other weapons systems subsystems partitions include 'gun-bullet-target' where the system is optimized to cause maximum damage to the target at the other end of the bullet interface.

7.8.7.3. Logistics systems

Once Total Cost of Ownership (TCO) and Life Cycle Costing (LCC) were taken into account at system design time, logistic systems were generally designed to support the mission and deliver optimal support to the operational system.

In the holistic view, it is the interface (subsystem) between the mission and support subsystems that keeps the mission functions operational. In many situations, once the CONOPS for the mission and support functions has been developed, the system is optimized for maximum operational availability of the operational subsystem. The trade-offs to optimize the operational availability of the mission system at design time deal with reliability, failure rates, failure modes and failure consequences, Mean Time To Repair (MTTR), etc.

7.8.7.4. The Apollo Program

The Apollo Program was a major systems engineering success. From the *Structural* perspective, consider the Apollo Program as the system containing three top-level physical subsystems, (1) the earth subsystem, (2) the lunar subsystem and (3) the interface subsystem between the earth and lunar subsystems, where:

1. ***The earth subsystem*** contained the (NASA Manned Spacecraft Centers and Headquarters.
2. ***The lunar subsystem*** was empty before the first landing and then contained an increasing number of Apollo Lunar Surface Experiments Packages (ALSEP)[15], the set of scientific instruments deployed by the astronauts at each of the landing sites.

[15] Each flight transferred an ALSEP from the earth to the lunar subsystems.

Two astronauts were part of this subsystem while on they were on the lunar surface.

3. ***The interface subsystem*** contained the spacecraft, the astronauts (three while in transit, one when in lunar orbit) and the NASA Communications Network (NASCOM) subsystems.

From this perspective, the Apollo Program seems to have been optimized to transfer men and ALSEPs between the earth and the moon in the most efficient manner within the constraints of the then available technology. This resulted in a manually intensive complex understandable earth subsystem. Unfortunately this subsystem arrangement was perpetuated into the post Apollo era for various reasons resulting in a minimally reusable overly expensive space transportation system commonly known as the Space Shuttle.

In addition note how the subsystem boundaries changed during the mission. The astronauts moved between the interface subsystem and the lunar subsystem. The Lunar Lander was originally a part of the interface subsystem and then became a part of the lunar subsystem when it was left behind after the return ascent.

7.8.7.5. Resupplying the MIR space station

MIR was a Soviet/Russian space station in Low Earth Orbit (LEO) from 1986 to 2001. When faced with the problem of resupplying MIR, the subsystem boundaries remained the MIR, the earth and the interface subsystem. The system was optimized for the delivery of personnel and cargo to MIR, personnel being delivered by manned vehicles and cargo mainly by unmanned autonomous vehicles. Simple, readily understandable and effective!

7.8.7.6. The human cardiovascular system

The human cardiovascular system delivers oxygen to the muscles in the human body. At the top-level, the system can be represented by the respiratory subsystem which oxygenates the blood, the muscles subsystem, and the heart and blood vessels which comprise the bulk of the interface between the lungs and the muscles subsystems.

7.8.7.7. A distance-learning classroom

The distance-learning classroom at Missouri University of Science and Technology (MS&T) for SysEng 412 Complex Engineering Systems Project Management in the Fall 2010 semester was a complex system. The traditional non-holistic view might have organised the subsystems as:

- A face-to-face classroom at MS&T equipped with the appropriate synchronous technology for including distant students in the learning process.
- The students in the face-to-face classroom[16].
- A synchronous distance-learning classroom using the Webex platform.
- An asynchronous distance-learning classroom using the Blackboard 9 platform.
- The distance mode students in the USA.
- The instructor in Singapore.
- The email system for asynchronous communications.
- The real-time support staff at MS&T. Note, support was available online during each weekly session and offline in non-real time with a timely response.

On the other hand, the holistic perspective partitions the system into two top-level subsystems and an interface subsystem. The three subsystems are the:

1. Instructor.
2. Students.
3. Interface subsystem consisting of the classrooms and other facilities.

The system was designed to optimize the learning experience based on the needs of postgraduate employed students studying in their spare time (Kasser, et al., 2008). The design of this iteration of SysEng 412 included a mixture of lectures, readings and problem-based learning activities using both synchronous and asynchronous activities. When the semester began, the study materials were loaded into Blackboard for asynchronous downloading prior to the weekly Webex synchronous session. The lecture was given synchronously; the students worked together synchronously and asynchronously and made a synchronous presentation in the weekly Webex synchronous sessions. However, a week or so after the semester began an anomaly showed up in the synchronous lectures. The instructor's Webex audio suffered from distortion that made it unintelligible at times according to some but not all students. Upon enquiring about the situation, the support staff acknowledged that this was a recurring problem when the instructor was located outside the US.

The interface system was quickly redesigned to keep the learning experience optimal. Subsequent lectures were pre-recorded as MP3 voice

[16] There weren't any in this instance.

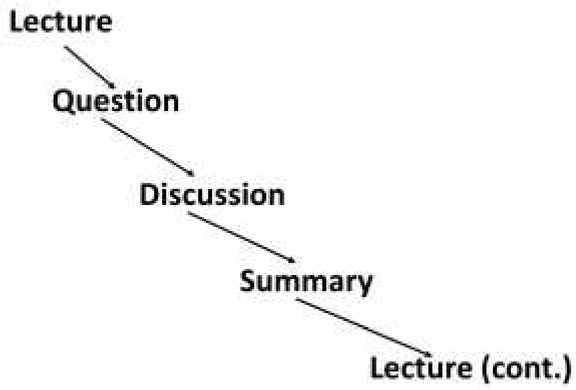

Figure 7.17 Synchronous lecture thread

quality bandwidth audio files and uploaded to the Blackboard area for the specific session together with the lecture slides. The students downloaded the lecture audio files together with the lecture slides and listened to the lecture asynchronously prior to the Webex synchronous session[17]. The redesigned lecture faced a delivery domain problem due to the differences between synchronous and asynchronous lectures. The major one being that the students could not ask questions in an interactive synchronous manner. This drawback was overcome using domain knowledge in the following manner.

- The instructor would cue the students to change slides in the pre-recorded lectures using wording such as "and on the next slide". Additionally, every now and again during the talk, the instructor would mention the slide number as a synchronization signal. At the appropriate points in the lecture where the instructor would pause and ask for questions, an 'any questions slide' was inserted into the lecture slides. The questions were posed asynchronously and a comment was added to each question that answers would be provided in the interactive session.
- The asynchronous lecture was reformatted to allow for multiple threads so that later content did not depend on a previous discussion in the same session. Perceptions from the *Continuum* perspective show that unlike the face-to-face classroom where lectures are interspersed with question and answer discussions as shown in Figure 7.17, the asynchronous classroom is multi-threaded not single-threaded as shown in Figure 7.18 since the

[17] Having the students review the lecture and other material prior to the classroom session has become known as a 'flipped classroom' in the literature.

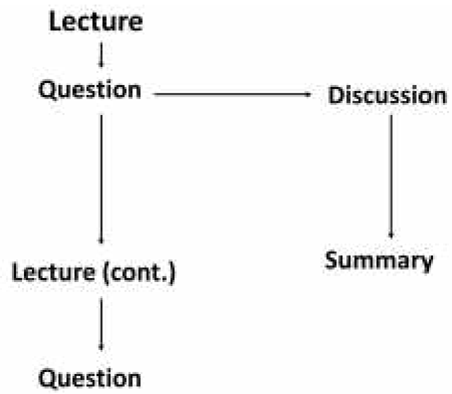

Figure 7.18 Asynchronous lecture threads

instructor cannot wait for a few days before continuing the lecture.

- During the interactive synchronous session, the instructor paged through the lecture slides summarizing the lecture, sometimes adding additional information and always stopping at the appropriate places for questions and comments.

The students soon caught on to the idea and the end result was a shortened synchronous session which allowed the students to spend more time on the problem-based learning activities (even more optimal). Indeed the system was flexible enough so that on one occasion when the instructor was travelling to a conference at the exact time the synchronous session was due to take place, the pre-warned students were able to prepare and upload asynchronous presentations to Blackboard and the whole session took place asynchronously (presentations and post presentation dialogue (questions and comments)) in Blackboard.

7.8.7.8. The library

The library-patron system provides desired information (books, journals, and publications) sourced in, or obtained by, the library subsystem to patron subsystem. Libraries have been optimizing the interface delivery for years finding newer and better ways to provide patrons with the desired information. Librarians just call this providing better service.

7.8.7.9. Forming the INCOSE Australia Chapter

After the Memorandum of Understanding (MOU) between the INCOSE and the Systems Engineering Society of Australia (SESA) expired in 2004, the members of SESA attending its annual general meeting voted that SESA <u>not</u> become a Chapter of INCOSE and remain an independent organization. This left an undesirable situation in which there was a desire and support for a Chapter of INCOSE in Australia, while at the same time the overwhelming majority of Australian systems engineers wanted a single professional organisation for systems engineers in Australia and feelings were running high on the issue. The innovative solution which came from the *Generic* perspective was to constitute a Chapter of INCOSE in Australia, INCOSE-Australia as *a special interest group within SESA*. This solution:

- Avoided a "civil war" within the systems engineering profession in Australia.
- Meant that nobody could join INCOSE-Australia without being a member of both INCOSE and SESA.
- Allowed those SESA members who desired INCOSE services and products to obtain them without having to join two professional societies;
- Allowed those systems engineers that did not desire the INCOSE products and services to be part of SESA.

In this situation, Australia has a single systems engineering professional society within the Engineers Australia constituency namely SESA. However, as far as INCOSE is concerned there are two systems engineering professional societies in Australia. In the traditional view, the two societies may be viewed as subsystems of the systems engineering community in Australia (the system). The innovative solution was made possible by considering SESA as containing the following non-traditional three functional subsystems:

- INCOSE Australia which constituted the members of SESA who were also members of INCOSE.
- The remaining non-INCOSE membership of SESA.
- The SESA Headquarters which received the dues payment from INCOSE.

The system was optimized for minimal interface activity on the interfaces between the subsystems by a simple modification or addition to the existing system. The original dues paying process shown in Figure 7.19 allowed systems engineers in Australia to pay their dues directly to SESA or via the Institute of Engineers Australia (IEAust). The modified dues paying process is shown in Figure 7.20. The modification allowed Australian systems engineers who wished to be part of INCOSE to pay their membership dues to INCOSE directly just like any other regular INCOSE member anywhere else in the world. INCOSE then bulk refunded a portion of the dues to INCOSE Australia but made the payment directly to SESA; the refunded portion covering the membership dues for

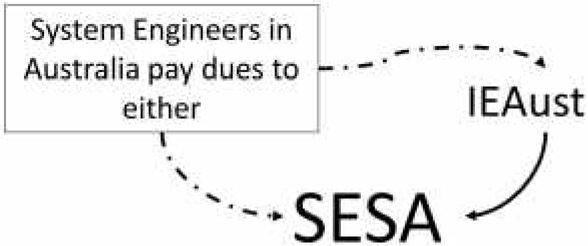

Figure 7.19 SESA dues payment process

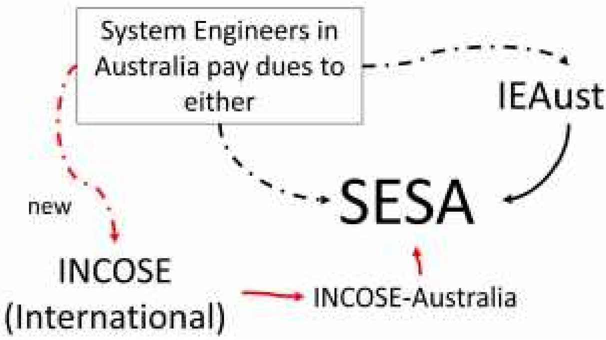

Figure 7.20 Modified SESA dues payment process

SESA. The single individual dues payment to INCOSE provided membership of both organizations. In addition, INCOSE Australia did not need a bank account as INCOSE Australia incurred no costs since all professional systems engineering society activities in Australia were SESA activities by definition. The only information that needed to be exchanged at the interface between the INCOSE Australia and SESA was the list of INCOSE Australia members that was passed to SESA for the purpose of providing mailing labels for the quarterly SESA newsletter. As a serendipitous benefit, SESA had the advantage of autonomy from INCOSE and did not have to conform to any INCOSE rules and regulations[18].

[18] The downside was that the handful of SESA members who were members of IEAust and also wanted to be members of INCOSE had to pay dues to both IEAust and INCOSE, which is what they had to do before the modification.

The elected officers of INCOSE Australia had little to do on behalf INCOSE Australia other than remembering to hold the required annual general meeting[19]; in particular there was nothing for the treasurer to do.

7.8.7.10. Discussion

The holistic approach to optimizing a system may be defined as an approach that *optimises* the system for *the interactions between the subsystems* at design time, rather than an approach that optimizes the subsystems after the subsystem boundaries have been determined. This approach is self-similar and should apply to any level in the system hierarchy thus dissolving the paradox/problem discussed by Machol and Miles. In each of the examples discussed in Section 7.8.7, even though the systems are complex, understanding the system functionality is reasonably straightforward. This is because the functionality of each subsystem can be understood, as can the interactions at the interface.

In some of the examples the subsystem boundaries were traditional, in others they were non-traditional. The tank development can be mapped into the holistic approach but the development wasn't holistic and the results were less than optimal. The objective was achieved but the price in loss of lives and materiel was higher than it could and should have been. The holistic approach to designing a system is a slightly different approach from that currently employed. It is a structured hierarchical approach to design and analysis. The functional allocation of the CONOPS is mapped into two major physical subsystems and an interface (subsystem) between them. The interfaces between the functional subsystems are then optimized.

Domain knowledge in the problem, solution and implementation domains (Section 5.1.3.2.1) is a critical element in the holistic approach to optimizing complex systems. The systems engineer uses the domain knowledge to visualize a conceptual two subsystems and optimized interface implementation of the CONOPS.

It was an analysis of the holistic approach to improving your sex life that provided the insight to create the two subsystems and optimal interface approach to optimizing complex systems. Use of the approach should also provide a serendipitous indirect benefit: not worrying about how to understand and optimize complex systems should reduce stress and consequently also improve your sex life.

[19] All professional systems engineering society activities with Australia are SESA activities by definition.

7.8.8. Partitioning the SOI into subsystems

Once the FCFDS has been partitioned into its subsystems, the SOI and adjacent systems, by the metasystem systems engineer, the SOI systems engineer then partitions the SOI into subsystems using the same process for creating a system, namely by going back to Section 7.8.1 and working on the SOI. This is in accordance with the concept that one systems engineer's subsystem is another systems engineer's system in the hierarchy of systems.

The internal subsystem partitioning within each adjacent system are the province of the particular adjacent system systems engineer just like the internal details of the SOI are the province of the SOI systems engineer. Note:

- In some cases the system boundaries may need to change over time, such as when an organization is reorganized and as discussed in cohesion and coupling above.
- The metasystem systems engineer may occasionally override the SOI subsystem partitioning to meet metasystem requirements as discussed in Section 7.8.6.1.3.

7.8.9. The recursive perspective

As may be noted from Section 7.8.8, the process for creating systems is recursive. The first time through the process, the SOI is entire undesirable situation which is partitioned into the solution system and adjacent systems. The second time through the process, the solution system is the SOI and the undesirable situation is the need to partition the SOI into its subsystems. The adjacent systems are the province of their own systems engineers. And so on down the system-subsystem hierarchy.

7.9. Summary

This Chapter:

1. Discussed the nature of systems because:
    1) Undesirable situations, desirable situations, problems and solutions tend to manifest themselves in systems.
    2) The process to change from an undesirable situation to a desirable situation incorporates the problem-solving process which often includes or overlays the System Development Process (SDP).
    3) The process is itself a system.
2. Began with a list of definitions of a system in Section 7.1

3. Perceived the nature of systems from the different HTPs in Section 7.2.
4. Introduced yet another definition of a system in Section 7.3.
5. Discussed basic system behaviour in Section 7.4
6. Discussed the properties of systems in Section 7.5.
7. Introduced a standard functional template for a system from which it should be possible to develop a set of reference functions for any class of system in Section 7.6.
8. Discussed complex systems in Section 7.7.
9. Discussed ways of reducing complexity in Section 7.8 including examples of how to optimise systems based on the interactions at the interfaces of the subsystems.

In some of the examples discussed above the subsystem boundaries were traditional, in others they were non-traditional. The tank development can be mapped into the holistic approach but the development wasn't holistic and the results were less than optimal. The objective was achieved but the price in loss of lives and materiel was higher than it could and should have been. The holistic approach to designing a system is a slightly different approach from that currently employed. It is a structured hierarchical approach to design and analysis. The functional allocation of the CONOPS is mapped into two major subsystems and an interface (subsystem) between them. The interfaces between the functional subsystems are then optimized.

Domain knowledge in the problem, solution and implementation domains (Section 5.1.3.2.1) is a critical element in the holistic approach to optimizing complex systems. The systems engineer uses the domain knowledge to visualize a conceptual two subsystems and optimized interface implementation of the CONOPS.

It was an analysis of the holistic approach to improving your sex life that provided the insight to create the two subsystems and optimal interface approach to optimizing complex systems. Use of the approach should also provide an indirect benefit – not worrying about how to understand and optimize complex systems should reduce stress and consequently also improve your sex life.

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8. Decisions and decision-making

This Chapter:

1. Discusses decision-making because decision-making is at the heart of problem-solving. Decision-making is the part of the problem-solving process, where the candidate solutions, options or choices are evaluated against predetermined selection criteria and a decision is made to select one or more of the options. The decision may be easy or difficult, simple or complicated. Some decisions can be made instantaneously; some decisions may require weeks or even years of study to gather the relevant information necessary to make the decision. Some people have problems making decisions; others make decisions instantaneously or intuitively.
2. Begins by discussing qualitative and quantitative decision-making Section 8.1.
3. Introduces a number of decision-making tools in Section 8.2.
4. Discusses decision traps that produce bad decisions in Section 8.3.
5. Discusses decision outcomes including how to avoid unanticipated consequences in Section 8.4.
6. Discusses sources of unanticipated consequences in Section 8.5.
7. Discusses risk and opportunity in decision-making in Section 8.6.
8. Discusses the four key elements in making decisions with several anecdotal examples in Section 8.7.
9. Summarises Decision Trees and Multi-attribute Variable Analysis (MVA) in Section 8.8.

8.1. Qualitative and quantitative decision-making

Perceptions from the *Continuum* perspective indicate, "*We need to differentiate between the quality of the decision and the quality of the outcome*" (Howard, 1973: page 55). A good decision can lead to a bad outcome and conversely a bad decision can lead to a good outcome. The quality of the decision is based on doing the best you can to increase the chances of a good outcome hence the development and use of decision-making tools to assist the decision maker to make the best decisions possible under the circumstances existing at the time the decision is to be made. Decisions can be made using quantitative and qualitative methods where:

- ***Qualitative:*** decision-making tends to be subjective and holistic being based on feelings about the selection criteria. Since the selection criteria are often not expressed, it can make use of unarticulated selection criteria. However:
    - It is difficult to justify the decision since it is subjective and based on unarticulated selection criteria.
    - The decision maker can focus on a subset of the selection criteria and ignore others.
- ***Quantitative:*** decision-making tends to be reductionist being based on predetermined selection criteria so it seems to provide an objective justification for the decision since the reasoning behind the decision is explicit. However:
    - Determining the weighting functions for the selection criteria is often subjective.
    - The decision is limited to the articulated predefined selection criteria.

The literature tends to discuss each tool and decision-making approach as being used in an either-or case, namely use one tool or the other to make a decision. However, in the real world we use perceptions from the *Continuum* perspective to develop a mixture of tools or parts of tools as appropriate. For example, determination of selection criteria is often a subjective approach, even when those criteria are later used in a quantitative manner.

8.2. Decision-making tools

Decision-making tools allow you to explicitly separate the variables and their attributes pertaining to decisions. While many types of these tools are available, this Chapter focuses on Pair Wise Comparisons (PWC), Decision Trees and MVA describing them in the context of examples.

8.3. Decision traps

Russo and Schoemaker provided ten decision traps, or factors that lead to bad decisions (Russo and Schoemaker, 1989); in summary, they are:

1. ***Plunging in:*** beginning to gather information and reach conclusions without taking the time to think though the issue.
2. ***Frame blindness:*** defining the wrong problem.

3. ***Lack of frame control:*** failing to define the problem in more than one way or being unduly influenced by other people's frames.
4. ***Overconfidence in your judgment:*** failing to collect key facts because you are sure of your assumptions and opinions[1].
5. ***Short-sighted shortcuts:*** relying inappropriately on "rules of thumb" such as implicitly trusting the most readily available information or anchoring too much on convenient facts.
6. ***Shooting from the hip:*** believing that you can keep all the information in your head and therefore "winging it" rather than following a systematic procedure when making the final choice.
7. ***Group failure:*** assuming that with many smart people involved, good choices will follow automatically, and therefore failing to manage the group decision-making process[2].
8. ***Fooling yourself about feedback***: failing to interpret the evidence from past outcomes for what it really is[3], either because you are protecting your ego or because you are tricked by hindsight.
9. ***Not keeping track:*** assuming that experience will make its lessons available automatically, and therefore failing to keep systematic records to track the results of your decisions and failing to analyse these results in ways that reveal their key lessons.
10. ***Failure to audit your decision-making process:*** failing to create an organized approach to understanding your own decision-making, so you remain constantly exposed to the previous nine mistakes.

These decision traps mainly due to poor critical thinking need to be avoided.

8.4. Decision outcomes

Actions have outcomes and making a decision is an action. Perceiving outcomes from the *Continuum* perspective:

- Outcomes lie on a probability of possibilities continuum ranging from 0% to 100% where an outcome with a probability of occurrence of 100% is a certain outcome and an outcome of 0% is one that is not going to happen (negative certainty). Anything in between is an uncertain outcome. The difference between certain and uncertain outcomes is:

[1] Perceptions from the *Generic* perspective perceive the similarity to the 'imperious immediacy of interest' source of unanticipated consequences discussed in Section 8.5.
[2] The assumption is the group has the appropriate domain knowledge to make a good decision.
[3] It is never the decision-maker's fault; it is always someone else's fault.

    - ***Certain:*** is deterministic since you can determine what the outcome will be before it happens. For example, if you toss a coin into the air, you are certain that it will come down[4] and come to rest with one side showing if it lands on a hard surface.
    - ***Uncertain:*** is non-deterministic since while you know there will be more than one possible outcome from an action, you can't determine which one it will be. For example, if you toss a coin, the outcome is non-deterministic or uncertain because while you know that the coin will show one of two sides when it comes to rest, you cannot be sure which side will be showing. However, you could predict one side with a 50% probability of being correct[5].
- Outcomes can be anticipated and unanticipated where:
    - ***Anticipated*** can be:
        - ***Desired:*** where the result is something that you want. For example, you want the coin to land showing 'heads' and it does.
        - ***Undesired:*** where the result is something that you don't want. For example, you want the coin to land showing 'heads' and it lands showing 'tails'.
        - ***Don't care:*** where you have no preference for the result. For example, if you have no preference as to which side is showing when the coin lands, you have 'a don't care' outcome.
    - ***Unanticipated*** once discovered, can also be desired, undesired and don't care.
- There can also be more than one outcome from an action, where each of the outcomes may be:
    - Dependent on, or independent from, the other outcomes.
    - Acceptable or not acceptable.
    - Desired, undesired or 'don't care'.

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[4] Unless you toss it so fast that it escapes from the Earth's gravity.

[5] So how can tossing a coin be certain and uncertain at the same time? It depends on the type of outcome you are looking for. Which side it will land on is uncertain, but that it will land on a side is certain. It is just a matter of framing the issue from the proposer perspective.

- Unanticipated the first time that the action is taken.
- A combination of the above.

8.5. Sources of unanticipated consequences

Unanticipated consequences or outcomes of decisions need to be minimized[6]. If we know the causes of unanticipated consequences we should be able to prevent them from happening. A literature search found Merton's analysis of unintended consequences in social interventions which discussed the following five sources of unanticipated consequences (Merton, 1936):

1. Ignorance.
2. Error.
3. Imperious immediacy of interest.
4. Basic values.
5. Self-defeating predictions.

These sources may be generalized as discussed below.

- ***Ignorance:*** this deals with the type of knowledge that is missing or ignored. Ignorance in the:
    - ***Problem domain*** may result in the identification of the wrong problem.
    - ***Solution domain*** may produce a solution system that will not provide the desired remedy.
    - ***Implementation domain*** may produce a conceptual solution that cannot be realized.
- ***Error:*** there are two types of errors, errors of commission and errors of omission (Ackoff and Addison, 2006) where:
    - ***Errors of commission*** do something that should not have been done.
    - ***Errors of omission*** fail to do something that should have been done such as in instances where only one or some of the pertinent aspects of the situation which influences the solution are considered. This can range from the case of simple neglect (lack of systematic thoroughness in examining the situation) to pathological obsession where there is a determined refusal or inability to consider certain elements of the problem (Merton, 1936).

[6] This also applies to unanticipated emergent properties (*Generic* perspective).

Errors of omission are more serious than errors of commission because, among other reasons, they are often impossible or very difficult to correct. "*They are lost opportunities that can never be retrieved*" (Ackoff and Addison, 2006: page 20). Merton adds that a common fallacy is the too-ready assumption that actions, which have in the past led to a desired outcome, will continue to do so[7]. This assumption often, even usually, meets with success. However, the habit tends to become automatic with continued repetition so that there is a failure to recognize that procedures, which have been successful in certain circumstances, need not be successful under any and all conditions[8].

- ***Imperious immediacy of interest:*** the paramount concern with the foreseen immediate consequences excludes the consideration of further or other consequences of the same act, which does in fact produce errors[9].
- ***Basic values:*** there is no consideration of further consequences because of the felt necessity of certain action enjoined by certain fundamental values. For example, the Protestant ethic of hard work and asceticism paradoxically leads to its own decline in subsequent years through the accumulation of wealth and possessions.
- ***Self-defeating predictions:*** the public prediction of a social development proves false precisely because the prediction changes the course of history. Merton later conceptualized the "the self-fulfilling prophecy" (Merton, 1948) as the opposite of this concept.

Perceptions from the *Generic* perspective show the similarity to the decision traps discussed in Section 8.3.

8.6. Risks and opportunities

Uncertainties in outcomes of actions can produce both risks and opportunities. For example, you can look at a bet as an opportunity to make money or as a risk of losing money. Consider risks and opportunities, they have:

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[7] Previous actions were within the line connecting points A and B in Figure 7.4 and the proposed action will go beyond point B.

[8] This assumption also applies to component reuse.

[9] Perceptions from the *Generic* perspective perceive the similarity to the decision traps in Section 8.3.

- ***Probability of occurrence:*** ranging from very unlikely to highly likely.
- ***Severity of impact:*** ranging from hardly noticeable to catastrophic and must be mitigated in the event of a risk, or too good an opportunity to miss if an opportunity.

8.6.1. Risks

A risk is a state of uncertainty where one or more of the possible outcomes of a decision involve a loss, catastrophe, or other undesirable outcome. Risks can be measured in terms of a set of possibilities each with quantified probabilities and quantified losses. For example, when I bet $100 on the outcome of tossing a coin, there is a 50% chance that I will lose the bet and the $100. These types of risks are known as calculated risks. Typical Active Brainstorming questions when considering risks might include:

- What if it is late?
- What if it breaks?
- What if it wears out sooner than specified?

The answers and the resulting actions taken would depend on the situation. The following principles shall govern the holistic management of risks associated with decisions.

- ***Risks and benefits are selection criteria for decisions***. The degree of risks and benefits are solution selection criteria allowing the degree of susceptibility to a specific risk or the possibility of taking advantage of a specific opportunity to be evaluated in conjunction with other criteria. For example when Fred will be determining the importance of the various selection criteria for his decision on which route to take home from Vivo City as discussed in Section 8.7.2 the opportunity to select from a larger number of buses will influence how he weights the importance of the selection criteria associated with transferring from subway to bus at Haw Par Villa.
- ***Make decisions with the appropriate personnel.*** Making decisions about the probability and severity of risks requires domain knowledge. This means that you need to include personnel with the appropriate domain knowledge as well those accountable for the success or failure of the actions that will implement the decision and incur the risk in the decision process.
- ***Risks with a catastrophic severity of impact must be mitigated, avoided or prevented*** irrespective of their probability of occurrence.

Table 8.1 Decision table for known outcomes of actions

	Certain	Uncertain	Certain
Probability of occurrence	0% (will never happen)	< 100% (might happen)	100% (will always happen)
Desired	Need to conceptualize an alternative action	Opportunity that should be planned for, depending on probability of occurrence	Preferred outcome
Don't care	Ignore	Opportunity that might be considered depending on probability of occurrence	Opportunity that could be taken advantage of
Undesired	Can be ignored	Risk that should be mitigated depending on probability of occurrence and severity of consequences	Outcome that must be prevented or mitigated depending on severity of consequences

8.6.2. Opportunities

An opportunity is a state of uncertainty which offers the possibility of a gain, or other desirable outcome namely the opposite of a risk. Opportunities can also be measured in terms of quantified probabilities and quantified losses. For example, when I bet $100 on the outcome of tossing a coin, there is a 50% chance that I will win the bet and win a $100.

Table 8.1 shows the links between the known outcomes of decisions and uncertainty from the holistic perspective. Many of the decision-making tools in the literature deal with the decisions being made in the desired-certain area. Don't care outcomes should not be neglected but should be looked at as opportunities. For example, if you are considering purchasing a Commercial-Off-The-Shelf (COTS) item and initially don't care about the colour then from the holistic perspective you might want to think about what additional benefits you might get from a specific colour. Typical Active Brainstorming questions when considering opportunities would be the opposite of those asked from the perspective of risk, such as:

- What if it is early?
- What if it performs above specification?
- What if it lasts longer than specified?

The answers and the resulting actions taken would depend on the situation.

If you know for sure that there will be an undesired outcome from an action that can cause a loss and you go ahead and deliberately perform that action, then the outcome is predictable and is not an accident.

8.7. The four key elements in making decisions

Since the decision-making process overlaps the problem-solving process up to the point where the decision is made, the decision-making process provides a different perspective on the grouping of the activities performed in problem-solving and decision-making. Since different perspectives provide different insights, perceive the process from the perspective of the following four key elements[10] in making decisions (Russo and Schoemaker, 1989: page 2):

1. ***Framing the problem:*** means considering what must be decided. This is the most critical art of the process because if the problem is framed incorrectly, then the wrong problem will be considered, the wrong questions will be asked, and the wrong solution will be realized. A template for framing the problem is presented and discussed in Section 9.11.
2. ***Gathering intelligence:*** means determining what factors are pertinent in the situation and what factors can be safely ignored. In other words, this is the process of reducing complexity to simplicity as discussed in Section 9.19. The pertinent factors relate to determining the solution options and the selection criteria for making the decision.
3. ***Coming to conclusions:*** a sound systemic and systematic approach considering all the parameters generally results in a better decision.
4. ***Learning (or failing to learn) from previous decisions:*** this is the application of the principles of pattern matching, feedback and improvement. You need to compare the expected outcomes of the decision with the actual outcomes and learn from the differences and understand the reasons for the differences. Pattern matching allows you to compare the current situation in which you are making the decision with other similar situations where the patterns in the data match and facilitate the decision. Feedback is the principle of closing the loop and learning from the effects of the decision (the good and the bad results) and not making the same mistake in the future. Not making the same mistake in the future leads to improvements in your decision-making which will result in more correct decisions.

Consider each of the four key elements in the following contexts:

[10] Perceptions from the *Generic* perspective indicate that this is the generic problem-solving process with the addition of a process improvement element.

1. Returning home from teaching a class discussed in Section 8.7.1.
2. Returning home from Vivo City discussed in Section 8.7.2.
3. Finding his perfect mate discussed in Section 8.7.3.
4. Booking a flight from Singapore to Newark NJ via Chicago discussed in Section 8.7.4.

8.7.1. Returning home from class

Fred is an Adjunct Professor at Hypothetical University who is teaching an evening class and needs to make a decision as to how he will get home afterwards. This is an example where all the outcomes are certain since Fred will be selecting from one or more known options.

8.7.1.1. Framing the problem

Framed in accordance with the problem formulation template in Section 9.11:

- ***The undesirable situation:*** that Fred is at the class location. The assumptions/context being that:
    - Fred does not own, or did not bring, a car to the classroom that day.
    - He will be going straight home after class.
- ***The FCFDS:*** Fred is at home.
- ***The problem:*** is to:
    1) Select the route for the journey
    2) Make the journey.
- ***The solution:*** the route picked for the journey

8.7.1.2. Gathering intelligence

Consider the options and the selection criteria, namely the controlled variables associated with the decision. The options to choose from are:

- Taxi.
- Bus.
- Subway.
- Walk.
- Get a ride from one of the students.

The pertinent information associated with the selection criteria is:

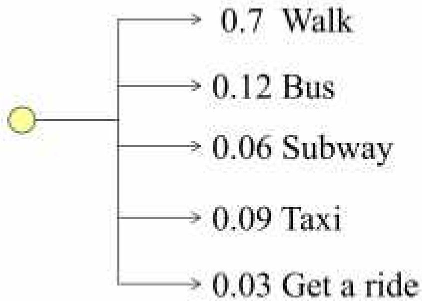

Figure 8.1 Decision Tree for getting home from class

- Taxi is the most expensive option but the fastest way home. Fred can telephone for a taxi from his cell phone and it should arrive at the front of the building within 15 minutes.
- Bus is the cheapest and slowest option apart from walking. The bus stop is within 100 meters of the building but he'll have to wait for the bus and he has no idea if it will be crowded or if he'll get a seat.
- Subway is faster and slightly more expensive than the bus, but the station is about 500 meters from the building. It has similar waiting and crowding considerations to the bus option.
- Walking is the cheapest and slowest option but the journey will take about three or four times as long as the bus/subway options with maximum waiting time for the vehicles. On the other hand he has the time and walking is good exercise.
- Getting a ride from a student will depend on the students and whether one or more is going in his direction.

The selection criteria should include the weather since the decision may be different on a sunny day to that of a rainy day.

8.7.1.3. Coming to conclusions

Each option has advantages (good points) and disadvantages (bad points). One traditional approach to making the decision is to use a Decision Tree. Decision Trees are concept maps showing all the pertinent factors to a decision in the form of a network of branches, hence the term Decision Tree. A Decision Tree and the preferences associated with each option for making the decision is shown in Figure 8.1. But where do the preferences come from? The preferences come from a number of subjective and objective factors associated with the option as discussed below.

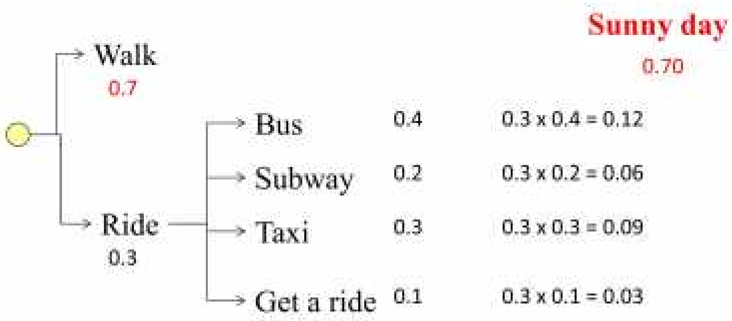

Figure 8.2 Alternative Decision Tree for sunny day decision

8.7.1.4. The sunny day decision

Fred's subconscious mind produces the preference numbers shown in Figure 8.1 for a sunny day for the following reasons:

- Walking scores 0.7, the highest, because it is a sunny day, the weather will be good when class ends and he is in no rush to get home.
- Taxi scores 0.09 because while it is the fastest, it is also the most expensive and he's not really in a hurry and so is willing to let the journey take longer.
- Bus scores 0.12 which is a little more than the taxi because he's not in that much of a hurry and can read a book while waiting for the bus and riding in it. Fred doesn't feel comfortable reading while riding the taxi; he feels that he has to watch that the driver is indeed taking the shortest and cheapest route.
- Subway scores 0.06 which is lower than the taxi because while the same factors as for the bus option apply, there is a longer walk to the subway station.
- Getting a ride from a student scores 0.03, the lowest, because he feels that getting a ride from someone in that bunch of students is unlikely.

The decision is the option with the highest preference number namely 0.7 for walking.

8.7.1.5. Smartening up the decision making process

The traditional approach to building Decision Trees is to list out the paths though the Decision Tree and work out the preferences for each decision point. The holistic thinking approach is to use smart thinking to simplify the tree before starting to draw it. For example, the basic or root decision is between walking and the others, all of which can be aggregated into riding in a vehicle of some kind as shown in Figure 8.2 where the first level decision is between walking and riding, and the second level of decision making is to assign preferences to the riding options and then calculate the preference for the option by multiplying the preferences along a path. Here 0.3 is the preference for the walk-ride decision and 0.7 the preference for walking.

The second level preferences are 0.4 for the bus, 0.2 for the subway, 0.3 for the taxi and 0.1 for getting a ride using the same reasons as before for assigning the preferences. The final value for each preference is the multiplied number of all the decisions in the branch. For example the preference for taking the bus is 0.3x0.4=0.12, where 0.4 is the choice of the bus as compared to the other riding options. Note that at each decision point the numbers should add up to 1.0. This approach as two major benefits:

1. The number of items being considered in each decision is reduced, simplifying the choice.
2. The tree can sometimes be pruned before working out all the preferences.

The decision between walking and riding is a choice between two options, an easier decision than choosing from one of the five options directly and shows up clearly in Figure 8.2.

If the Decision Tree is to be used once for a single decision, then once the 0.7 preference for walking is stated, there is no need to determine the branches for any of the other options since the 0.7 overrides all the others. However, if the Decision Tree is to be used on more than one occasion in which the preferences may change for any reason, the branches do need to be identified.

8.7.1.6. The rainy day decision

Figure 8.2 shows the preferences for a sunny day, but how does rain affect the decision. The Decision Tree for the rainy day is shown in Figure 8.3. Riding now gets 0.9 because while Fred doesn't mind walking in the rain, he'd rather not. The decision as to which ride to select becomes:

- Taxi scores the 0.5, highest, as it is the best way to keep dry in the rain.
- Bus scores 0.3, less than the taxi, because he has to walk about a 100 meters in the rain.
- Subway scores 0.1, lower than the bus because there is a longer walk to the subway station.

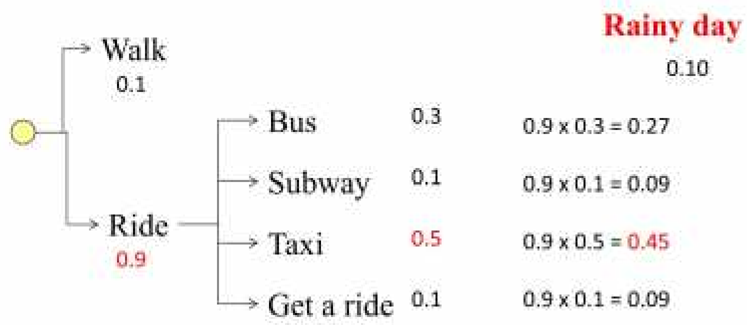

Figure 8.3 Alternative Decision Tree showing rainy day preference

- Getting a ride from a student also scores 0.1 because he feels that getting a ride from that bunch is unlikely rain or sun.

When the numbers are multiplied the decision to go home via taxi is the preferred at 0.45.

8.7.1.7. The Pair Wise Comparison (PWC) alternative

An alternative to Decision Trees is the Pair Wise Comparison (PWC) technique recommended in the literature as a decision-making tool when the decision has to be made from a large number of choices. PWC is used as a part of Interpretive Structural Modelling (ISM) (Warfield, 1976) and Analytical Hierarchy Process (AHP) (Saaty, 1980). The assumptions behind PWC include:

- In general, while people have difficulty selecting from, and ranking, a large number of options, they can choose between two alternatives or rank a few items in order of preference.
- Each decision is being made under conditions of certainty where the preference is for either one of the alternatives or the other.
- The preference is based on selection criteria that may or may not be defined.

To make a decision using PWC, Fred would create a matrix table in a spreadsheet with the options listed in both the rows and the columns. To keep the matrix useable, he'd label the columns with the row numbers rather than the text just like in an N^2 chart. The cell common to each row and column is blocked out with a '-' since there is no point in comparing an option with itself. The lower half of the table is ignored or blocked out because the choices in it duplicate the top half but in reverse and cancel out. Fred would then add one row below the list of choices. This additional row will contain the number of 0's in the column after the table has been completed so label it 'number of 0's.

Table 8.2 PWC matrix for decision on a sunny day

	Taxi	Bus	Sub-way	Walk	Ride	1's	0's	Total	Rank
Taxi	-	0	0	0	1	1	0	1	4
Bus	-	-	1	0	1	2	1	3	3
Sub-way	-	-	-	0	1	1	1	2	2
Walk	-	-	-	-	1	1	3	4	1
Get a ride	-	-	-	-	-	0	0	0	5
0's in Rows	0	1	1	3	0				

To complete the matrix Fred would add four columns following the list of choices and label the additional columns as:

- ***1's:*** these cells will contain the number of 1's in the row for that option as explained below.
- ***0's:*** these cells will contain the number of 0's for that option transposed from the column count as explained below.
- ***Total:*** these cells will contain the sum of the 1's and 0's columns as explained below.
- ***Rank:*** these cells contain the ranking of the option in the totals. If a spreadsheet is used, then the cells would contain the formula for the ranking function.

So using PWC for the sunny day situation, Fred compares the choice between taxi (row) and bus (column). The preference is for a bus so the common cell gets 0. Moving along the row, the preference between taxi and subway is subway so the common cell gets 0. Moving along the row, the preference between taxi and walking is walking so the common cell gets 0. Moving along the row, the preference between taxi and getting a ride is taxi so the common cell gets 1. Fred then moves down to the next row and compares the preferences for the bus with the remaining options in that row, and so on down the rows. Once the table is completed the decisions are processed as follows: The number of 1's in each row are added together and stored in the corresponding cells in the column labelled 1's.

- The number of 0's in each column is added together and stored the corresponding cells in the row marked '0's in Rows.
- The values in the '0's in Rows row are transposed into a 0's column located next to the column labelled 1's.

Table 8.3 PWC matrix for decision on a rainy day

	Taxi	Bus	Subway	Walk	Ride	1's	0's	Total	Rank
Taxi	-	1	1	1	1	4	0	4	1
Bus	-	-	1	1	1	3	0	3	2
Sub-way	-	-	-	1	1	2	0	2	3
Walk	-	-	-	-	1	1	0	1	4
Get a ride	-	-	-	-	-	0	0	0	5
0's in Rows	0	0	0	0	0				

- The last step is to add up the values in the 1's and 0's columns and store them in the column labelled 'Total' as shown in Table 8.2

The row with the highest number in the 'Total' column represents the decision. In this instance, the Walk option received a 4 so it is the preferred choice. The decisions would be different on a rainy day where the preference is for the taxi as shown in Table 8.3.

8.7.1.8. Learning (or failing to learn) from previous decisions

One way of learning is to compare the actual outcomes from the decision with the expected outcomes, understand why they were different and adjust the preferences for the next time the decision is to be made. For example:

- Walking provides additional opportunities for shopping for groceries, take-away food or other items. This applies on rainy days as well as for sunny ones. Would this make a difference? If yes, then the preference would need to be adjusted.
- The wait for a taxi depends on the time of day. There may be a difference in waiting time if the class finishes early. Would that make a difference? If yes, then the preference for taxis would change according to time of day.
- When Fred leaves the building this evening, if a taxi should pass by, and he's feeling tired then he'll override the decision to walk and flag it and take a taxi home. This may mean that he needs to add tiredness as a selection criterion for the next time he determines the preferences for the decision.

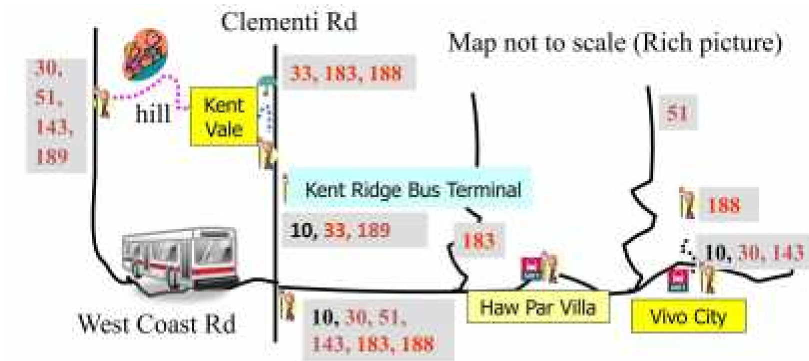

Figure 8.4 Rich picture showing options for Vivo City to Kent Vale travel

8.7.2. Returning home from Vivo City

Consider each of the four key elements in the context of another situation wherein Fred wishes to travel from the shopping mall in Vivo City to his home in Kent Vale by public transport. This is another example where all the outcomes are certain since Fred will be selecting from one or more known options.

8.7.2.1. Framing the problem

In this situation the problem could be framed as one of the following:

- ***The undesirable situation:*** Fred wishes to travel from the shopping mall in Vivo City to his home in Kent Vale by public transport but does not know which choice to make.
- ***The FCFDS:*** the choice has been made.
- ***The problem:*** might be stated as:
    1) Which route to take today?
    2) Which route will provide the fastest route home today?
    3) Which route will provide the greatest probability of always being the fastest route home?
- ***The solution:*** needs to be developed.

After researching the bus routes and taxi stand locations, Fred framed the problem to ignore other routes and focus on the southern route narrowing down the choices to the combinations of subway and bus options travelling along the southern route shown in the Rich Picture representation in Figure 8.4.

8.7.2.2. Gathering intelligence

The pertinent factors relate to the information about the solution options and the selection criteria for making the decision.

8.7.2.3. Solution options

In this situation the options that Fred can choose from include:

1. Taxi.
2. Subway (shown as MRT in Figure 8.4) part of the way and bus the rest of the way.
3. A number of direct buses and indirect transfer combinations.

Where:

- ***Taxi:***
  - Will take Fred from door to door and is the fastest once he's actually sitting in the taxi. However since Vivo City is a shopping mall and entertainment centre there is generally a long queue waiting for taxi.
  - Is the most expensive option.
- ***The subway/bus combination*** gets him part of the way relatively quickly, but then there is a wait for the bus and a walk from the bus stop.
- ***Buses*** provide a number of options, with waiting times for the buses and the walk from the bus stop. The waiting times and the walk from the bus stop will depend on the bus stop at Vivo City and at the transfer point. There are several options including those shown in Figure 8.4. Fred can take:
  - Any one of three direct buses, the 30, 143 and 188. However the 188 stops in a different location from the 30 and 143, about a three-minute longer walk than to the 30/143 bus stop.
  - The subway part of the way to Haw Par Villa at which point he'd have to transfer to a bus and has more options; the 10, 30, 51, 143 or 188.
  - The 10 from Vivo City or Haw Par Villa and transfers at Clementi Rd. He'll then have the options of the 183 as well as the 30, 51, 143 and 188.
  - The 10 and transfer at the Kent Ridge bus terminal. He'll then have the options of the 33 and 189.
  - The 33, 183 and 188 which will drop him at the front gate bus stop about 150 meters from his front door and

the whole walking route is more or less protected from vertical rain by an overhead roof.

- The 30, 51, 143 and 189 which drop him at the bottom of a hill about 250 meters from his front door via the back gate to the apartment development. Should it rain, he will need an umbrella to avoid getting wet.
- Other options via different bus routes and transfer points such as the 166 to Clementi Interchange which are not shown because they were excluded from consideration when the problem was framed.

8.7.2.4. Selection criteria

The pertinent selection criteria in this situation are:

- Cost.
- Travel time.
- The number of transfers.
- The number of different buses at the transfer point.
- The weather.
- The destination bus stop.

Where:

- ***Cost:*** there is a difference between the taxi and bus/subway fare. The taxi will cost about eight times the cost of the bus/subway option. However, if Fred spends more than $100 on shopping then the taxi fare would be less than 10% of the money spent on the shopping.
- ***Travel time:***
  - Is made of the waiting times and the time traveling.
  - Will be different for the taxi and for each bus.
  - May also depend on the time of day, the weather and traffic on the roads before the bus reaches the stop where he'll board it.
- ***The number of transfers:*** there is a choice, of 0, 1, 2 and 3. The 30, 143 and 188 buses provide the only options that do not require a transfer. Otherwise Fred can transfer at Haw Par Villa, Clementi Rd. and the Kent Ridge Bus Terminal. A transfer at Haw Par Villa and/or Clementi Rd. each provide additional buses while a transfer at the Kent Ridge Bus Terminal reduces the number of options to two buses (33 and 189).
- ***The number of different buses at the transfer point:*** based on the assumption that more buses will shorten the waiting time.

- ***The weather:*** affects traffic and may be a subjective factor because:
    1) Choosing a bus that stops at the bottom of the hill means a walk in the rain on some days.
    2) The difference in cost between the taxi and bus/subway options may be less significant if it is raining than when it is not.
    3) On rainy days, the importance of the selection criteria may change depending on the amount of rain descending.
- ***The destination bus stop:*** the degree of preference for the front or back gate may influence the choice of bus and the need to transfer.

The amount of additional information associated with each selection criterion needed to make the decision will depend on which of the three problem statements from Section 8.7.2.1 is applicable. This is another aspect of the importance of framing the correct problem. It not only leads to the correct solution, it can also reduce the scope of work needed to realize that solution.

8.7.2.5. Coming to conclusions

Consider some of the techniques that can be used to make the decision in a systemic and systematic manner.

8.7.2.6. The solution options

If Fred lists out the options for getting home from Vivo City, the list could look like the following:

1. Taxi to either front or back gate[ii].
2. 10 and transfer at Clementi Rd. to 30 to back gate.
3. 10 and transfer at Clementi Rd. to 51 to back gate.
4. 10 and transfer at Clementi Rd. to 143 to back gate.
5. 10 and transfer at Clementi Rd. to 183 to front gate.
6. 10 and transfer at Clementi Rd. to 188 to front gate.
7. 10 and transfer at Kent Ridge to 33 to gate.
8. 10 and transfer at Kent Ridge to 189 to back gate.
9. 143 and transfer at Clementi Rd. to 183 to front gate.
10. 143 and transfer at Clementi Rd. to 188 to front gate.
11. 143 to back gate.
12. 188 to front gate.

[ii] Or directly to the apartment building itself so there is no walk from the gate.

Table 8.4 Partial blank PWC matrix for Traveling home from Vivo City

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	10 and change in Clementi Rd. to 30 back gate															
2	10 and change in Clementi Rd. to 51 back gate															
3	10 and change in Clementi Rd. to 143 back gate															
4	10 and change in Clementi Rd. to 183 front gate															
5	10 and change in Clementi Rd. to 188 front gate															
6	10 and change in Kent Ridge to 33 front gate															
7	10 and change in Kent Ridge to 189 back gate															
8	143 and change in Clementi Rd. to 183 front gate															
9	143 and change in Clementi Rd. to 188 front gate															
10	143 to back gate															
11	188 to front gate															
12	30 and change in Clementi Rd. to 183 front gate															
13	30 and change in Clementi Rd. to 188 front gate															
14	30 to back gate															
15	51 and change in Clementi Rd. to 183 front gate															
16	51 and change in Clementi Rd. to 188 front gate															

13. 30 and transfer at Clementi Rd. to 183 to front gate.
14. 30 and transfer at Clementi Rd. to 188 to front gate.
15. 30 to back gate.
16. Subway and 10 and transfer at Clementi Rd. to 30 to back gate.
17. Subway and 10 and transfer at Clementi Rd. to 51 to gate.
18. Subway and 10 and transfer at Clementi Rd. to 143 arriving at the back gate.
19. Subway and 10 and transfer at Clementi Rd. to 183 to front gate.
20. Subway and 10 and transfer at Clementi Rd. to 188 to front gate.
21. Subway and 10 and transfer at Kent Ridge to 189 to back gate.
22. Subway and 10 and transfer at Kent Ridge to 33 to front gate.
23. Subway and 30 and transfer at Clementi Rd. to 183 to front gate.
24. Subway and 30 to back gate.
25. Subway and 51 and transfer at Clementi Rd. to 183 to front gate.
26. Subway and 51 and transfer at Clementi Rd. to 188 to front gate.
27. Subway and 51 to back gate.
28. Subway and 143 and transfer at Clementi Rd. to 183 to front gate.
29. Subway and 143 and transfer at Clementi Rd. to 188 to front gate.
30. Subway and 143 to back gate.
31. Subway and 188 to front gate.
32. Others.

Options such as a 188 which goes to the front gate and a transfer to a bus that would take him to the back gate (30, 51,143 and 188) have been eliminated from the list.

8.7.2.7. The PWC technique

Making the decision using PWC would require a 32x32 matrix such as the one partially shown in Table 8.4. To make the decision, begin by comparing the option in the first row of choices with the option in the second column of choices. If the option in the row is preferred to that in the column put a 1 in the common cell. If the option in the column is preferred to that in the row, put a 0 in the common cell. So in the example in Table 8.4, if the taxi alternative is preferred to the "10 and transfer in Clementi Rd. to 30 back gate" choice associated with the column, a 1 would be inserted in the common cell; if that other alternative is preferred to the taxi, a 0 would be inserted in the common cell. Repeat for all blank cells in the matrix moving along the rows and making comparisons between the item in the row and the item in the column. Once the table is completed the decisions are processed as follows:

- Add up the number of 1's in each row and store the total in the cell in the column labelled 1's.
- Add up the number of 0's in each column and store the total in the row marked 0's.
- Copy the number of 0's for each column into the 0's column from the 0's row for the column into the 0's column for the row. For example, copy the number of 0's in the Taxi column in Table 8.4 to the cell in the 0's column for the taxi row.
- Add up the numbers in the 1's and 0's columns in each row and store the totals in the total column for that row.
- Make sure no total is greater than the number of options.

The row with the highest total becomes the decision of choice. If more than one row has the same highest total (less than the number of choices) the decision favours either row (a "don't care" condition).

PWC is designed for simplifying decision making when there are a large number of options. The fallacy in PWC is that when there are a large number of options, PWC takes too much time and using smart thinking to reformulate the problem may produce an equal or better solution as discussed in Section 11.5.

8.7.2.7.1.1. *Smartening up the decision-making*

PWC is designed for use in situations where a large number of options or items are to be compared such as in this situation. It might take Fred more than an hour to create the matrix and work through the table. However, before using it, Fred can use holistic thinking to reduce the workload in at least the following ways:

1. Pre-selection when making a decision when not using PWC to rank the options discussed in Section 8.7.2.7.1.1.1.
2. Reducing the number of options discussed in Section 8.7.2.7.1.1.2.

8.7.2.7.1.1.1. *Pre-selection when making a decision*

When using PWC to make a decision observe that if the first row is all 1's then the option in that row is the preferred option and you do not need to complete the table. So make use of this observation and think about the choices before inserting them into the PWC matrix.

Table 8.5 Alternative PWC decision matrix for sunny day

	Walk	Bus	Subway	Taxi	Ride	1's	0's	Total	Rank
Walk	-	1	1	1	1	4	0	4	1
Bus	-	-	1	1	1	3	0	3	2
Subway	-	-	-	1	1	2	0	2	3
Taxi	-	-	-	-	1	1	0	1	4
Get a ride	-	-	-	-	-	0	0	1	5
Rows		0	0	0	0				

- Draw up a short list (seven or less) of the ones that seem the most preferable.
- Preselect the most preferable choice from the short list and place it in the first row and column.
- Put the remaining items on the short list in the following rows and corresponding columns. Rethink the matrix row and column values after making decisions between items on the short list. The preference may be seen without having to work through all the rows.

For example, look at Table 8.2; the decision table for getting home after class. The whole table has to be completed before the decision can be seen. On the other hand, the decision can be seen as soon as the first row of Table 8.3 is completed since the taxi option was placed in the first row and was preferred to all other options. Similarly in the alternative arrangement for the sunny day decision matrix shown in Table 8.5 the decision can be seen after completing the first row. Fred could have set up the alternative table because he felt that he had a preference for walking

Table 8.6 Initial N^2 chart for travelling from Vivo City to Kent Vale

Vivo City	0	0	0	0		0									
0	Taxi								0					0	
0		10	0	0	0	0	0	0		0	0	0	0		
0		0	30	0	0	0	0	0	0			0	0		
0		0	0	143	0	0	0	0	0				0		
		0	0	0	51	0	0	0	0				0		
0		0	0	0	0	188	0	0						0	
		0	0	0	0	0	Haw Par villa					0			
		0	0	0	0	0		Clementi Rd				0			
			0	0	0				Back gate				0		0
		0								Kent Ridge Terminal	0		0		
		0								0	33			0	
		0	0	0	0	0	0	0				183		0	
		0	0	0	0				0	0			189	0	
						0							0	Front Gate	0
									0					0	Kent Vale

Table 8.7 N^2 chart linking locations by transportation option

Vivo City	Subway, 10, 30, 143, 188	10, 30, 143, 188	10	Taxi, 30, 143	Taxi, 188	
Subway, 10, 30, 143, 188	Haw Par Villa	10, 30, 51, 143, 188	10	30, 51, 143	188	
10, 30, 143, 188	10, 30, 51, 143, 188	Clementi Rd	10	30, 51, 143	183, 188	
10	10	10	Kent Ridge Terminal	189	33	
Taxi, 30, 143	30, 51, 143	30, 51, 143	189	Back gate		o
Taxi, 188	188	183, 188	33		Font gate	o
				o	o	Kent Vale

and wanted to use PWC to confirm his subconscious choice.

8.7.2.7.1.1.2. *Reducing the number of options*

The Rich Picture shown in Figure 8.4 contains the pertinent information for making the decision for travelling between Vivo City and Kent Vale abstracted from a map of Singapore, a subway map and a bus route guide. This information can be drawn in N^2 chart format as shown in Table 8.6. Once the N^2 chart has been completed patterns can be seen and the chart simplified as shown in Table 8.7. The simplification is to put the locations in the cells in the chart and link the locations by transportation option; namely using the *Continuum* perspective to perceive the bus, subway and taxis as signals travelling along the interfaces between the locations. This redesign shows clearly that the option to take the 10 and transfer at Kent Ridge Terminal provides fewer bus choices than all the others and reduces the number of options from 33 to 11 as shown in the PWC matrix in Table 8.8.

If the problem of travelling between Vivo City and Kent Vale is then further bounded by defining the destination as either the front or the back gates, Table 8.7 may be simplified as shown in Table 8.9 by removing one row and one column. The grey row and column in the table should be deleted to avoid clutter.

Table 8.8 shows a pattern of implied preferences. The taxi option is never selected, while the other choices indicate a preference for arriving at the front gate of the destination. The direct bus to the front gate option ranks lower than the subway/bus transfer option presumably be-

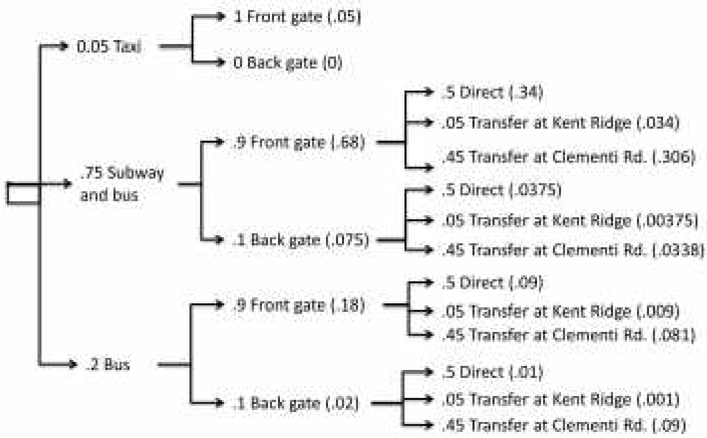

Figure 8.5 Decision Tree for return from Vivo City

cause of the longer walk to the single bus (188) at Vivo City and the choice of two buses (183 and 188) at Haw Par Villa.

8.7.2.8. Decision Trees

PWC does not explicitly weight the selection criteria. So to weight them another decision-making tool such as a Decision Tree should be used. The difference between PWC and Decision Trees is that while in PWC the choice is always between two alternatives and the preferences are either-or (preference of 50-50), Decision Trees allow for a choice between more than one option and allows weighted preferences at each decision point. As an example, a Decision Tree can be set up based on the reduced set of options shown in Table 8.8 and could appear as shown in Figure 8.5 where each of the options have been assigned numbers based on weighting the preferences (the weighting numbers are shown before the option). The weighting numbers for the preferences at each decision point always add up to 1. Figure 8.5 has been set up for three sequential decisions:

1. The root decision is to choose between taxi, subway bus combination and bus without the subway.
2. The second decision is to choose between the front gate and the back gate at the destination.
3. The third decision is to choose between the options of a direct bus or transferring at either Clementi Rd. or Kent Ridge.

Table 8.8 Redesigned reduced PWC matrix

		1	2	3	4	5	6	7	8	9	10	11	1's	0's	Total	Rank
1	10 to Kent Ridge and bus to back gate		0	0	0	0	0	0	0	0	0	1	1	0	1	10
2	10 to Kent Ridge and bus to front gate			0	0	0	0	0	0	0	0	1	1	1	2	9
3	Bus to back gate				1	0	0	1	1	0	0	1	4	2	6	4
4	Bus to Clementi Rd. and bus to back gate					0	0	1	1	0	0	1	3	2	5	6
5	Bus to Clementi Rd. and bus to front gate						1	1	1	1	0	1	5	4	9	2
6	Bus to front gate							1	1	1	0	1	4	4	8	3
7	Subway and 10 to Kent Ridge and bus to back gate								0	1	0	1	2	2	4	7
8	✓ Subway and 10 to Kent Ridge and bus to front gate									0	0	1	1	3	4	7
9	Subway and bus to back gate										0	1	1	5	6	4
10	Subway and bus to front gate											1	1	9	10	1
11	Taxi												0	0	0	11
	Number of 0's in column		1	2	2	4	4	2	3	5	9	0				

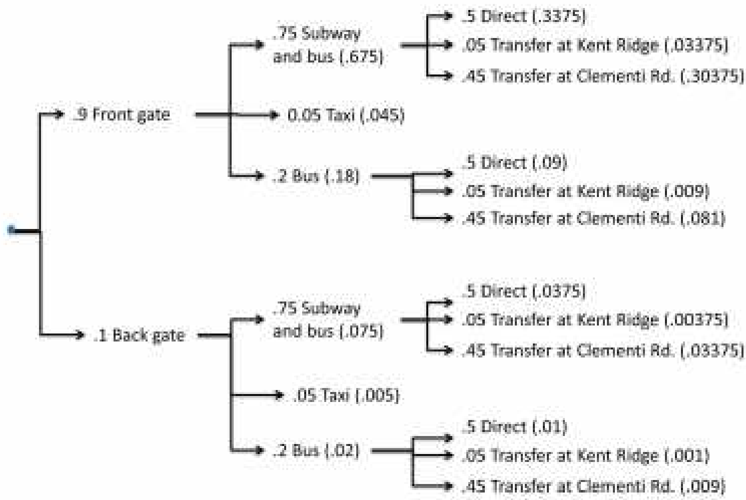

Figure 8.6 Alternative Decision Tree

4. The numerical value for the outcome of each option is the value of the preference number assigned to the option multiplied by the corresponding numbers for all previous decisions in that path and is shown after the option. For example, the preference for subways and bus is 0.75 and the preference for the front gate is 0.9 so the preference for front gate via subway and bus is (0.75x0.9) or 0.68. When results are ranked the preferred decision is subway and a direct bus to the front gate (0.34) and the second preference is for subway and bus to the front gate via a transfer at Clementi Rd. (0.338).

8.7.2.8.1. Smartening up the decision-making

Setting up the Decision Tree requires some thought. So when making the decision about getting home from Vivo City, should the Decision Tree start with the decision between a route that ends up at the front gate or at the back gate, or should the Decision Tree start with the choice between taking a taxi or not taking a taxi? An alternate Decision Tree set up for a different sequence of decisions is shown in Figure 8.6 where:

- The root decision is between the front gate and the back gate at the destination.
- The second decision is between taxi, subway bus combination and bus without the subway.
- The third decision is between the options of a direct bus or transferring at either Clementi Rd. or Kent Ridge.

Table 8.9 Bounding the travelling problem

Vivo City	**Subway,** 10, 30, 143, 188	10, 30, 143, 188	10	**Taxi,** 30, 143	**Taxi,** 188	
Subway, 10, 30, 143, 188	Haw Par Villa	10, 30, 51, 143, 188	10	30, 51, 143	188	
10, 30, 143, 188	10, 30, 51, 143, 188	Clementi Rd	10	30, 51, 143	183, 188	
10	10	10	Kent Ridge Terminal	189	33	
Taxi, 30, 143	30, 51, 143	30, 51, 143	189	Back gate		o
Taxi, 188	188	183, 188	33		Font gate	o
				o	o	Kent Vale

The outcome is the same, which is not surprising since the same preferences are used, but the actual numbers are slightly different.

8.7.2.9. Multi-attribute Variable Analysis (MVA)

There are times when the decision maker needs to select an option based on how well it meets a number of selection criteria with different degrees of preferences. A better tool for making decisions in this type of situation is some form of Multi-attribute Variable Analysis (MVA) which comes in several shapes and sizes. The process for using this version of MVA is as follows:

1. Determine the options discussed in Section 8.7.2.9.1.
2. Determine the selection criteria discussed in Section 8.7.2.9.2.
3. Create the MVA matrix for the decision discussed in Section 8.7.2.9.3.
4. Work out the importance of each of the selection criteria discussed in Section 8.7.2.9.4.
5. Develop utility curves for the selection criteria discussed in Section 8.7.2.9.5.
6. Evaluate each option against the selection criteria discussed in Section 8.7.2.9.6.
7. Weight the evaluations by the importance discussed in Section 8.7.2.9.7.
8. Read off the decision discussed in Section 8.7.2.9.8.
9. Determine if a sensitivity analysis is necessary and if so perform it discussed in Section 8.7.2.9.9.

8.7.2.9.1. Determine the options

The options are the bus routes, 10, 30, 143, 188, and a combination of subway and bus. Taxi is not to be considered in this instance as it generally has a long waiting time at the taxi queue and is perceived as being too expensive.

8.7.2.9.2. Determine the selection criteria

With respect to getting home from Vivo City, the selection criteria might be:

- ***Starting location:*** the shortest distance to the starting location would score the highest. The bus stop for the 188 is the furthest to walk; the subway station is closest and is air-conditioned, while the bus stop for the 10, 30, and 143 is slightly further than the subway station.
- ***Destination:*** can be the front gate or the back gate.
- ***Transfers:*** the minimum number of transfers needed would score the highest.
- ***ransfer points:*** combining the three transfer points into a single selection criterion would be complex so they can be left separately as:

    1) Haw Par Villa.
    2) Clementi Rd.
    3) Kent Vale Terminal.

- ***Travel time:*** The length of time for the journey including estimates of waiting times at the bus stops and subway stations. The shorter the travel time, the higher the score.

8.7.2.9.3. Create the MVA matrix for the decision

The first step in the process is to create the blank MVA matrix for the decision shown in Table 8.10 in its completed form. List the criteria, add a column for the importance of the criteria then insert a set of columns for each option to be evaluated. Label that set as 'Evaluation'. Next create a second set of columns for each option and label that set as 'Weighted'. Lastly add a row at the bottom to contain the totals. If a spreadsheet is used, then the row column should contain a formula to sum the contents of the values in the column.

Table 8.10 Completed MVA matrix for returning from Vivo City

Criteria	Importance	Evaluation					Weighted (Evaluation * Importance)				
		10	30	143	188	Subway	10	30	143	188	Subway
Starting location	0.8	0.8	0.8	0.8	0.3	1	0.64	0.64	0.64	0.24	0.8
Destination	1	0	0.5	0.5	0.8	1	0	0.5	0.5	0.8	1
Transfers	0.3	0.8	1	1	1	0.8	0.24	0.3	0.3	0.3	0.24
Transfer points											
Haw Par Villa	0.9	1	1	1	1	1	0.9	0.9	0.9	0.9	0.9
Clementi Rd.	1	0.5	0.5	0.5	0.5	0	0.5	0.5	0.5	0.5	0
Kent Vale	0.1	0.1	0	0	0	0	0.01	0	0	0	0
Travel time	0.5	0.1	0.5	0.5	0.5	1	0.05	0.25	0.25	0.25	0.5
Total		3.8	5.3	5.3	5.1	5.3	2.49	3.39	3.39	3.29	3.59

8.7.2.9.4. Work out the importance of each of the selection criteria

Work out the importance of each of the selection criteria on its own on a scale of 0 to 1. This is an evaluation of each of the criteria on its own without attempting to compare and rank the criteria. So in thinking about each of the criteria, they might be weighted as:

- ***Starting location:*** gets 0.8 because is somewhat important.
- ***Destination:*** gets 1 because is important.
- ***Transfers:*** gets 0.3 because it is not really important.
- ***Transfer points:*** is broken out into the individual transfer locations to be considered separately. This is simpler than trying to work out the value of various combinations of transfer locations.
- ***Transfer locations:***
    - Clementi Rd. gets 1 because it has the most transfer options.
    - Haw Par Villa gets 0.9 because it has a large number of transfer options.
    - Kent Vale gets 0.1 because Fred doesn't really want to transfer there due to limited options.
- ***Travel time:*** gets 0.5 because it is not that important, as there should be a difference of less than 15 minutes between the slowest and fastest travel times

When you evaluate the importance of the attributes, if one of the selection criteria is allocated a 0 then it has no importance and can be removed from the table which will simplify the table. That is why this step is performed before performing the evaluations. However, there should be a note somewhere to effect that the criterion was considered as not being important (not influencing the decision) since when something is not listed perceptions from the *Continuum* perspective indicate that we do not know if it was forgotten or considered and discarded.

NGT (Section 2.6.4) is a useful tool to use to determine the importance of the selection criteria in situations where a group is making the decision and opinions differ at the start of the discussion.

8.7.2.9.5. Develop utility curves for the selection criteria

A utility curve such as the one shown in Figure 8.7 is the graphical representation of the weighting of the attributes of the variable depending on the utility of that attribute which means that they may have any shape including binary (yes-no), linear, curved, exponential or some specific custom shape for that specific situation. NGT (Section 2.6.4) is a useful tool to use to determine the values of the attributes in the utility curves in situations where a group is making the decision and opinions differ at the start of the discussion. Consider the selection criteria and the curves that can be developed.

- ***Starting location:*** has three attributes:
  - The subway station gets 1 because is close and air-conditioned.
  - The bus stop for the 10, 30, and 143 gets 0.8 because is slightly further than the subway station.
  - The bus stop for the 188 gets 0.3 because is the furthest to walk.
- ***Destination:*** has three attributes:
  - Front gate gets 1 because it is most desirable.
  - Back gate gets 0.5 because it is less desirable.
  - A 'does not connect to the destination' gets 0 because there is no point in taking that bus with the expectation of not transferring.
- ***Transfers:*** has two attributes:
  - A direct connection gets 1 because is the most desirable.
  - At least one transfer gets 0.8 because is less desirable.
- ***Transfer points:*** has two attributes even though there are three transfer points or locations:
  - A transfer at that location gets 1.
  - No transfer at that location gets 0.
- ***Travel time:*** this one is more subjective than the others.
  - The subway bus combination gets 1 because it is perceived to be fastest since the subway covers half the distance with no traffic congestion.
  - A direct bus to either gate gets 0.5 because it is perceived to be slightly slower than the subway.
  - A choice that requires a transfer gets 0 because the waiting time will increase the journey time.

8.7.2.9.6. Evaluate each option against the selection criteria

This step is when each option is considered in turn against each criterion using the utility curve for that criterion. So, commencing with 'starting location', the first criterion, the 10, 30 and 143 each receive a 0.8 because the bus stop is slightly further than the subway station[1]. The subway will

[1] This is where the evaluation is subjective since it is based on some intuitive subjective process which converts 'slightly further' to a value of 0.8.

get a 1. When evaluating the options against the 'destination' criterion, the 10 will get a 0 because it does not go to the destination, the 30 and 143 will get a 0.5 because they go to the back gate while the 188 will get a 1 because it goes to the front gate. After evaluating all the options against all the criteria and adding up the totals, it can be seen that the 30, 143 bus and subway options received the highest score of 5.3.

8.7.2.9.7. Weight the evaluations by the importance

Each evaluation is the weighted by relative importance on a scale of 0 to 1. The weighted values for each of the criteria are then multiplied by the their individual scores to produce the final score.

8.7.2.9.8. Read off the decision

The subway option has the highest score of 3.59 which makes it the preferred route.

8.7.2.9.9. Determine if a sensitivity analysis is necessary and if so perform it.

This is where you look at the difference in the value between the preferred option and the next best option. If the numbers are small then you have a choice between:

- Accepting that you have identified a 'don't care' situation where either option can be selected.
- Going back to the matrix and slightly adjusting the importance of the selection criteria and evaluations that contribute to the decision to see if the adjustments change the decision. If they do, then you need to rethink the numbers and the decision. If the adjustments have no effect on the decision then the decision is probably correct and you may proceed to implement it.
- Adding a new selection criterion to decide between the options.

8.7.2.10. Learning (or failing to learn) from previous decisions

The use of prior experiences can simplify the problem by reducing the number of choices. For example:

- As stated in section 8.7.2.1 the problem has been framed to ignore those other routes and focus on the southern route. This is because prior experience based on a limited sample of journeys by taxi showed that the taxi drivers also selected the southern route.
- If other factors such as tiredness or weather can affect the decision with a large change in value depending on some condition, then that condition should be considered for the root branch. For example, if the weather is a major influence on the prefer-

ence then the root branch should be between rainy day and non-rainy day options. Non-rainy days include days when the temperature and humidity are so high that air-conditioned taxis may become the desired mode of transportation.

8.7.2.11. Finding the fastest time

If Fred had formulated the problem as finding the fastest way home then he would have had to determine additional information in order to make the decision. For example, he would need to know:

- The traveling times between Vivo City and Haw Par Villa by subway (shortest time when the train leaves the station as soon as Fred boards it; longest time when Fred just misses a train and has to wait the full service interval).
- The traveling times by bus between the various transfer points on the way.
- The service interval of each of the buses to determine the waiting times.
- Road conditions including congestion and delays.

All these items of information involve uncertainty and Fred would now have to make a decision in which uncertainty is involved. Fred would then have to set up an alternative table to Table 8.10. This alternative table would show the shortest and longest travel times (rows) for each of the options (columns). Fred would then make the decision using probability theory to work out the most probable fastest route. Whether he considers differences due to weather or time of day will depend on how he framed the problem.

8.7.3. Finding his perfect mate

As another example of using MVA, consider the situation in which Fred, a divorced male person, wants to set up an objective decision process to find his perfect mate. This is another example where all the outcomes are certain since Fred will be selecting from one or more known or yet to be identified options. However, this situation provides an example that illustrates some other aspects of MVA and decision-making. Fred framed the problem as:

- ***The undesirable situation:*** the need for an objective decision process to find his perfect mate.
- ***The FCFDS:*** he has an objective decision process to find his perfect mate.
- ***The problem:*** to create the objective decision process to find his perfect mate.

- ***The solution:*** the FCFDS.

Fred decides to try MVA because he perceives it as an objective decision-making process and begins with the four key elements as follows.

8.7.3.1. Determine the options

The options or candidates are the women Fred will meet. However, in this example they (the number of options) may not be known at the start of the process.

8.7.3.2. Determine the selection criteria

Fred establishes a set of (subjective) selection criteria[2] that includes the following in alphabetical order:

- ***Alcohol[3]:*** a range of attributes from 'never touches a drop' to 'alcoholic' with intermediate stages of 'occasional glass of wine' and 'social drinker'.
- ***Beauty:*** a range of attributes from 'cannot bear to look at' to 'turns all heads when she enters a room'.
- ***Cigarettes[4]:*** a range of attributes from 'non-smoker' to '100 or more cigarettes per day'.
- ***Character:*** a range of attributes from 'honest' to 'dishonest'.
- ***Children (current):*** a range of attributes from 'no children' to 'four or more'.
- ***Children (future):*** a range of attributes from 'don't want any' to 'want up to four or more'.
- ***Education:*** a range of attributes from 'high school dropout', through 'high school graduate', 'undergraduate degree', and 'graduate degree' to 'doctorate'.
- ***Financial independence:*** a range of attributes from 'needs to be supported' to 'multi-millionaire'.
- ***Hobbies and interests:*** where the desirable hobbies match Fred's and the undesirable hobbies are ones that he does not want to get involved with. Others would be 'don't cares'.
- ***Integrity:*** a range of 'cannot tell the truth' to 'always tell the truth'.

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[2] Someone else would probably have a different set of selection criteria with different weightings.

[3] Fred has used solution language; he should have used 'type of drinker' in functional language.

[4] Another example of solution language, he should have used 'smoker' in functional language. What happens if she smokes a pipe?

Table 8.11 Initial MVA matrix table for perfect mate decision

Variable	Importance	Candidate 1	Candidate 2	Candidate 3
Alcohol	1			
Beauty	0.3			
Cigarettes	1			
Character	1			
Children (Current)	0.8			
Children (Future)	1			
Education	1			
Financial independence	0.6			
Hobbies and interests	0.8			
Integrity	1			
Intelligence	1			
Professional	0.75			
Profession	0.25			
Religion	0.5			
Tolerance for differences	1			
Emotions – quick to anger	0.6			
Emotions – likes intimacy	0.8			
Total	N/A			

- ***Intelligence:*** a range of attributes from 'completely dumb' to 'smarter than him'.
- ***Professional:*** a range of attributes from 'office worker' to 'sales assistant in a shop'.
- ***Profession:*** there is a list of desirable professions, undesirable professions and don't care professions.
- ***Religion:*** there is a list of desirable religions, undesirable religions and don't care religions.
- ***Tolerance for differences:*** a range of attributes from 'completely intolerant' to 'tolerant' passing though degrees of tolerance on specific items. For example, she may not play golf but would be tolerant of her partner's need to play.

- ***Others:*** include how they handle emotions and intimacy.

8.7.3.3. Create the MVA matrix for the decision

At this point in time, Fred has identified a number of selection criteria he cares about based on his life experience, knows that he is going to evaluate the importance of those criteria and will evaluate an unknown number of candidates against those selection criteria so he creates an initial MVA matrix table.

8.7.3.4. Work out the importance of each of the selection criteria

Fred then works out the importance of each of the selection criteria on a scale of 0 to 1 and enters the information in the MVA matrix as shown in Table 8.11. He is determining how important they are on a stand-alone basis. The table shows that some criteria such as non-smoking, children, and education are very important, while others have different degrees of importance. As in the previous example in section 8.7.2.9.4, Fred evaluates each criterion on its own and does not attempt to compare and rank them.

8.7.3.4.1. Essential and optional selection criteria

Fred also has to make a decision as to whether each of the selection criteria is essential or optional. The difference being:

- ***Essential:*** a candidate becomes ineligible for selection if she does not get above a certain value on the utility curve for this criterion. For example, if Fred is looking for a non-smoker and he considers non-smoking as essential, if a candidate smokes, then she becomes ineligible and can be removed from the decision matrix.
- ***Optional:*** a candidate can be selected even if she does not get above a certain value on the utility curve for this criterion. For example, a candidate can still be selected even if she gets 0 for these criteria.

In general, assigning an importance of 1 to a selection criterion makes it an essential criterion.

8.7.3.5. Develop utility curves for the selection criteria

Fred then develops the utility curves for each of the selection criteria as follows.

8.7.3.5.1. Alcohol (type of drinker)

The attributes for the alcohol selection criterion range from 'never touches a drop' to 'alcoholic' with intermediate stages of 'occasional glass

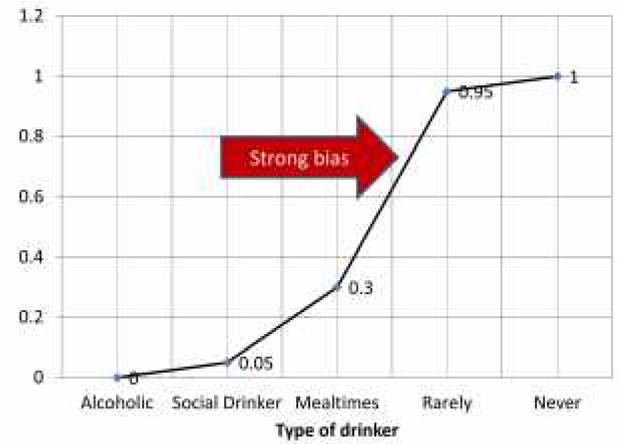

Figure 8.7 Fred's utility curve for Alcohol (type of drinker)

of wine' and 'social drinker'. These attributes can be assigned values on a scale of 0 to 1 depending on Fred's preferences[5], where for example:

- Never touches a drop gets 0.
- Occasional glass of wine gets 0.8.
- Social drinker gets 0.5.
- Alcoholic gets 0.

The assigned weighting shows that Fred is not interested in either an alcoholic or someone who does not drink at all. Fred decides that this is an essential selection criterion and a candidate must score an attribute of more than 0.1 (not be an alcoholic and not drink at all) to be eligible.

When the values assigned to the attributes are plotted as a graph as shown in Figure 8.7, the graph is known as a utility curve. The curve shows his bias towards selecting someone who does not drink very much. The usefulness of the untidily curve is for assigning a number to an in-between observation of the candidate. For example, a candidate who occasionally drinks get something between 0.3 and 0.95 depending on the occasions.

8.7.3.5.2. Education

The attributes for the education selection criterion range from 'high school dropout', through 'high school graduate', 'undergraduate degree', and 'graduate degree' to 'doctorate'. These attributes can be assigned values on a scale of 0 to 1 depending on Fred's preferences, where for example:

---

[5] Subjective

- Doctorate gets 1.0.
- Graduate degree gets 0.8.
- Undergraduate degree gets 0.6.
- High school diploma gets 0.1.
- High school dropout gets 0.

This weighting shows that while the preference is not linear, Fred's preference is biased towards women who have completed tertiary education. Fred also decides that this is an essential selection criterion and a candidate must score an attribute of at least 0.6 (have an undergraduate degree at a minimum) to be eligible.

8.7.3.5.3. Profession

The attributes for the profession selection criterion range from 'unemployed' though 'practitioner' and 'manager' to 'owner or boss' where Fred's preferences are:

- Unemployed gets 0.
- Professional practitioner gets 0.5 (nurse, mechanic, computer programmer etc.).
- Manager gets 0.9.
- Owner or boss gets 1.

Fred decides that this is an optional selection criterion.

8.7.3.5.4. Religion

This is a similar situation to the 'transfer points' selection criterion in section 8.7.2.9.2. Here, the attributes for the religion selection criterion range from 'same religion', 'no religion', 'don't care about the other person's religion' or list specific religions with a yes/no evaluation. For example, if Fred is a Christian and only wants a mate who is a Christian, then the selection criterion for religion becomes essential. In this instance, Fred decides that this is an optional criterion, and the attitude for differences is covered in the 'tolerance for differences' criterion.

8.7.3.5.5. Tolerance for differences

This is also a similar situation to the 'transfer points' selection criterion in section 8.7.2.9.2 where the tolerance for specific differences selection criterion are listed separately. The attributes are:

- Tolerant of differences gets 1.
- Grumbles but tolerant gets 0.1.
- Not tolerant gets 0.

Fred also decides that this is an essential selection criterion and after some further thought decides that a candidate must score a 1 to be eligible because those grumbles will become annoying in time.

8.7.3.5.6. The remaining selection criteria

Fred then determines the values for the attributes of the remaining selection criteria in a similar manner.

8.7.3.6. Evaluate each option against the selection criteria

Fred must now find his candidates and evaluate them. So for example, Fred goes to a party where he meets Sandra who interests him. They talk and he evaluates her as follows:

- As far as the alcohol variable is concerned, Fred watches[6] how much she drinks and figures out that she seems to be a social drinker so he evaluates her as 0.5 for this criterion.
- As far as the education variable is concerned she has a high school diploma so he evaluates her as 0.1 for this variable.

At the same party Fred meets Gillian, talks with her and evaluates her as follows:

- As far as the alcohol variable is concerned she does not drink at all so Fred evaluates her as 0.
- As far as the education variable is concerned she has an undergraduate degree so Fred evaluates her as 0.6.

As Fred talks with Sandra and Gillian he evaluates them on other some of the other criteria as well. Fred then meets Mary, Jessica and one or two others at the party, at other parties or via various means of introduction and goes out on dates with some of them. After some time he might picture his perfect mate as a little bit of Jessica, a little bit of Mary, a little bit of Sandra and a little bit of some of the others (Bega, 1999). However in the real world of today[7] he has to make a decision between the candidates so he completes the evaluations for each candidate. When he notices that a candidate does not meet an essential selection criterion he shades the cell in grey to facilitate identification of ineligible candidates.

[6] Fred uses his eyes to verify that her behaviour supports her words.

[7] Perceptions from the *Temporal* perspective indicates that while something is impossible today, there may come a time in the future when he will be able to create his perfect mate from a little bit of each of the candidates.

Table 8.12 Weighted selection matrix for a perfect mate

		Evaluation					Weighted				
Criteria	Importance	Sandra	Gillian	Mary	Jessica	Jane	Sandra	Gillian	Mary	Jessica	Jane
Alcohol	1	0.5	0	0.2	0.7	0.8	0.5	0	0.2	0.7	0.8
Beauty	0.3	0.9	1	0.4	1	1	0.27	0.3	0.12	0.3	0.3
Cigarettes	1	1	1	0.5	0	1	1	1	0.5	0	1
Character	1	0.3	0.8	0.9	0.9	0.9	0.3	0.8	0.9	0.9	0.9
Children (Current)	0.8	1	1	0.2	0.6	0.5	0.8	0.8	0.16	0.48	0.4
Children (Future)	1	0.5	0.5	1	0.1	1	0.5	0.5	1	0.1	1
Education	1	0.1	0.6	0.8	1	0.6	0.1	0.6	0.8	1	0.6
Financial independence	0.6	0.8	0.7	0.8	1	0.1	0.48	0.42	0.48	0.6	0.06
Hobbies and interests	0.8	1	0.9	0.5	0.4	0.2	0.8	0.72	0.4	0.32	0.16
Integrity	1	0.5	0.7	0.9	0.8	0.8	0.5	0.7	0.9	0.8	0.8
Intelligence	1	0.2	0.8	0.8	0.8	1	0.2	0.8	0.8	0.8	1
Professional	0.75	1	1	1	1	0.4	0.75	0.75	0.75	0.75	0.3
Profession	0.25	1	1	1	1	0.2	0.25	0.25	0.25	0.25	0.05
Religion	0.5	0.4	0.6	0.3	0.7	0.9	0.2	0.3	0.15	0.35	0.45
Tolerance for differences	1	0.4	0.6	0.8	0	1	0.4	0.6	0.8	0	1
Emotions – quick to anger	0.6	0.8	0.8	0.4	1	0.1	0.48	0.48	0.24	0.6	0.06
Emotions – likes intimacy	0.8	1	1	1	1	0.2	0.8	0.8	0.8	0.8	0.16
	13.4	11.4	13	11.5	12	10.7	8.33	9.82	9.25	8.75	9.04

8.7.3.7. Weight the evaluations by the importance

After performing the evaluations, Fred then multiplies the individual evaluations against the importance of the criteria and produces the weighted selection matrix shown in Table 8.12.

8.7.3.8. Read off the decision

Fred looks at the bottom line in Table 8.12 and sees that while Gillian has the highest score she and all the other candidates are ineligible because they fail to meet at least one of the essential criteria. Fred is now faced with a further choice, he can:

1. Continue to identify new candidates and evaluate them.
2. Change his mind and downgrade essential selection criteria to optional and re-evaluate the current candidates to see if an eligible winner will emerge.
3. Identify additional selection criteria. However, this will not help him to overcome the failure of these candidates to meet the essential selection criteria.
4. Perform all of the above.

Fred also noted that Mary moved up into second place after the weighting but at the moment since the candidate in the first place remains in the first place, second place position is not relevant.

8.7.3.9. Determine if a sensitivity analysis is necessary and if so perform it

Fred determines that a sensitivity analysis is not necessary and decides to continue looking for his perfect mate.

8.7.3.10. The emotional factor

A few days later he meets Lily and his heart goes thump. He falls in love at first sight and moves the MVA decision-making matrix spreadsheet into the trash bin. This ending to the anecdote illustrates two important but often-unmentioned aspect of decision-making discussed below:

1. Some decisions tend to be made emotionally discussed in Section 8.7.3.10.1.
2. Modifying the selection criteria discussed in Section 8.7.3.10.2.

8.7.3.10.1. Decisions tend to be made logically and/or emotionally

The literature on decision-making and problem-solving identified two opinions on decision-making. We make decisions:

1. Logically and/or rationally.
2. Emotionally rather than logically and then use the logic to justify the emotional decision.

Perceptions from the *Continuum* perspective indicate that it is not an either-or situation, rather some decisions are made rationally and some decisions are made emotionally.

8.7.3.10.2. Modifying the selection criteria

As Fred evaluates prospective mates he could change the values associated with the attributes of the criteria/variables in the utility curves. His first set of attributes was based on remembered experience. However when he meets other women he may find that the reality is different to the expected and something is not really as important as he thought it was or something might be more important. Should that happen he could adjust the values in the table and re-evaluate the result. That is why he should complete the entire evaluation for a candidate even if the candidate fails an essential criterion. In addition, Fred can also identify a new selection criterion while performing his search and add it to the MVA decision-making matrix. For example when he met Lily he felt an immediate attraction that he did not feel when meeting any of the other candidates. Consequently, he could add an essential ‘felt attraction’ or ‘chemistry’ selection criteria with attributes of ‘yes’=1, ‘no’=0 and ‘perhaps’=0.5 to the MVA decision-making matrix where a minimum score is 0.5. If he then decides to override his emotions and do the logical thing, if Lily does not meet the other essential selection criteria he will be faced with an interesting problem.

8.7.4. Booking a flight from Singapore to Newark NJ via Chicago

The previous examples of decision-making have all featured decisions being made where the variables and outcomes are known or certain even though the selection criteria may be subjective. These are known as decision making under conditions of certainty. There is an alternative category of decision-making known as decision-making under conditions of uncertainty. This Section introduces the topic with a discussion of one example of decision-making under conditions of uncertainty. For another example see Section 10.3.1.3 which describes decision making in a situation where the choice is unclear and more information is needed.

Consider the situation wherein Fred will be flying from Singapore to Newark NJ via Chicago. When he looks at the airline schedule he sees that his flight is scheduled to arrive in Chicago at 1320 hours and he has a choice of two transfer flights, one leaving Chicago at 1500 hours the other leaving Chicago at 1830 hours. This is an example where all the outcomes and the parameters affecting the decision are known but their attributes are uncertain.

8.7.4.1. Framing the problem

Fred frames the problem as follows:

- ***The undesirable situation:*** Fred's flight is scheduled to arrive in Chicago at 1320 hours and he has a choice of two transfer flights, one leaving Chicago at 1500 hours the other leaving Chicago at 1830 hours. Fred would like to get to Newark early as he can but does not know which transfer flight to book.
- ***The FCFDS:*** Fred gets to Newark early.
- ***The problem:*** Does he take the minimum risk and book on the 1830 flight which will get him to Newark but with a long layover, or does he book on the 1500 flight?
- ***The solution:*** to be determined.

Fred begins with the four key elements as follows.

8.7.4.2. Gathering intelligence

Being a holistic thinker Fred realises that he does not have enough information to make an informed decision and performs some Active Brainstorming from the *Operational* and *Quantitative* perspectives to identify the information he needs to make an informed decision (Section 6.2.2.2), which includes:

Table 8.13 Assumed transit times in Chicago (minutes)

	Minimum	Average	Maximum
Pass though immigration	15	42	60
Transfer between terminals	15	25	35
Pass security	5	17.5	30
Security to departure gate	10	12.5	15
Total	**45**	**97**	**140**

- Early or late aircraft arrival times and frequencies and by how much.
- Time to deplane.
- Time to travel between arrival and departure gates.
- Time to transfer between terminals.
- Time to pass though security.
- Time to transfer from security to departure gate.
- Time to board plane.
- Time departure gate closes (minutes before flight).

Fred then researches the situation and finds out that the variables for the decision include[8]:

- Arrival time, which tends to be 1320 hours±30 minutes.
- The departure gate is located in a different terminal to the arrival gate.
- Time to deplane and pass though immigration and customs ranges from 15 to 60 minutes.
- Time to transfer between terminals ranges from 15 to 35 minutes.
- Time to pass security in the departure terminal ranges from 5 to 30 minutes.
- Time from security to departure gate ranges from 10 to 15 minutes.
- Departure gate closes 15 minutes before flight. Since the departure gate closes 15 minutes before the flight, the time to board the plane happens after the gate is closed, the information is irrelevant and does not need to be considered.
- The seating for the flight to New Jersey is always allocated 15 minutes before the scheduled departure time even if the flight is delayed.

[8] These numbers are assumptions and should not be used for anything other than educational purposes.

Fred arranges this information in the table shown in Table 8.13 splitting up the times into minimum, average and maximum

8.7.4.3. Coming to conclusions

Fred is uncertain if he has enough time to transfer between the arrival and departure gates before the early flight leaves. The time between on-time arrival and gate closing is (1445-1320) or 85 minutes. If the plane from Singapore arrives on time and the transit between the arrival and departure gates is the average of 97 minutes, then Fred will miss the connecting flight by (97-85) or 12 minutes. However, if his plane lands earlier and/or the transit time is shorter he may be able to catch the connecting flight. On the other hand even if the plane lands earlier he will miss the connecting flight if the transit time is longer. Fred needs to reduce the uncertainty in the variables affecting the transfer time. One way to do that is to find out the reasons for the spread in the transit times. For example, consider:

- Time to deplane and pass though immigration and customs ranges from 15 to 60 minutes. The time may vary according to time of day rather than being a more or less random number. For example, if several flights arrive at the same time there will be a large number of passengers going through immigration and customs and the waiting time will be longer. So Fred needs to know if the time to deplane and pass through immigration and customs at 1320 hours±30 minutes is normally closer to 15 or closer to 60 minutes.
- Time to pass security in the departure terminal ranges from 5 to 30 minutes. Again this may depend on the time of day and Fred needs to know the range of values at 1320 hours±30 minutes.

When Fred narrows down the uncertainty he may find that:

- He has no chance of making the earlier flight. In which case he would book on the later flight.
- He can always make the earlier flight. In which case he would book on the earlier flight.
- There may still be a probability of missing the earlier flight. Fred will then have to invoke probability theory to determine the probability of making the earlier flight and then decide to take a calculated risk or settle for the later flight.

The lessons learned from this example include:

- The more uncertainty Fred can remove from the variables the lower the risk probability.

- Fred needs to know the conditions under which the statistics he identified were gathered. In general terms, he needs to know the assumptions behind the data and whether those assumptions are valid in his situation.
- Splitting the variables considered in the decision into parts and reducing uncertainty of the parts reduces the uncertainty of the whole.

8.7.4.4. Cost effective decision making

The effort spent in making the calculations must be an effective use of the time. If Fred determines that the airline permits double booking, Fred may not bother with any of the calculations and book a standby seat on the earlier flight and a regular seat on the later flight[9]. Fred did not consider this option in the example, because he framed the problem as booking a seat on either the early or late flights. He did not consider a situation that would allow him to book seats on both flights.

8.8. Decision Trees and MVA

This Chapter discussed Decision Trees and MVA to illustrate the similarities and differences in the tools. MVA can be considered as a Decision Tree with all the choices placed into the root branch and the weighting set by the importance of the variable and its attribute as evaluated on the utility curve.

Decision Trees and MVA clearly indicate the logic behind the decision. Assuming that the evaluation against the selection criteria is made logically and objectively, MVA decouples the objective selection part of the decision from the subjective determination of the importance of the selection criteria and creation of the utility functions.

There is no reason if the selection criteria allow it, why you cannot use a Decision Tree to preselect the subset of the selection criteria for a decision using MVA. It is equivalent to a two-branch Decision Tree with a root node where one branch has a very high preference.

8.9. Summary

This Chapter:

1. Discussed decision-making because decision-making is at the heart of problem-solving. Decision-making is the part of the

[9] If there is no extra charge then he does not have to do the calculation. If there is an extra charge then he has to decide which is more cost effective: booking the two seats or doing the calculation.

problem-solving process, where the candidate solutions, options or choices are evaluated against predetermined selection criteria and a decision is made to select one or more of the options. The decision may be easy or difficult, simple or complicated. Some decisions can be made instantaneously; some decisions may require weeks or even years of study to gather the relevant information necessary to make the decision. Some people have problems making decisions; others make decisions instantaneously or intuitively.

2. Began by discussing qualitative and quantitative decision-making, in Section 8.1.
3. Introduced a number of decision-making tools in Section 8.2.
4. Discussed decision traps that produce bad decisions in Section 8.3.
5. Discussed decision outcomes including how to avoid unanticipated consequences in Section 8.4.
6. Discussed sources of unanticipated consequences in Section 8.5.
7. Discussed risk and opportunity in decision-making in Section 8.6.
8. Discussed the four key elements in making decisions with several anecdotal examples in Section 8.7.
9. Summarised Decision Trees and Multi-attribute Variable Analysis (MVA) in Section 8.8.

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9. Problems and Solutions

The core pure systems engineering problem-solving function is thinking. Thinking:

- Is the major sub-function in problem-solving.
- Goes hand in hand with asking and answering questions (Paul and Elder, 2006).

Problem-solving is used in all the applications of systems engineering in all domains. This Chapter:

1. Discusses problems and solutions, the assumptions behind problem-solving, and ways to remedy problems and introduces a holistic approach to managing problems and solutions.
2. Begins with the properties a of good problem statement in Section 9.1.
3. Discusses the problem posed by the different meanings of the word 'problem' in Section 9.2.
4. Discusses the initial reaction to a problem in Section 9.3.
5. Discusses the traditional problem-solving process in Section 9.4.
6. Provides some examples of the holistic thinking approach in Section 9.5.
7. Examines the relationship between problems and solutions in Section 9.6.
8. Discusses the holistic extended problem-solving process in Section in Section 9.7.
9. Discusses the difference between problems and symptoms in Section 9.8.
10. Discusses the assumptions underlying formal problem-solving in Section 9.9.
11. Discusses the components of problems in Section 9.10.
12. Discusses a problem formulation template used in this book in Section 9.11.
13. Classifies problems in four ways in Section 9.12.
14. Defines the problem classification matrix discussed in Section 9.13.
15. Describes ways of remedying problems in Section 9.14.

16. Compares varieties of the problem-solving process in Section 9.15.
17. Discusses the System Lifecycle (SLC) as an example of a complex problem solving process in Section 9.16.
18. Discusses the real world including two examples of how people adapt it when problem solving often in unexpected ways in Section 9.17.
19. Discusses remedies for complex problems based on the structure of the problem rather than the complexity of the problem in Section 9.18.
20. Discusses the complex problem solving process perceived as being made up of multiple series-parallel iterations of the non-complex problem-solving process in Section 9.19.
21. Discusses the dynamic complex situational loop in Section 9.20.

9.1. Properties of a good problem statement

The properties of a good problem statement include the attributes of good questions discussed in Section 3.4.1.2, as well as being:

- Answer implementation independent, namely, does not provide or bias the answer.
- Quantitative.
- Unambiguous.
- Pertinent.
- Having well-defined boundaries (external and internal).
- Stated as a function if appropriate to the type of problem.
- Stated as creating a desirable situation rather than the absence of an undesirable situation.

9.2. The different meanings of the word "problem"

The word 'problem' has different meanings since the word 'problem' has been defined or used to mean at least three things:

1. A question proposed for solution or discussion (dictionary.com, 2013).
2. Any question or matter involving doubt, uncertainty, or difficulty (dictionary.com, 2013). For example, this type of problem might be:
    a. ***An undesirable situation.*** You might hear someone end a sentence with, "*… and that's the problem*" when they mean, "*… and that's the undesirable situation*".
    b. ***The underlying cause of an undesirable situation,***

usually a failure of some kind. For example, one may hear someone say, *"my phone stopped working; the problem was a discharged battery"*. In reality, they mean that the cause of the phone stopping working was a discharged battery; the symptom or effect was that the phone stopped working.

3. The need to determine the necessary sequence of activities to convert an initial undesirable situation into a desirable situation[1].

9.3. The initial response to a problem

The holistic initial response to a problem should be:

1. STALL (Section 3.4.3).
2. Formulate (frame) the problem (Section 9.11).
3. Follow the holistic extended problem-solving process discussed in Section 9.7 to remedy the undesirable situation and create the solution.

9.4. The traditional problem-solving process

This Section discusses problem-solving and the relationship between problems and solutions. Problem-solving is used in all the applications of systems engineering in all domains. The first step in problem-solving is examining the situation to determine the nature of the problem. When examining a situation, the systems engineer makes observations, performs research to answer questions that cannot be answered immediately and develops an understanding of the situation as shown in Figure 9.1 which is an expanded version of Figure 7.12 to emphasize the need to understand the situation before making a hypothesis. See Section 7.8.7.1 for an example of using this process to optimize your sex life. The output of this thinking process in systems engineering is:

- A statement of the cause of the undesirability.
- A conceptual solution that remedies the undesirability.
- An approach to realize the conceptual solution.

All three of which are hypotheses until they have been tested.

When thinking about a situation, in general:

[1] Once the necessary sequence of activities is determined, the subsequent problem is to plan the process to perform the necessary sequence of activities. Once the plan is created, the subsequent problem is to realize the desirable situation by carrying out the plan.

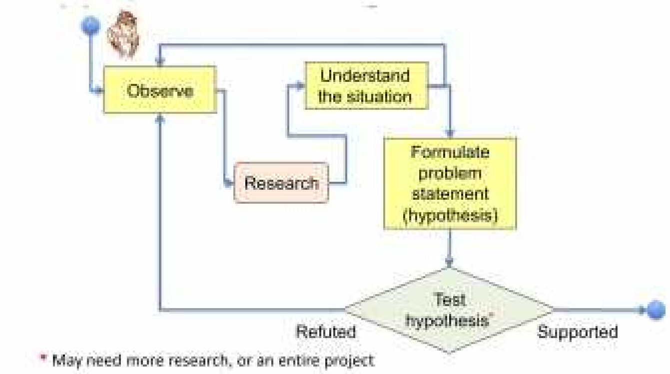

Figure 9.1 Approach to dealing with situations

- ***Why questions:*** used to develop an understanding of the situation. See the five why's (Serrat, 2009).
- ***What questions:*** help to define the root cause of an undesirable symptom and also what needs to be done to remove the cause.
- ***How questions:*** tend to provide solutions.

The *Functional* perspective of the decision-making/problem-solving process based on Hitchins' version (Hitchins, 2007: page 173) shown in Figure 9.2[2] depicts the series of activities which are performed in series and parallel that transform the undesirable situation into the strategies and plans to realize the solution system operating in its context. The process contains the following major milestones and tasks:

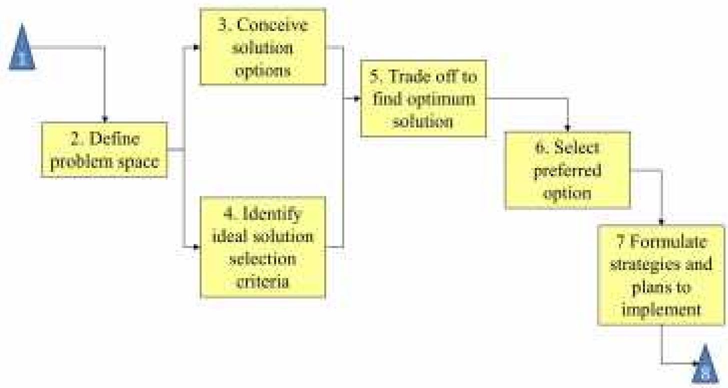

Figure 9.2 Modified Hitchins' view of the problem-solving decision making process

[2] Hitchins' version process has been modified to add milestones at the beginning and end of the process.

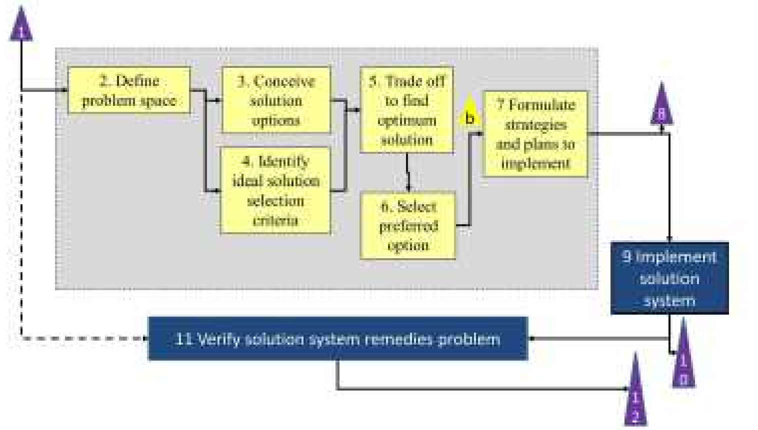

Figure 9.3 Functional perspective of the decision-making process with the implementation states added

1. The milestone to provide authorization to proceed discussed in Section 9.4.1.
2. The process to define the problem discussed in Section 9.4.2.
3. The process to conceive several solution options discussed in Section 9.4.3.
4. The process to identify ideal solution selection criteria discussed in Section 9.4.4.
5. The process to perform trade-offs to find the optimum solution discussed in Section 9.4.5.
6. The process to select the preferred option discussed in Section 9.4.6.
7. The process to formulate strategies and plans to implement the preferred option discussed in Section 9.4.7.
8. The milestone to confirm consensus to proceed with implementation discussed in Section 9.4.8.

Once the stakeholder consensus is confirmed at Milestone 8 at the end of Figure 9.3, the project can move on to the Implementation states shown from the *Functional* perspective in Block 9 of Figure 9.2 where the additional following major milestones and tasks are:

9. The process to implement the solution system often using the System Development Process (SDP).
10. The milestone review to document consensus that the solution system has been realized and is ready for validation.
11. The process to validate the solution system remedies the evolved need in its operational context.

12. The milestone to document consensus that the solution system remedies the evolved need in its operational context.

Consider each step briefly.

9.4.1. Milestone to provide authorization to proceed

The process is based on an assumption that prior to Milestone 1, someone created the project plan that would be followed in performing Tasks 2 to 7 and end at Milestone 8. Consequently, this milestone provides the authorization to proceed with the project that uses the systems engineering approach to remedying the problem.

9.4.2. Define the problem

This is the sequence of activities in which:

1. The undesirable situation is studied.
2. An understanding of the situation is made.
3. The underlying cause identified.

Tools used include the tools for thinking and communicating discussed in Section 2.7, causal loops for describing relationships, Active Brainstorming (Section 6.2) and the ISTs (Section 6.3.2).

In the event the situation is complex or complicated, several underlying causes or problems may be identified. In general, this situation is characterised by a failure to obtain stakeholder consensus on the underlying cause of the undesirability in the situation. In such a situation, the complex problem-solving process described in Section 9.18 should be followed to evolve the remedy.

Once the variables and constants in the situation have been identified and the relationships determined, the situation is deemed to be understood and the underlying cause or causes identified. However, perceptions from the *Continuum* perspective and critical thinking indicate that there still may be other unknown variables that may or may not affect the situation. This situation is known as Simpson's paradox (Savage, 2009) discussed in Section 4.3.2.6.12.

9.4.3. Conceive solution options

The conception of multiple solutions is one of the differences between the holistic thinking systems engineering approach to problem-solving and traditional problem-solving which identifies one solution and then runs with it. This is the sequence of activities which conceives at least two different solution options, each of which is documented in the form of a draft CONOPS. Thinking tools used include Active Brainstorming (Section 6.2) and the ISTs (Section 6.3.2). In most instances the options should be generated as if cost and schedule were not an issue. Affordability (cost) and needed by date (schedule) should be used as selection criteria to select an affordable and achievable option. However there may be situations in which the solution has to use available resources. Such situations tend to occur in training situations, where the budget is limited and cannot be changed or when the solution has to be found within a short period of time.

9.4.4. Identify ideal solution selection criteria

The sequence of activities which identify appropriate solution selection criteria were discussed in the decision-making examples in Chapter 8. A typical set of criteria is provided in Section 9.19.2 in the context of developing a remedy for the undesirable effects of traffic congestion.

9.4.5. Perform trade off to find the optimum solution

The sequence of activities to perform the trade-offs were discussed in the decision-making examples in Chapter 8.

9.4.6. Select the preferred option

Most of the activities were discussed in the decision-making examples in Chapter 8. If none of the options remedies the undesirable situation, or all the solutions are too expensive, or will take too long to realise then the choices to be made include:

1. Absolve the problem for a while until something changes.
2. Decide to remedy parts of the undesirable situation, sometimes known as reducing the requirements, until the remedy is feasible. Ways of doing this include:
    1) Removing the lower priority aspects of the undesirable situation and determining the new cost/schedule information until the solution option becomes affordable or can be realised in a timely manner as shown in Figure 9.4. This is a holistic approach to the concept of designing to cost.
    2) Using the complex problem-solving process described in Section 9.18 to remedy the causes of undesirability with the highest priorities.
3. Continue to look for an affordable and feasible solution that will remedy the undesirable situation in a timely manner. This will be Fred's preferred choice in the example in Section 8.7.3.

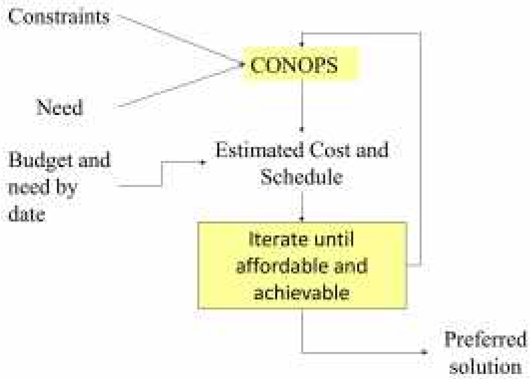

Figure 9.4 Iterate until affordable and feasible

9.4.7. Formulate strategies and plans to implement the preferred option

The sequence of activities is split into the following dimensions:

1. ***Product:*** developing a complete set of matched specifications for the solution system and its subsystems that will provide a remedy to the undesirable situation while operating in context. These activities use the ideas stored in OARP and FRAT developed (Sections 6.3.2.1 and 6.3.2.2) during the brainstorming and Active Brainstorming activities performed in the previous tasks.
2. ***Process:*** developing the project plan for realizing the solution system. The plan arranges activities in the three streams of work (development, test and management) discussed in Section 9.16.6 into a solution SDP building on the ideas in SPARK developed (Section 6.3.2.3) during the brainstorming and Active Brainstorming activities performed in the previous tasks. The problem here is defined as creating the project plan; depending on the scope and situation, solution options lie in different points on the system solution implementation continuum (Section 4.3.2.6.2.2) and include various combinations of performing the whole or part of the realization process in-house or outsourcing the work and different mixtures of technology and people. The various conceptual plan options should be developed in the appropriate level of detail to show they are feasible, selection criteria identified and weighted and a decision made on the optimal implementation approach for that specific project at that specific point in time. Once the decision is made, the selected plan is fleshed out and consensus developed before presentation at the milestone review. One example of how this can be achieved is

discussed in the Multiple-Satellite Operations Control Center (MSOCC) switch upgrade situation in Section 10.2.

9.4.8. Milestone to confirm consensus to proceed with implementation phase

This is the milestone that demonstrates stakeholder consensus that the preferred solution will remedy the undesirable situation in an affordable and timely manner by:

1. Agreeing that the solution will remedy the undesirable situation when the solution is to be placed into service. Namely the needs have not changed significantly. This mitigation for the effect of change in the undesirable situation is built into project management methodologies such as PRINCE2 (Bentley, 1997).
2. The project plan for realizing the solution system is feasible; namely the cost estimates are reasonably accurate and affordable, and the schedule estimates are realistic and will provide the solution in a timely manner.

Once the decision is confirmed, the project can move on to the realisation phases and this milestone becomes Milestone 1 of the realisation phases of the project.

9.5. Examples of the holistic thinking approach

Chapter 10 contains examples of the way this approach was adapted in different situations. The approach is self-similar since each task can potentially contain the same sequence of activities. The literature abounds with descriptions of different varieties of this approach, often called processes, as well as different methodologies and thinking tools that can be used in the activities such as SSM (Checkland, 1991: pages 163 to 183) which was discussed in Section 4.4.1.

9.6. The relationship between problems and solutions

The relationship between problems and solutions seems to be based on the assumption that there is a well-defined problem and a single well-defined correct solution as shown Figure 9.5 which starts with a problem, shows that there are a number of solutions, one of which is the single correct solution and all of the other solutions are incorrect. This focus on a single correct solution is adopted from mathematics.

Perceptions from the *Continuum* perspective indicate that:

Figure 9.5 The single correct solution

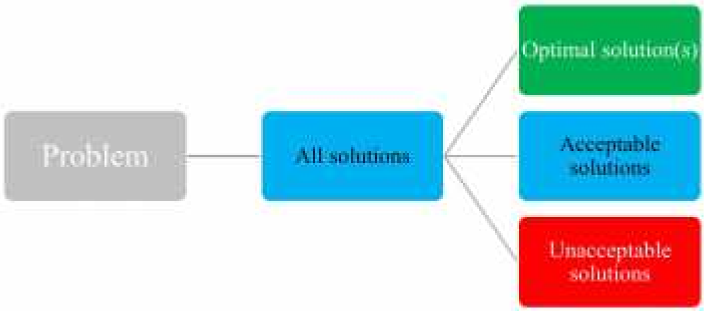

Figure 9.6 The full range of solutions

- Systems engineering deals with problems that generally have a range of equally acceptable solutions. For example, you are hungry, which is generally an undesirable situation. Your problem is to figure out a way to remedy that undesirable situation by consuming some food to satisfy the hunger.

  There are a number of solutions to this problem including cooking something at home, going out to a restaurant, collecting some takeaway food, and telephoning for home delivery. Then there is the choice of what type of food; Italian, French, Chinese, pizza, lamb, chicken, beef, fish, vegetarian, etc. Now consider the vegetables, sauces and drinks. There are many solutions because there are many combinations of types of food, meat, vegetables and method of getting the food to the table.

  Which solution is "the right one?" The answer is "it depends". In nearly every situation, an acceptable solution is one that satisfies your hunger in a timely and affordable manner, meets any other dietary requirements you may have and does not cause any gastric problems. If several of the solution options can perform this function and you have no preference between them, then each of them are just as correct or acceptable as any of the other ones that satisfy your hunger. The words 'right solution' or 'correct solution' should be thought of as meaning 'one or more acceptable solutions' as shown in Figure 9.6.

- Conventional systems engineering and project management wisdom suggests that when a decision cannot be made because two choices score almost the same in the decision making process, the decision maker should perform a sensitivity analysis at this point varying the parameters and/or the weighting to see if the decision changes. By recognizing that there may be more than one acceptable solution, the situation may eliminate the need for the sensitivity analysis.
- An alternative relationship between problems and solutions may be represented as shown in Figure 9.6 which leads to the concept of acceptable solutions instead of using the relationship shown in Figure 9.5 that aims at a single correct solution. Figure 9.6 can also be used to show the relationship between 'satisfy' and 'satisfice' where:
    - ***Satisfy*** means provide solutions that are optimal.
    - ***Satisfice*** means provide solutions that are acceptable.

9.7. The holistic extended problem-solving process

Because "*problems do not present themselves as givens; they must be constructed by someone from problematic*[3] *situations which are puzzling, troubling and uncertain*" (Schön, 1991), the problem-solving process must be considered in its context by perceiving it from the *Big Picture* perspective. Unlike the traditional approach to problem-solving which begins with a problem and ends with a solution, the holistic approach takes a wider perspective and begins with an undesirable situation which has to be converted to a Feasible Conceptual Future Desirable Situation (FCFDS) as shown in Figure 9.7.

From this perspective, the observer becomes aware of an undesirable situation that is made up of a number of related factors. A project is authorized to do something about the undesirable situation. The problem solver tries to understand the situation, determine what makes the situation undesirable and then create a vision of a FCFDS. The problem then becomes one of how to move from the undesirable situation to the FCFDS. Once the problem is identified, the remedial action is taken to create the solution system which will operate in the context of the FCFDS. This remedial action for complex problems often takes the form

[3] or undesirable

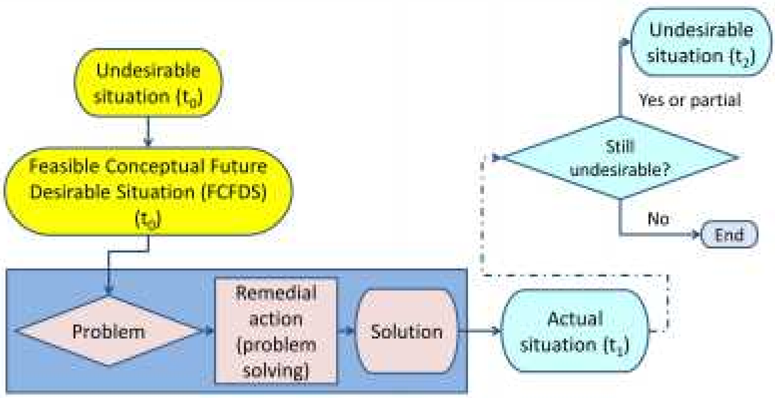

Figure 9.7 The extended holistic problem-solving process

of a System Development Process (SDP) for the solution system that will become operational in the context of the FCFDS.

Once realized, the solution system is tested in operation in the actual situation existing at time t_1 to determine if it remedies the undesirable situation. However, should the remedial action take time, the undesirable situation may change from that at t_0 to a new undesirable situation existing at t_2. If the undesirable situation is remedied, then the process ends; if not, the process iterates from the undesirable situation at t_2. In summary, in general:

- There is an undesirable or problematic situation.
- A FCFDS is created.
- The problem is how to transition from the undesirable situation to the FCFDS.
- The solution is made up of two parts:
    1) The transition process.
    2) The solution system operating in the context of the FCFDS.

If the remedy requires a project, the FCFDS may be designed by systems engineers, the transition process designed by systems engineers and process architects (often project management), the transition process is generally then managed by project management, while the solution system is developed by engineers.

Consider the following example of the extended holistic problem-solving process in a simple situation where Fred is on his way to work in the morning. Framing the problem:

Figure 9.8 Fred's back gate

- ***The undesirable situation:*** having left his apartment, Fred approaches the back gate to his condominium apartment shown in Figure 9.8. He sees a few people milling about on his side of the gate. When he gets close to the other people, he is told that the gate is locked and the lock is broken so that nobody can get through. Fred needs to get through the gate quickly or he will miss his express bus and be late for work. The only other gate, the main gate is a 200 Meter detour in the wrong direction. If Fred has to exit via the main gate he will most probably miss his bus.
- ***The FCFDS:*** Fred goes through the locked gate in time to catch the express bus.
- ***The problem:*** how to get through the locked gate quickly.
- ***The solution:*** to be determined.

9.7.1. The remedial action (problem-solving process)

Fred considers the situation and letting his mind wander around the perspectives perimeter shown in Figure 4.4 doing some holistic thinking.

9.7.1.1. The Operational perspective

In the normal mode of operation people go through the gate in both directions (inward and outward) using their keys to open the gate.

9.7.1.2. The Functional perspective

The locks in the gate open when a key is inserted and turned; the human pushes the door open and passes through the gate. The locks close (lock) automatically when the gate is returned to the resting or closed position.

9.7.1.3. The Structural perspective

The lock on each side of the gate has a mechanism which when activated by the key opens the single locking mechanism. The same key works when inserted in either side of the gate.

9.7.1.4. The Scientific perspective

The inference from the perceptions is that one of the two locking mechanisms (the one on the inside lock) has failed.

9.7.2. The conceptual solution

Fred infers that he should try to open the gate from the outside by inserting a hand holding the key through the bars and then keying the outside lock. The lock should open if the hypothesis of the cause of the failure is correct.

9.7.3. The solution

And that is what Fred did. It worked and he was through the gate in less than 20 seconds. The milling throngs looked at him in amazement. He smiled back, waived and hurried to the bus stop.

9.7.4. Remedied the undesirable situation?

The undesirable situation had been remedied because Fred had passed through the gate in time to catch the express bus. No further action was needed. In fact when Fred returned home that evening the lock had been repaired.

9.8. Problems and symptoms

The undesirable situation manifests itself as symptoms which are used to diagnose the underlying problem. Having diagnosed the problem action is then taken to remedy the problem. The traditional approach is represented by the causal loop shown in Figure 9.9. An action can tackle the problem or a symptom. There will be delays due to various elements in the situation, so that the effect of an action may not be immediately obvious. Sometimes a second action is taken before the effect of the first one is observed leading to the need for a further action to remedy the effect of the second one. The delays can be short or long as discussed in Section 4.3.2.7. Sometimes the action partially remedies the problem;

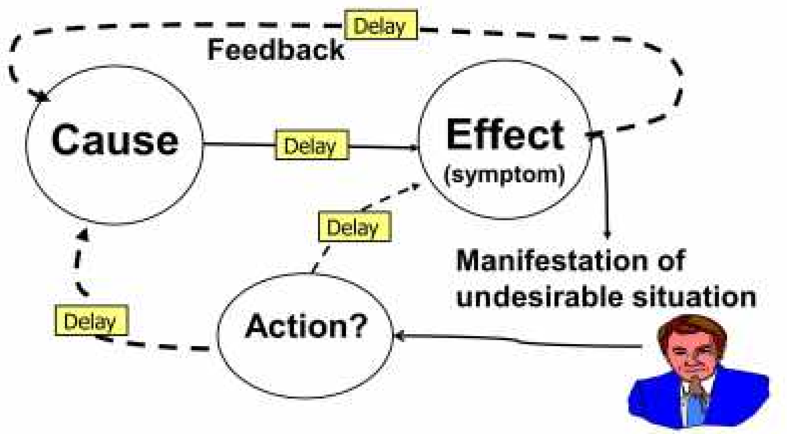

Figure 9.9 Problems, causes and effects (symptoms)

sometimes the action only mitigates the symptoms and produces a new undesirable situation as illustrated in Figure 9.7.

There are two classes of problems in Figure 9.9 namely the:

1. ***Product problems:*** the cause of the undesirable situation. These problems are often referred to by their effects, usually due to a failure of some kind, one example being "the problem was due to a failed integrated circuit". This is an example of the sloppy use of words because the correct terminology should have been the undesirable situation (the failure) was due to a faulty integrated circuit. The problem had been to diagnose the cause of the failure and a way to repair the failed part. See the ALSEP Command Verification Word (CVW) issue in Section 11.6 for an example.
2. ***Process problems:*** namely what to do about the situation to realise a transition from the undesirable situation to the FCFDS. In general, this Chapter discusses process problems.

9.9. Assumptions underlying formal problem-solving

Problem-solving like most other things is based on a set of assumptions. Waring provided the following four assumptions underlying formal problem-solving (Waring, 1996):

1. The existence of the problem may be taken for granted.
2. The structure of the problem can be simplified or reduced so as to make its definition, description and solution manageable.

3. Reduction of the problem does not reduce effectiveness of the solution.
4. Selection of the optimal solution is a rational process of comparison.

However:

- While the existence of the problem may be taken for granted, it may take a while for the stakeholders to agree on the nature of the problem. SSM (Checkland, 1991: pages 163 to 183) discussed in Section 4.4.1 was invented for this purpose.
- The literature on decision making, one of the key elements in problem-solving, has two schools of thought on Waring's fourth point. One school of thought agrees with Waring that decision-making is logical; the other school of thought holds that decision making is emotional. Perceptions for the *Continuum* perspective indicate that some decisions are made emotionally and others are made logically. See Fred's decision-making process for selecting his ideal mate in Section 8.7.3 for but one example.

9.10. Components of problems

Problems have five components (Ackoff, 1978: pages 11 and 12):

1. ***The decision maker:*** the person faced with the problem.
2. ***The control variables:*** aspects of the problem situation the decision maker can control.
3. ***The uncontrolled variables:*** aspects of the problem situation the decision maker cannot control which constitute the problem environment[4].
4. ***Constraints:*** imposed from within or without on the possible values of the controlled and uncontrolled variables.
5. ***The possible outcomes:*** produced jointly by the decision maker's choice and the uncontrolled variables. The desired outcome may be represented as a specified relationship between the controlled variables and the uncontrolled variables, as a design or as a FCFDS. The uncontrolled variables may give rise to unanticipated properties of the solution often called undesirable outcomes.

[4] There may be unknown uncontrolled variables, see Simpson's paradox in Section 4.3.2.6.12.

9.11. A problem formulation template

The following four-part problem formulation template based on the extended holistic problem-solving process used in the book assists the problem-solving process in framing the problem. The four parts are:

1. ***The undesirable situation:*** as perceived from the each of the descriptive HTPs.
2. ***The Feasible Conceptual Future Desired Situation (FCFDS):***
    - As inferred from perceptions from the descriptive HTPs.
    - Generally the situation without the undesirable aspects as well as containing some improvements.
3. ***The problem:*** how to ***convert*** the FCFDS into reality (the *Scientific* perspective).
4. ***The solution:*** is:
    1) Something that:
        i. Remedies the undesirable situation.
        ii. Has to be interoperable with evolving adjacent systems over the operational life of the solution and adjacent systems (the *Temporal* perspective).
    2) Comprises two interdependent parts:
        i. The SDP or transition process that converts the undesirable situation to a desirable situation.
        ii. The solution system operating in the context of the FCFDS.
    3) Is often identical to the FCFDS for non-complex systems.

Placing the FCFDS before the problem is based on the dictum of working back from the answer (Ackoff, 1999) and allows risk management to be incorporated into task planning instead of being an add-on as in the current systems engineering and project management paradigms. The risk management is achieved by ensuring that risks identified in a task are mitigated or prevented in earlier tasks in the project.

9.11.1. Framing classroom exercises using the problem formulation template

This Section provides an example of a generic problem formulation template for framing classroom exercises as follows:

1. ***The undesirable situation:*** the need to successfully[5] complete the exercise in a timely manner.
2. ***The FCFDS:*** having successfully completed the exercise in a timely manner
3. ***The problem:*** to figure out how to create and deliver a product that meets the requirements of the exercise.
4. ***The solution:*** a product that meets the requirements of the exercise.

Students should be provided with the opportunity to practice using the template by framing the problem posed by the specific exercise or assignment by adapting the generic problem formulation template to their situation.

9.11.2. The benefits of using the problem formulation template

The benefits include being forced to think about the situation. In working out the steps of what to do to remedy the problem by providing the solution, students will be forced to plan their work. Accordingly, the template assists in building in best practices by building planning ahead into student projects. And of course it is just as suitable in the real world of systems engineering.

9.12. Classification of problems

Before trying to solve problems it would be useful to have a classification of types of problems and ways to remedy them. The undesirable situation is the lack of such a classification, the FCFDS is a classification system and the problem is to provide a classification of problems. So, using the holistic approach shown in Figure 9.14 the literature was searched (Section 9.16.1.3) and several ways of classifying problems in various domains were identified including the:

1. Level of difficulty of the problem discussed in Section 9.12.1.
2. Research and intervention problems discussed in Section 9.12.2.
3. Structure of the problem discussed in Section 9.12.3.
4. Complexity of the problem discussed in Section 9.12.4.

[5] Success is defined by the desired grade.

9.12.1. The level of difficulty of the problem

Ford introduced four categories of increasing order of difficulty for mathematics and science problems: easy, medium, ugly, and hard (Ford, 2010). These categories may be generalized and defined as follows:

1. ***Easy:*** problems that can be solved in a short time with very little thought.
2. ***Medium:*** problems that:
    1) Can be solved after some thought.
    2) May take a few more steps to solve than an easy problem.
    3) Can probably be solved without too much difficulty, perhaps after some practice.
3. ***Ugly:*** problems are ones that will take a while to solve. Solving them:
    1) Involves a lot of thought.
    2) Involves many steps.
    3) May require the use of several different concepts.
4. ***Hard:*** problems usually involve dealing with one or more unknowns. Solving them:
    1) Involves a lot of thought.
    2) Requires some research.
    3) May also require iteration through the problem-solving process as learning takes place (knowledge that was previously unknown becomes known).

Classifying problems by level of difficulty is difficult in itself because difficulty is subjective since one person's easy problem may be another person's medium, ugly or hard problem. For example, consider an undesirable situation faced by Fred who arrives in a foreign country for a visit and lodges in an apartment. Fred has to do his own cooking. As Fred cannot speak the local language, he is in a number of undesirable situations. Consider the one in which the kitchen has a gas cooker but he has no way to ignite the gas. The corresponding desirable situation is that Fred has something to ignite the gas[6]. Assuming Fred has local currency or an acceptable credit card, is the problem of purchasing something that will ignite the gas easy, hard or something in between? The answer is 'it depends'. Classifying the difficulty of the problem depends on a number of issues including:

---

[6] Note the use of functional language instead of 'matches' in solution.

- If Fred has faced this problem before in the same country? If so, what did he do then?
- If Fred knows where to purchase matches or a gas lighter.
- If Fred even knows how to say "matches" or "gas lighter" in the local language. If he does not know the words, he may not be able to ask anyone to provide the items.

Thus as far as Fred is concerned, the problem is:

- ***None existent:*** if Fred has matches, a gas lighter, a cigarette lighter or another instrument with which to light the gas.
- ***Easy:*** if Fred knows where to purchase matches or a gas lighter and knows the local words.
- ***Medium:*** if Fred knows where to purchase matches or a gas lighter and does not know the local words. After all, he can go to the store or relevant location and look around until he sees matches or lighters on a shelf and then purchase them.
- ***Hard:*** if Fred does not know where to purchase matches or a gas lighter and does not know the local words. The problem is hard because two unknowns have to become known for a solution to be realized.

9.12.2. Research and intervention problems

The classification of problems into research and intervention problems is as follows:

9.12.2.1. Research problems

This type of problem manifests when the undesirable situation is the inability to explain observations of phenomena or the need for some particular knowledge. In this situation:

- ***The undesirable situation:*** the inability to explain observations of phenomena or the need for some particular knowledge.
- ***The FCFDS:*** the ability to explain observations of phenomena or the particular knowledge.
- ***The problem:*** how to gain the needed knowledge.
- ***The solution:*** the knowledge often in the form of the supported hypothesis.
- ***The problem-solving process:*** in this instance, is commonly known as the Scientific Method, and works forwards from the current situation in a journey of discovery towards a future situation in which the knowledge has been acquired.

The Scientific Method:

- Is a systemic and systematic way of dealing with open-ended problems
- Maps into Figure 9.1.
- Has been stated in different variations as the following sequence of activities:

    1) Observe an undesirable situation.
    2) Perform research to gather preliminary data about the undesirable situation.
    3) Formulate the hypothesis to explain the undesirable situation.
    4) Plan to gather data to test the hypothesis. The data gathering may take the form of performing an experiment, using a survey, reviewing literature or some other approach depending on the nature of the undesirable situation and the domain.
    5) Perform the experiment of otherwise gather the data.
    6) Analyse the data (experimental or survey results) to test the hypothesis.
    7) If the hypothesis is supported, then the researcher often publishes the research. If the hypothesis is not supported, then the process reverts to Step 2.

- Uses inductive reasoning (Section 5.1.3.1.2) to create the hypothesis and deductive reasoning (Section 5.1.3.1.1) to support it.

In the real world, the hypothesis is often created from some insight or a "hunch" in which the previous steps are performed subconsciously. The research then designs the data collection method, collects and examines the data to determine if the hypothesis is supported. In this situation:

- The publication is generally written as if the steps in the Scientific Method have been performed as described above.
- Half the data is used in defining the hypothesis and half the data in used in testing the hypothesis.

There is also an unfortunate tendency to ignore or explain away data which does not support the hypothesis for reasons that include:

- The researcher is only looking for data to support the hypothesis (See factors that lead to bad decisions in Section 8.3).
- The data sample may be defective.

It is important to verify such data, because if the data are valid, they may indicate an instance of Simpson's paradox (Section 4.3.2.6.12) and

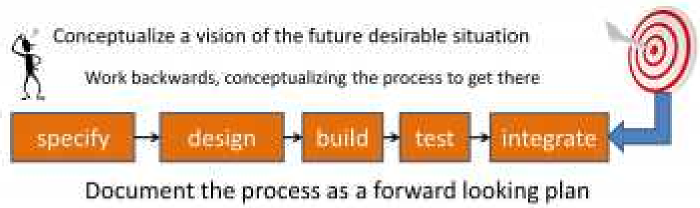

Figure 9.10 The forwards-backwards-forwards SDP – process flow view

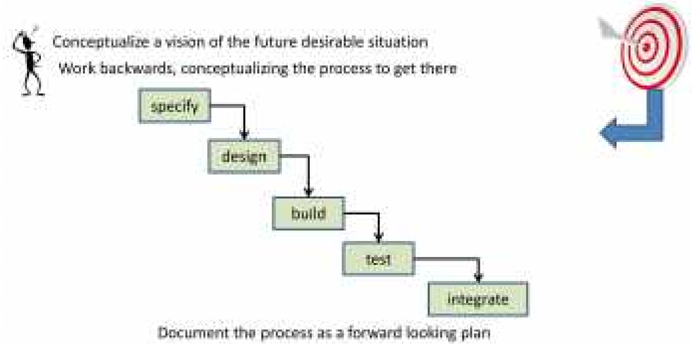

Figure 9.11 The forwards-backwards-forwards SDP – waterfall view

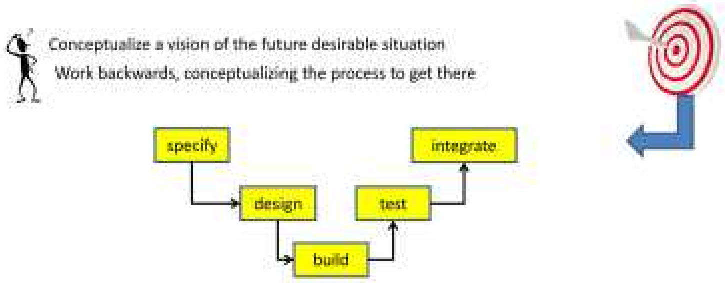

Figure 9.12 The forwards-backwards-forwards solution SDP – V view

provide the opportunity for further research which could lead to the identification of one or more previously unknown and accordingly unconsidered variables in the situation which would then provide a better understanding and perhaps a Nobel Prize or equivalent in the specific research domain.

9.12.2.2. Intervention problems

This type of problem manifests when a current real-world situation is deemed to be undesirable and needs to be changed over a period of time into a FCFDS. In this situation:

- ***The undesirable situation:*** may be a lack of some functionality that has to be created, or some undesirable functionality that has to be eliminated.
- ***The FCFDS:*** one in which the undesirable situation no longer exists.
- ***The problem:*** how to realize a smooth and timely transition from the current situation to the FCFDS minimizing resistance to the change.
- ***The solution:*** the transition process to move from the undesirable situation to the FCFDS together with the solution system operating in the situational context.
- ***The problem-solving process*** first uses the research problem-solving process working forwards to produce concepts of a number of FCFDS that will remedy the current undesired situation, selects the best one, and then works backwards to the current problematic or undesirable situation determining how the transition was implemented working back from the answer (Ackoff, 1978; Hitchins, 1992: page 120). The information created in this backwards looking process is then used to document the:
    - FCFDS.
    - Realization plans documented as a forward process starting from the current situation and ending with the deployment of the FCFDS.

The forwards-backwards-forwards solution system development process (SDP) perceived from the *Operational* perspective is illustrated in:

- Figure 9.10 as a process flow chart.
- Figure 9.11 as a waterfall view of the same process.
- Figure 9.12 As a V view of the same process.

The decision maker or problem-solver is faced with an undesirable situation. Once given the authority to proceed:

- He[7] uses the problem-solving process to conceptualize a vision of the solution system operating in the FCFDS which becomes the target or goal to achieve.
- Then the problem he faces is to create the transition process and the solution system that will be operational in the FCFDS.

[7] The word 'he' represents 'he' or 'she' in this Section.

- He uses his imagination and PAM charts (Section 2.7.2.3) to work backwards from the FCFDS to the present undesirable situation creating the transition process.
- He then documents the process as a sequential process working forwards from the present undesirable situation to the FCFDS.

As shown in the figures, the process may be drawn in the form of a flow chart (Figure 9.10), a classic waterfall view (Figure 9.11), or a V view (Figure 9.12) which is used to show relationships between development and testing aspects of the process. This version of the problem-solving process is the context in which most systems engineering activities take place.

Both the research and intervention problem-solving processes contain a series of sub-problems[8] each of which have to be solved in turn to arrive at the solution.

Once the problem is identified, before even attempting to find a solution, one should use the relevant starter questions from the Generic perspective for Active Brainstorming listed in Section 6.2.2.5 to determine if anyone else has faced the same or a similar problem, what they did about it, what results they achieved and the similarities and differences between their situation and the current situation. As mentioned in Section 4.3.2.5 this is the concept behind TRIZ.

9.12.3. The structure of the problem

Perceived from the *Continuum* perspective, problems lie on a continuum which ranges from 'well-structured' through 'ill-structured' to 'Wicked'. Consider each of them.

9.12.3.1. Well-structured problems

Well-structured problems are problems where the existing undesirable situation and the FCFDS are clearly identified. These problems may have a single solution or sometimes more than one correct solution. Examples of well-structured problems with single correct solutions are:

- Mathematics and other problems posed by teachers to students in the classroom. For example, in mathematics, 1+1=2 every time.
- Making a choice between two options. For example, choosing between drinking a cup of coffee and drinking a cup of tea. However, the answer may be different each time.

[8] Which can in turn be research or intervention.

- Finding the cheapest airfare between Singapore and Jacksonville, Florida if there is only one cheapest fare. However the answer may be different depending on the time of the year.

Examples of well-structured problems with several correct but different solutions are:

- What brand of coffee to purchase? Although the solution may depend on price, taste and other selection criteria, there may be more than one brand (solution) that meets all the criteria.
- Which brand of automated coffee maker to purchase?
- What type of transportation capability to acquire?
- Finding the cheapest airfare between Singapore and Jacksonville, Florida if two airlines charge the same fare.

Well-structured problems with single solutions tend to be posed as closed questions, while well-structured problems with multiple solutions tend to be posed as open questions (Section 3.4.1.1).

9.12.3.2. Ill-structured problems

Ill-structured problems, sometimes called 'ill-defined' problems or 'messy'[9] problems are problems where either or both the existing undesirable situation and the FCFDS are unclear (Jonassen, 1997). Examples of ill-structured complex problems are:

- The initial feeling that something is wrong and needs to be changed which triggers the problem-solving process.
- Where to dispose of nuclear waste safely? This is where the FCFDS is unclear.
- How to combat international terrorism? This is where different stakeholders perceive different causes of the situation and different ways of dealing with the causes.

9.12.3.3. Wicked problems

Wicked problems are extremely ill-structured problems[10] first stated in the context of social policy planning (Rittel and Webber, 1973). Wicked problems (Shum, 1996):

- Cannot be easily defined so that all stakeholders cannot agree on the problem to solve.

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[9] When complex

[10] Technically there is no problem since while the stakeholders may agree that the situation is undesirable, they cannot agree on the problem.

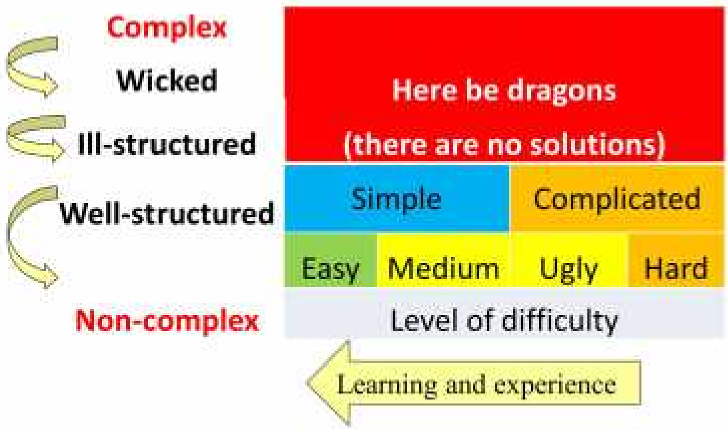

Figure 9.13 Problem classification matrix framework

- Require complex judgements about the level of abstraction at which to define the problem.
- Have no clear stopping rules (since there is no definitive 'problem', there is also no definitive 'solution' and the problem-solving process ends when the resources, such as time, money, or energy, are consumed, not when some solution emerges).
- Have better or worse solutions, not right and wrong ones.
- Have no objective measure of success.
- Require iteration - every trial counts.
- Have no given alternative solutions - these must be discovered.
- Often have strong moral, political or professional dimensions.

9.12.4. The complexity of the problem

The complexity the problem is determined by the number of issues, functions, or variables involved in the problem; the degree of connectivity among those variables; the type of functional relationships among those properties; and the stability among the properties of the problem over time (Funke, 1991). See Section 7.7 for a discussion on the need to separate the subjective level of difficulty known as complicated from the factors contributing to complexity.

Insight from the *Scientific* perspective infers that it is not the complexity of the problem that makes problem-solving difficult because complexity can be managed as discussed in Section 7.7.2.3, rather it is the attempt to solve ill-structured problems that causes the difficulty.

9.13. A problem classification matrix framework

The complexity and level of difficulty of problems are combined in the two-dimensional problem classification map shown in Figure 9.13 where the terminology is in accordance with the definitions in Section 1.7. The two dimensions are:

- ***Complexity:*** ranges from non-complex through complex well-structured problems to complex ill-structured problems and Wicked problems.
- ***Level of difficulty:*** ranges from easy to hard; where simple problems can be easy and medium while complicated problems are those that are ugly and hard.

Different people may position the same problem in different places in the framework. This is because as knowledge is gained from research, education and experience a person can reclassify the subjective difficulty of a problem down the continuum from 'hard' towards 'easy'. As discussed below, there are no solutions to ill-structured and Wicked problems; they must be converted to well-structured problems before the main problem-solving process can begin.

9.14. Remedying problems

There are four ways of dealing with a problem (Ackoff, 1978: page 13), where only the first three actually remedy the problem. The four ways are:

1. ***Solving the problem*** is when the decision maker selects those values of the control variables which maximize the value of the outcome.
2. ***Resolving the problem*** is when the decision maker selects values of the control variables which do not maximize the value of the outcome but produce an outcome that is good enough or acceptable (satisfices the need).
3. ***Dissolving the problem*** is when the decision maker reformulates the problem to produce an outcome in which the original problem no longer has any meaning. These are generally the innovative solutions.
4. ***Absolving the problem*** is when the decision maker ignores the problem or imagines that it will eventually disappear on its own. Problems may be intentionally ignored because they are too expensive to remedy, or because the technical or social capability needed to provide a remedy is not known, unaffordable or not available.

Table 9.1 Varieties of the problem-solving process

<table>
<tr><th>Reference</th><th>SSM</th><th>GDRC</th><th>OVAE</th><th>Scientific Method</th></tr>
<tr><td>1. Planning</td><td colspan="4">Assumed</td></tr>
<tr><td rowspan="2">2. Situation analysis</td><td>Step 1</td><td>1. Problem definition</td><td>1. Identify and select the problem</td><td>1. Observe</td></tr>
<tr><td>Step 2</td><td>2. Problem analysis</td><td>2. Analyse the problem</td><td rowspan="3">2. Research</td></tr>
<tr><td rowspan="2">3. Conceptual solution design</td><td>Step 3</td><td>3. Generating possible solutions</td><td rowspan="2">3. Generate potential solutions</td></tr>
<tr><td>Step 4</td><td>4. Analysing the solutions</td></tr>
<tr><td>4. Solution selection</td><td>Step 5</td><td>5. Selecting the best solution(s)</td><td rowspan="2">4. Select and plan the solution</td><td>3. Formulate the hypothesis</td></tr>
<tr><td>5. Solution realization planning</td><td>Step 6</td><td>6. Planning the next course of action (next steps)</td><td>Plan the experiment</td></tr>
<tr><td>6. Solution realization</td><td>Step 7</td><td>-</td><td>5. Implement the solution</td><td>Perform the experiment</td></tr>
<tr><td>7. Test and evaluation</td><td>-</td><td>-</td><td>6. Evaluate the solution</td><td>4. Analyse the experimental results to test the hypothesis</td></tr>
<tr><td>8. In-service</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>9. Disposal</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
</table>

9.15. Comparing varieties of the problem-solving process

The literature contains many versions of the problem-solving and decision-making process. Each description tends to depict parts of the same linear sequential linear series of activities as the SEP. Three examples are:

1. Hitchins' version of systems engineering which covers the early states of the SDP ending when the solution and strategies and plans to realise the solution system have as been conceptualised as shown in Figure 9.2.

2. The Global Development Research Center (GDRC) version which covers the problem identification-solution identification steps (GDRC, 2009).
3. The Office of Vocational and Adult Education (OVAE) version which goes beyond the GDRC version and contains steps that not only realize the solution but evaluate the solution to determine if the solution remedied the problem (OVAE, 2005).

The SSM, GDRC, OVAE and Scientific Method (Section 9.12.2.1) variations on the problem-solving process are compared in Table 9.1 to show the similarities and differences in the grouping of tasks. For example, Steps 1, 2 and 3 of the GDRC and OVAE processes seem to align. Steps 4, 5 and 6 of the GDRC version are bundled into Step 4 of the OVAE version. Steps 5 and 6 in OVAE's version are absent in the GDRC version. Thus the GDRC version ends with the last box in Figure 9.3 while the OVAE version ends with realizing the solution and maps into the whole of Figure 9.2.

Notice that:

- The planning state is generally left out of the various descriptions.
- The activities in the in-service and disposal states of the System Lifecycle (SLC) generally do not show up in the various descriptions of the problem-solving process and in many versions of the SDP/SLC.

In addition, the problem-solving and decision-making processes are identical, where:

- ***Problem-solving*** is the name of the process from a helicopter or bird's eye external view of the entire process.
- ***Decision-making*** is the name of the same process from a viewpoint anchored to the decision-making blocks in Steps 5 and 6 of Figure 9.2.

The four key elements of decision-making discussed in Section 8.7 also constitute an example of the problem-solving process with the addition of steps to evaluate and improve the process in accordance with avoiding the decision traps discussed in Section 8.3.

9.16. The System Lifecycle (SLC)

The SLC is a complex example of the problem-solving process. If all the tasks and activities performed in the variations of the problem-identification-solution-provisioning process described in the literature were elaborated into smaller tasks and drawn in a very large N^2 chart (Section 2.7.5.5) the various descriptions of the problem-solving process in the literature could be considered as different groupings of the elaborated tasks in N^2 chart. The differences between versions of the various problem-solving processes seen in the groupings would be because:

1. The aggregation of low-level tasks into higher order activities is different in each version.
2. Some of the tasks and activities may have been omitted in that particular version.

Since most situations are similar but not identical, it is unlikely that a published process, tool or methodology will be appropriate to every occasion. Consequently, the problem solver's initial problem is to create or architect the problem-solving process to be used in their specific situation. That is why Chapter 10 provides some examples. A good way of creating a process is to modify or tailor a conceptual model approach which provides a reference grouping of the various tasks and activities. The conceptual model contains a full set of activities which may or may not be used in any specific tailored version of the problem-solving process.

This Section describes the first seven states of the SLC which is known as the SDP because the SDP focuses on the development of the solution system that will operate within the FCFDS. The activities in each state implement the systems engineering problem-solving approach because the state begins with a milestone and ends with a product at a completion milestone. The completion milestone of one state is often the authorization to proceed to the milestone of the subsequent state. As perceived from the *Functional* perspective, the nine states of the SLC are:

1. The Project Planning State discussed in Section 9.16.1.
2. The Current Situation Analysis State discussed in Section 9.16.2.
3. The Conceptual Solution Design State discussed in Section 9.16.3.
4. The Solution Selection State discussed in Section 9.16.4.
5. The Solution Realization Planning State discussed in Section 9.16.5.
6. The Solution Realization States discussed in Section 9.16.6.
7. The Test and Evaluation State discussed in Section 9.16.7.
8. The In-Service State discussed in Section 9.16.8.
9. The Disposal State discussed in Section 9.16.9.

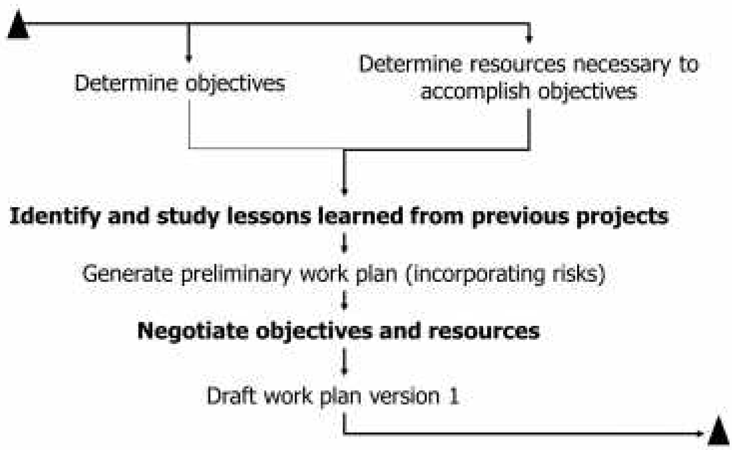

Figure 9.14 Process for planning a task or a project

The assumption in this model is that the undesirable elements in the current situation are complicated and/or complex enough to warrant a project to be undertaken to remedy the situation.

9.16.1. The Project Planning State

This State of the SDP begins with a trigger. The trigger that initiates the SDP is someone:

- In a situation having a feeling that something is undesirable.
- Wishing to remedy the situation
- Being in a position to do so.

The product produced in this state of a project is a plan for completing the remainder of the project. The plan has many names including project plan, work plan, task plan, etc. The project can be as simple as making a cup of tea, or as complex as landing a man on the moon. The plan can be as informal as a few thoughts in the case of a task that has been done many times before, or a formal document signed off by all the stakeholders for a complex project.

The planning process is the first part of the forwards-backwards-forwards process discussed in Section 9.12.2 shown from the *Operational* perspective in Figure 9.11. The functional view is shown as a linear sequence in Figure 9.14. The contribution of this view of the process is to point out two important elements that are not generally performed, namely:

1. Identifying and applying of lessons learned from prior projects.
2. Negotiating objectives and resources.

Consider the following functions or tasks performed in planning a project.

9.16.1.1. Determining objectives

These activities determine the objectives of the project. The task begins with determining or confirming the objectives for the task and resources that will be available to achieve those objectives. Sometimes they are provided, other times they have to be identified.

9.16.1.2. Determining resources necessary to accomplish the objectives

These activities are the first iteration of the forwards-backwards-forwards sequence of activities discussed in Section 9.12.2. The product produced by these activities is the first draft of the plan. This draft is an ideal plan that does not take into account any limitations of resources such as budget, personnel and time.

9.16.1.3. Identifying and applying of lessons learned from prior projects

The process architect should pose the following questions from the *Generic* perspective as a minimum:

- Has anyone done this task or a similar one before?
- Did they succeed or fail?
- Why?
- What is the difference between those other task(s) and this one that might change those results?

Obtaining answers to these questions, performing the analysis, and presenting the result, requires access to the organization's lessons learned database. Once access is provided, the first action is to determine if anyone has faced a similar task and identify the lessons learned from those tasks. The process architect identifies what worked, what didn't work in the previous situations; compares the situations to the current one and determines if those factors apply, and what effect they may have. This step of the process may be thought of as prevention, pattern matching, risk management or even inheritance in its object-oriented sense. This step is critical since it can prevent mistakes from being made, and wrong approaches from being taken. Yet process methodologies such as PRINCE2 (Bentley, 1997) generally require the lessons learned to be documented at the end of a process but do not require that the lessons learned be reviewed at the start of the next project. Project lessons learned documents or databases seem to be write-only memories except in Capability Maturity Model (CMM) Level 5 organisations!

9.16.1.4. Generating the preliminary work plan

The product produced by this State of the process is the draft plan containing the draft Work Packages (WP) and the summary views of the work plan in the form of the draft schedule, the Work Breakdown Structure (WBS)/WPs and the staffing, risk and cost summaries. The draft plan must be produced without being constrained by budget and resources. The resource budgets in the work packages must be as realistic as possible at this time. Adjusting this ideal draft plan to a plan which takes the real world constraints into account happens in the next phase of this process.

9.16.1.5. Negotiating objectives and resources

This State of the process negotiates the objectives and resources. The draft work packages are adjusted to meet the time and cost budgets. If the resources available do not meet the draft budgets, then low priority work packages may have to be flagged, removed or delayed. This process, incorporates prevention of defects (at least some known ones) by definition, hence reduces the cost of doing work. Early identification of inadequate schedule time or other resources allows the project manager to attempt to deal with the situation in the implementation phase of the project in a proactive manner rather than a reactive manner.

9.16.1.6. Drafting work plan version 1

Once any adjustments have been made as a result of the negotiations, the plan can be approved and signed off. The plan is turned over to the project manager and the main realization task begins with the activities in Section 9.16.2.

If realistic schedules and objectives are set, the project manager is able to plan ahead, anticipate and implement changes, so schedules and budget goals are met. As a consequence, the project receives very little senior management visibility. All goes reasonably well, and in the main, senior management in general, does not realize or recognize the achievements of the process architect and project manager (Kasser, 1995a: page 4). If unrealistic schedules are set, or insufficient resources are allocated to the project, the project will be doomed as discussed by Yourdon in his description of a death-march project (Yourdon, 1999), but at least everyone will know why the project is doomed well ahead of time! This situation manifests itself in the John Wayne style of reactive management, continually fighting crises, leading to high visibility (Kasser, 1995a: page 135). All the problems are visible to senior management, who tend to reward the project manager for saving the project, sometimes from the very problems that the same project manager introduced.

As Deming wrote, "*Heard in a Seminar: One gets a good rating for fighting a fire. The result is visible; can be quantified. If you do it right the first time, you are invisible. You satisfied the requirements. That is your job. Mess it up, and correct it later, you become a hero*" (Deming, 1986: page 107). Thus if you want to be promoted, your approach should be to build failure and recovery into the project. Instead of preventing problems, anticipate them, but let them happen. Only apply corrective measures after the making the problems visible to upper management. If you implement a project in this manner, it will make you a hero at the expense of the organization".

9.16.2. The Current Situation Analysis State

This State:

- Is where the planning stops and the real work begins.
- Contains the activities involved in trying to gain an understanding of the situation. These activities are making the observations about the problematic undesirable situation to analyse the situation and identify the underlying root cause or causes of the feeling that something needs to be changed. SSM is but one tool designed for use in this phase as discussed in the Command, Control, Communications, and Intelligence (C3I) morale issue Case Study in Section 10.1. You may find it useful to sort the perceptions about the situation according to the perspectives perimeter if the situation is complex or complicated as discussed in Section 6.1 and shown in the RAFBADS description in Section 6.4.3.

You can apply Active Brainstorming as a part of the situational analysis to determine what information you have gathered about the situation from multiple sources and what information you still need. Identify what questions don't have answers and gather the necessary information. This is a key step towards identifying the correct underlying cause of the undesirable situation. Depending on the difficulty of the problem, the situation analysis should begin with the following traditional four questions from the *Generic* perspective:

1. Who has faced this situation before?
2. What did they do about it?
3. What were their results?
4. What is different between their situation and this one?

The next step is to sort the ideas for changing the situation into the ISTs (Section 6.3), use:

" A holistic thinking perspective on a promotion strategy.

- The HTPs to store the information in a systemic and systematic manner as discussed in Section 6.1.
- OARP (Section 6.3.2.1) for the ideas about the problem, namely what would be involved making the transition from the current undesirable situation to the FCFDS.
- FRAT (Section 6.3.2.2) for the ideas about the FCFDS in terms of needed mission and support, normal and contingency mode functions.
- SPARK (Section 6.3.2.3) for the ideas about realizing the solution system that will be operational in the FCFDS.

The LuZ SEGS-1 project description in Section 6.4.1 provides an example of documenting observations from the HTPs, identifying the undesirable elements in the current situation and using Active Brainstorming to think about remedying the undesirable situation and storing the resultant ideas in the ISTs.

According to conventional wisdom, this State should end with a definitive statement of the problem; in this case a statement of what has to be done to realize the FCFDS starting from the current undesirable situation. In general:

- ***Easy well-structured problems*** are simple problems and require little if any research and analysis before creating the solution.
- ***Medium well-structured problems*** are less simple and require some research and analysis before creating the solution.
- ***Ugly well-structured problems*** are complicated yet require little if any research and analysis before creating the solution.
- ***Hard well-structured*** non-complex problems are more complicated and require research and analysis before creating the solution.

In many situations however, the problem solver seeks to gain an understanding of the problem and produces a FCFDS in an iterative manner and does not produce a problem statement. In these situations, the problem has effectively been articulated in terms of an acceptable FCFDS, and the first two phases of the problem-solving process have been combined.

Reasons why the problem cannot be remedied will often surface during this state. These reasons should not be constraints that stop the process, these reasons should be treated as inhibitors because they are barriers that inhibit the solution from being implemented (Pfeffer and Sutton, 2000: page 67). When these inhibitors surface they should be reframed from a different perspective as new problems to be remedied.

9.16.3. The Conceptual Solution Design State

This State contains the activities that:

1. Create or design a number of conceptual FCFDS that could remedy the undesirable features of the current situation.
2. Create or identify the solution selection criteria that will then be used to select the best conceptual FCFDS within the constraints of the situation.

9.16.3.1. Creating the FCFDS

The sub-problem in this State is to create a number of FCFDS in which the undesirable features of the current situation no longer exist. Moreover, an FCFDS may contain a number of intermediate FCFDS. Ideally these FCFDS are created by different teams with different skill sets and experience, working in parallel following the research problem-solving process, which is often called the design process in this situation, with little if any communications between the teams to avoid cross fertilization of ideas. If resources are available, each team should try to remedy the undesirable aspects of the current situation in a different manner, one by solving, a second by resolving and the third by dissolving the problem. Each FCFDS may be mapped on to the following two continua:

1. ***The system implementation continuum*** or design space discussed in Section 4.3.2.6.2.2. Each FCFDS will lie on a different point on the system implementation continuum with a different mixture of people, technology, a change in the way something is done, etc.
2. ***The Temporal Continuum***. Each FCFDS may be in a number of parts, some parts:

    - Providing short-term remediation.
    - Providing long-term remediation.
    - Prevention of a repetition of the problem.

    The short-term and long-term FCFDSs may or may not be:

    - Identical.
    - Different.
    - Implemented at the same point in time
    - Implemented different points in time.

Understanding these properties of solutions allows solutions to be realized in evolutionary stages starting with a manual solution which evolves through various incarnations of semi-automatic solutions into a fully automatic solution. For example, many urban rapid transit rail systems providing solutions to people-moving problems have evolved through these incarnations.

To complicate the situation, the correct solution may not be identical in every situation. For example, consider the following commonly asked question in a mathematics class, "If Joe can build a wall in 10 hours, how long will it take Mick and Pat to build the same wall?" In the mathematics class, the answer is 5 hours. In a project management class the answer will be different. Mick and Pat may not work at the same rate and there may be some coordination required so the answer (estimate) would be an estimate of about 6 hours.

However, if the problem had been stated as, "If Joe built a wall in 10 hours, how long will it take Mick and Pat to build the same wall?" the answer would be, "the wall is already built, why would we even consider having Mick and Pat build that wall?" The question, as phrased, in this context does not make sense unless it is a duplicate identical wall in another location.

Proper formulation of the problem statement is important. The problem should have been stated in this context as, "how long would it take Mick and Pat to build a copy, or a duplicate identical wall".

9.16.3.2. Creating solution selection criteria

Ideally, another group of people create solution selection criteria during this phase. Solution selection criteria are attributes of the solution option pertaining to the manner in which the option meets the need such as cost, time to realize the solution, political constraints, risks, certain (lack of) resources, learning curves, compatibility with existing technology and other constraints, etc. The generic types of solution selection criteria including those discussed in Section 8.7.3.4.1 are:

- ***Essential:*** the option cannot be selected if this attribute is not present unless none of the options have this attribute, in which case the situation must be re-evaluated to determine if the criterion is really essential.
- ***Desirable:*** the option can be selected if this attribute is not present.
- ***Don't care:*** which once identified are labelled as such to show that they may be pertinent and have not been overlooked. An example of a 'don't care' selection criterion in the choice of which car to purchase might be the colour if the purchaser has no preference for colour.

- ***Other:*** which once discovered can be essential, desirable or 'don't care'.

Solution selection criteria are developed to select or choose one of the options (the desired solution). For example, in the problem situation discussed in Section 9.12.3.1 if there are several tickets for travel between Singapore and Jacksonville at the identical lowest price, then other criteria such as departure time or length of journey including waiting times at intermediate airports can be used to choose between the solutions.

9.16.4. The Solution Selection State

This State contains the activities that select a FCFDS for realization. The conceptual FCFDSs are evaluated against the solution selection criteria with several possible outcomes including:

- One selectable FCFDS remedies all the undesirable features of the current situation.
- Several selectable FCFDS remedy all the undesirable features of the current situation.
- Elements from several of the FCFDS can be adapted to produce a better selectable FCFDS.
- A FCFDS that remedies all of the undesirable features of the current situation cannot be found. For example, a FCFDS cannot be identified, or the identified solutions cannot be realized due to cost, implementation time or other constraints.
- A FCFDS can only be found that remedies some of the undesirable features of the current situation but not the entire set of undesirable features.
- All combinations of selectable FCFDSs that remedy some of the undesirable features of the current situation do not remedy the entire set of undesirable features. For example, the solutions may all remedy the same undesirable feature, or some solutions may remedy different undesirable features, leaving some of the undesirable features without a remedy.

  In the outcomes in which the undesirable features of the current situation cannot be remedied, the problem must be redefined or absolved[12]. If the problem is redefined then the previous phases of the SDP are iterated until a modified FCFDS is selected[13].

[12] If the decision is made to absolve the problem, the process terminates at this point.
[13] With a corresponding cost escalation and schedule delay for the time spent in the repeat of the earlier phases of the SDP.

- Ends with description of a selected FCFDS[a] that will alleviate the undesirable features of the current situation within the constraints posed by the environment and other factors.

9.16.5. The Solution Realization Planning State

This State:

- Contains the activities that creates the realization plan or plans to acquire (develop, purchase or a combination thereof) and prove the solution following the intervention problem-solving process (Section 9.12.2.2).
- Contains many of the activities used to plan this project described in Section 9.16.1.
- Might produce one or more plans (depending on the scope of the solution to be realized) and a set of acceptance criteria, which when met, will provide consensus that the changed situation no longer contains the undesirable features of the current situation. This is where a gap analysis of how to bridge the gap between the FCFDS and the current situation is performed, working back from the FCFDS to the current situation and then the plans are documented starting from the current situation and working forward to end with an operational FCFDS.

From the *Temporal* perspective, history has shown that changes tend to be resisted. Consequently, resistance to change must be identified and taken into account when planning the transition from the current undesirable situation to the FCFDS.

9.16.6. The Solution Realization States

During these States, personnel perform the interdependent activities that design, build, test, integrate and deliver the solution system to the location where it is needed. The three interdependent streams of work activities that implement the plans to convert the FCFDS into a real and practical changed situation merge at planned predefined milestones as shown in Figure 9.15 (Kasser, 1995a: page 140). The three streams of work are:

1. ***Management:*** performing the necessary planning, organizing, directing, controlling, staffing and reporting functions to ensure that resources (equipment and personnel) are available when needed within the constraints of schedule and budget.

[a] This could be a CONOPS, a matched set of specifications, a simulation, a model, a photograph, a schematic or even an object.

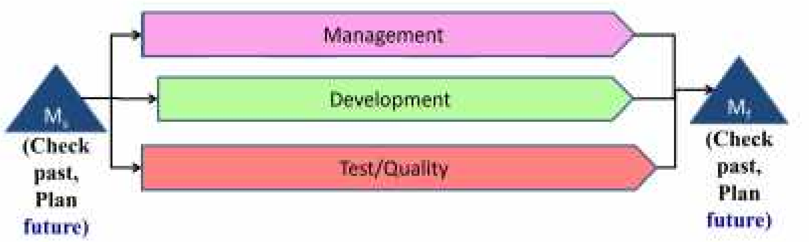

Figure 9.15 The three streams of work to realize a solution to a problem

2. ***Development***, which continues to develop the solution according to the concepts approved at the previous milestone.
3. ***Test/Quality***, which performs the prevention, testing, verification, validation, configuration control and quality function activities.

The FCFDS emerges from the combination of things that make up the FCFDS. These things include the activities performed to realize the solution (the process) as well as the integrated elements or components assembled into the solution and the interaction between the components (the product or the system).

These States end when the solution system is ready to be proven or tested.

9.16.6.1. Emergent properties

The solution emerges from the anticipated properties of the parts and the interactions between the parts. Some of the other emergent properties exhibited by the solution can be anticipated while other emergent properties might be unanticipated, each having desired as well as undesired consequences as discussed in Section 7.5.2. The personnel realizing the solution are presumed to have the expertise to avoid, prevent or at least minimize unanticipated emergent properties and consequences.

9.16.6.2. Changes during the realization states

If the realization states take a long time, then it is likely that the current situation will change for the better or worse during the states. The need for remedying the undesirable features resulting from these changes must be evaluated periodically[15] to ensure that the solution will remedy the undesirable features of the changed situation. At any point during this state, if the solution does not remedy the undesirable features of the changed situation, the state must:

[15] At major milestone reviews for example

- Transition back to the earlier state (most preferable).
- Include the appropriate redesign activities from the earlier states of the SDP[16].
- Must be terminated, ending the project.

9.16.7. The Test and Evaluation State

This State contains the activities that determine the degree to which the solution system:

- Remedies the undesirable features of the current situation including those of any changes that have occurred since the process began.
- Contains unanticipated emergent properties. All undesirable unanticipated emergent properties or features must be removed in this phase.

9.16.8. The In-Service State

This State:

- Is also known as the Operations, Maintenance (O&M) and Upgrade State.
- Contains the activities that take place as long as new undesirable activities do not show up. Sometimes latent defects in the solution show up and must be remedied during this state. Should a new undesirable situation appear during this state, a parallel SDP cycle iterates to realize a further FCFDS that remedies the new undesirable situation. The FCFDS is then upgraded to the solution system in the replacement FCFDS and any other necessary changes in the situation.
- Lasts for as long as the solution system remedies the undesirable situation and is affordable.
- Ends when the solution system is about to be taken out of service.

9.16.9. The Disposal State

This State begins once the solution system is taken out of service and contains the activities that dispose of the solution.

9.17. The real world

The description of the SLC represents the classroom situation because a linear sequential process is easy to teach and to understand. However, the

[16] The same problem-identification-solution-provisioning process

Figure 9.16 Temporary diversion for pedestrians

real world is somewhat different and more complex for a number of reasons including:

- While passing through the realization states, someone may discover that an error has been made in an earlier state and the process has to restart at an earlier state to recover from the error, hence incur cost and schedule escalations.
- After the solution system has emerged transforming the undesirable situation into a FCFDS, a new undesirable situation may show up and the process needs to repeat.
- If remedying the problem takes a long time, one or more undesirable situations may show up while the undesirable situation is being remedied and if an undesirable situations need to be remedied quickly they will trigger a second SDP before the first one ends. Should this happen then the time-ordered-multi-phased evolutionary approach discussed in Section 9.18.1 needs to be invoked.
- People do their own things and may not behave as expected.

Consider the following examples of real-world situations:

1. The pedestrian rerouting experience discussed in Section 9.17.1.
2. Dealing with Fred's oversleeping problem discussed in Section 9.17.2.

Figure 9.17 Pedestrians taking the dangerous short cut

9.17.1. The pedestrian rerouting experience

Consider a pedestrian rerouting experience as a simple example of how undesirable situations can cascade requiring several unanticipated iterations of the problem-solving process. In 2011 the company constructing a new apartment building needed to protect the entranceway into the apartment development from small objects that could potentially fall from the upper floors during the construction. So they engineered a solution by constructing a covered area and diverted pedestrians around it as shown in Figure 9.16. The pedestrians, when faced with going three quarters around a square or taking the short route tended to take the short cut as shown in Figure 9.17 which meant that the pedestrians had to step out into the road: a hazardous situation. The engineers, noticing this undesirable situation extended the fence along the driveway by about 30 Meters to stop them from stepping out into the road. This meant that pedestrians had to remember to walk out into the driveway 30 Meters before they reached the detour sign. The new undesirable outcome was an extension of the hazardous situation rather than eliminating it. This was because pedestrians coming the other way walked in the road for an extra 30 Meters sharing it with incoming traffic. A little bit of holistic thinking would have predicted the pedestrian behaviour and might have provided a different safer solution.

9.17.2. Dealing with Fred's oversleeping problem

The traditional problem-solving process was developed to deal with non-complex problems such as the one facing Fred, now back at work. Fred is in an undesirable situation, he cannot wake up in the morning which makes him late for work on most days. Fred's supervisor triggered the problem-solving process on Friday when he warned Fred that if he (Fred) came to work late on the following Monday morning, he would be replaced. Consider Fred's approach to remedying this undesirable situation in each of the states of the SLC assuming Fred follows the process.

9.17.2.1. Framing the problem

Fred thought about the situation (performed a situational analysis) and decided that he liked his job and did not want to be replaced. This meant that he needed to make sure he got to work on time not only on the Monday but also on every subsequent day for the foreseeable future. He analyses the situation and framed the problem as:

- ***The undesirable situation:*** after the alarm has woken him in the morning it took him too long to become fully awake. Fred needs a systemic and systematic way of getting to work on time and does not know how to do it.
- ***The FCFDS:*** Fred has a systemic and systematic way of ensuring he is fully awake in time to get to work on time.
- ***The problem*** was to make a transition from the current undesirable situation to the FCFDS.
- ***The solution*** was unknown and would be determined by implementing the research problem-solving process or journey of discovery.

So Fred decided to try the problem-solving process shown in Figure 9.2 in his personal life as well as in his professional life.

9.17.2.2. The conceptual solution design

Fred thought about the situation and asked for suggestions from his office peers and friends during the tea and lunch breaks. Between them they identified a number of FCFDS each located on a different point along the system solution implementation continuum (Section 4.3.2.6.2.2). The solutions included:

1. Living closer to the office to shorten the morning commute.
2. Setting the alarm clock for an earlier time.
3. Taking a cold shower in the morning.
4. Drinking a cup of coffee immediately after waking up in the morning.

5. Going to bed earlier in the evening (so as to wake up earlier in the morning).

Fred developed the following selection criteria[17] for the choice of FCFDS:

1. Having to wake up earlier is undesirable.
2. He likes going to bed late and is not willing to go to bed much earlier.
3. He is willing to spend up to (budget) $100.
4. He does not want to move apartments.
5. Having a cold shower instead of a warm one is undesirable.

Fred checked that his budget was feasible by looking at the price of coffee makers advertised for sale in the Sunday newspaper. Having done that, he didn't bother to look up the cost of renting apartments nearer to his work because he didn't really want to move[18].

9.17.2.3. Solution selection

The solution Fred selected was number 4, namely to drink a cup of coffee immediately after waking up in the morning. He then had a number of further options including having the coffee delivered and making the coffee himself[19]. He chose to make the coffee himself. He then had further choices. He could have purchased an automatic coffee maker with a timer, a manual coffee maker or boiling water and using a packet of instant coffee. Fred ruled out boiling water and using instant coffee because he liked freshly brewed coffee. Since he could not make up his mind between the manual and automatic coffee makers, he developed the following solution selection criteria to make an objective decision.

- ***Cost:*** the lower the better. Fred looked at (researched) the prices for each type of appliance. Automatic coffee makers were on sale for between $89 and $129; manual coffee makers were on sale for between $39 and $59. So cost was not a problem.
- ***Reliability:*** the longer the warrantee the better. Fred didn't necessarily want a long warrantee period, per sé. He thought (assumed) that since warrantee repairs or replacements were a cost to the manufacturer which all but wiped out the profit on the

[17] Fred could have developed a utility curve for the degree of undesirability of each selection criteria, if such curves were to be needed.

[18] There is no point in investigating solutions that will not be considered for various reasons.

[19] He still hasn't selected his perfect mate as discussed in Section 8.7.3 so she can't make the coffee for him; assuming she would be willing. Perhaps he should add willingness to perform that task as one of his selection criteria.

sale, a longer warrantee period was an indicator of higher reliability in the product.

- ***User friendliness:*** which he defined as the minimum amount of work to be performed after the alarm sounded in the morning. He chose to ignore the difference in the learning curve for each appliance. The learning curve became a 'don't care' criterion.

All coffee makers needed to be preloaded with water and coffee prior to heating the water. This was no problem; he could prime them before going to bed the previous evening. The two FCFDS were (*Operational* perspective):

1. Using a manual coffee maker and turning on the electricity after the alarm sounded.
2. Using an automatic coffee maker, the appliance would present him with a brewed cup of coffee at the specified time and the aroma would provide an incentive to get out of bed.

Both FCFDSs were within his budget and Fred didn't have any other essential selection criteria, consequently Fred chose to purchase the automatic coffee maker (user-friendly) solution with the longest warrantee.

9.17.2.4. Solution realization planning

Fred's procurement options were to purchase one locally or via mail order over the Internet. Since he needed a coffee maker by Monday morning purchasing one over the Internet was not a feasible realization approach since it would not arrive in time. So he decided he would look though the advertisements in the Sunday paper; pick out an appliance and then drive over to the store and make the purchase. The planned process was to read the newspaper over breakfast, then make the drive. That would allow him the afternoon to test the appliance before relying on it for the following Monday morning. The plan also contained an allowance for the contingency event or risk of car problems precluding the purchase. This was because the plan also allowed for enough time to replace a tire in the event he had a flat tire, or get to the store in another manner in case of other types of car problems.

9.17.2.5. Solution realization

Fred carried out the planned process without further problems. He selected the store based on the pictures in the advertisements and once there examined the different appliances. Since they all had the same warrantee period, he chose the nicest looking automatic coffee maker on the shelf which was priced at $89.90[20].

9.17.2.6. Test and evaluation

Once home, he performed the development acceptance test by setting up the appliance in the kitchen, priming it with coffee and water, setting the timer for an hour later and going out to work in the garden. When he came back into the kitchen at the appropriate time, a delightful aroma of freshly brewed coffee assailed his nostrils. He poured himself a cup, sat down and enjoyed the brew. The technology worked, but would it provide a solution, namely would it change the undesirable situation? Fred would have to wait until the following morning to find out. The operational acceptance test began Sunday evening, when Fred cleaned and primed the coffee maker before going to sleep. That Monday morning when the alarm sounded he awoke to the delightful aroma of freshly brewed coffee; he leapt out of bed poured himself a cupful, drank deeply, shook himself and went into the warm shower[21]. That morning he arrived at work at a record early time. The situation had changed for the better; the undesirable situation had been remedied.

9.17.2.7. In-service

The in-service period began Monday evening when Fred primed the coffee maker. From then on, Fred was always early for work. He never ran out of coffee because he implemented a logistic policy of always having a spare packet of coffee so he would never run out. His reorder process was that when he opened the last packet, he purchased a replacement before using up the operational packet. He also did not experience an overnight electrical power failure.

9.17.2.8. Disposal

This phase is in the future since the appliance is still operational. Fred, however, has decided that when the appliance breaks down, he will dispose of it by recycling it.

9.18. Remedies for complex problems

Consider the three types of complex problems:

1. Well-structured complex problems discussed in Section 9.18.1.
2. Ill-structured complex problems discussed in Section 9.18.2.

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[20] Subjective subconscious qualitative selection criteria

[21] After having first put the cup down on the table. It is important to identify each step in a process clearly and this description was ambiguous: Fred could have taken the cup into the shower.

3. Wicked problems discussed in Section 9.18.3.

9.18.1. Well-structured complex problems

Well-structured complex problems consist of a set of interconnected non-complex problems. The undesirable situation posing the well-structured complex problem or set of non-complex problems may be transformed to a more desirable situation in the following manners:

- ***Time-ordered-multi-phased evolutionary approach:*** by remedying one or more of the problems, integrating the solutions, re-evaluating the situation and then repeating the process for the subsequent set of problems in the manner represented in Figure 9.7.
- ***One shot approach:*** by remedying all of the problems in parallel and then integrating the solutions to form the FCFDS. This approach should only be used when the remedy for one problem does not affect another problem.

Choice of which problem to tackle will depend on a number of factors including urgency, impact on undesirable situation, the need to show early results and available resources.

NASA used the time-ordered-multi-phased evolutionary approach in the 1960's when faced with the well-structured complex problem of landing a man on the moon and returning him safely to earth within a decade. The problem was elaborated into several sequential well-structured sub-problems, each of which was solved one at a time and tested on the various spaceflight missions leading to the Apollo 11 landing mission. These sub-problems included:

- How to place men in space and return them safely to earth?
- How to dock two spacecraft in orbit?
- How to enable men to work in space?
- How to enable men to travel to the moon and back?
- How to land men on the moon and return them to orbit?
- How to provide communications between the ground and the men in space?

This sequential evolutionary process is sometimes known as '*build a little, test a little*' and evolves the solution from a baseline or known state to the subsequent milestone which then becomes the new baseline.

In general, undesirable well-structured complex situations must be remedied by evolving a solution using multiple passes of the problem-solving process where each iteration produces a better (less undesirable) situation. Moreover, to make it more complex, one party's remedy may be another party's undesirable situation and foster further change. For example the tank was developed to remedy the undesirable well-structured situation that machine guns were slaughtering attacking infantry attempting to cross the no man's land between the trenches in World War I (Section 7.8.7.2). So, while tanks remedied an undesirable situation for the attacking forces, tanks created a new undesirable situation for the defending forces who then developed anti-tank weapons, which led in turn to further changes in military doctrine and technology, and so on.

9.18.2. Ill-structured complex problems

The undesirable situation causing the ill-structured complex problem cannot be remedied until the ill-structured problem has been transformed into a well-structured problem. Consequently, finding a solution requires converting the ill-structured complex problem into a well-structured complex problem or series of problems. Determining the real cause(s) of the undesirable situation and finding solutions sometimes means doing both functions in an iterative and interactive manner. In this situation, initially:

- ***The undesirable situation*** is an ill-structured problem.
- ***The FCFDS*** is one or more well-structured problems.
- ***The problem*** is how to convert the ill-structured problem into one or more well-structured problems.
- ***The solution*** is the FFDS.
- ***The problem-solving process*** converts the ill-structured problem into one or more well-structured problems.

Take care when converting ill-structured problems into a series of well-structured problems because you can end up with different and sometimes contradictory well-structured problems which would generate different and sometimes contradictory solutions.

9.18.3. Wicked problems

The fundamental paradox with respect to Wicked problems is that there are no such problems; since while the stakeholders may agree that the situation is undesirable, they cannot agree on "the problem", hence the attributes of Wicked problems listed in Section 9.12.3. Since changing the paradigm may dissolve paradoxes, change the way Wicked problems are conceptualized. Conceptualize Wicked problems, not as problems but as Wicked situations in which, the undesirable situation is where different stakeholders perceive different symptoms, problems and solutions. Sometimes this is because the stakeholders often lack an understanding of the point of view or concerns of other stakeholders.

As perceived from the *Generic* perspective, Wicked situations may manifest themselves in the first step of the Scientific Method problem-solving process (Section 9.12.2.1) even if nobody is consciously using the Scientific Method to address the problem. That is, the current situation is under observation, but a working hypothesis to explain the causes of the observations (desirable and undesirable) has yet to be developed. Examples of such situations are:

- The state of the art of chemistry before the development of the periodic table of the elements.
- The state of electrical engineering before the development of Ohm's law.

9.19. The complex problem-solving process

Ackoff wrote that proactive problem-solving is always embedded in a planning process. No problem is treated in isolation, but each problem is formulated as one of a set of interrelated problems that is treated as a whole. Proactive planning consists of designing a FCFDS and finding ways of moving toward it as effectively as possible (Ackoff, 1978: page 26) or working back from the answer (Ackoff, 1978; Hitchins, 1992: page 120). Section 9.15 mentioned that there are different aggregations of the activities performed in the problem-solving process, and introduced the problem-solving process for solving non-complex problems. This Section discusses a modified version of the problem-solving process for use when solving complex problems:

1. The Current Situation Analysis State in Section 9.19.1.
2. The Conceptual solution Design State in Section 9.19.2.
3. The Solution Selection State in Section 9.19.3.
4. The Solution Realization Planning State in Section 9.19.4.
5. The Solution Realization State in Section 9.19.5.
6. The Test and Evaluation State in Section 9.19.6.
7. The In-Service State in Section 9.19.7.
8. The Disposal State in Section 9.19.8.

9.19.1. The Current Situation Analysis State

Since it is not always possible to convert an ill-structured complex problem to one or more well-structured problems an alternative approach needs to be used. So this example bypasses trying to convert the ill-structured problem into one or more well-structured problems and focuses instead on gaining consensus on the nature of the FCFDS that will remedy the undesirable situation. For example, consider the undesirable situations that can result from traffic congestion in a large city. The mayor, feeling under pressure to do something about the growing traffic congestion in her city, provides the trigger to initiate the problem-solving process which begins with the ill-structured problem of how to remedy the undesirable effects of traffic congestion.

This State contains the activities involved in perceiving the problematic situation from the perspectives perimeter to analyse the situation and identify the underlying root cause or causes of the feeling that something needs to be changed (*Scientific* perspective). The situation analysis begins with the traditional four questions from Section 9.16.1 as well as other questions from various perspectives which might include the following:

- *Temporal* perspective:
    - How did the traffic become congested in our city?
    - What will happen if we don't do anything?
- *Functional* perspective:
    - Why is the traffic congested?
- *Operational* perspective:
    - Who is travelling?
    - When (time of day and seasonal) do they travel?
    - Where do they travel to and from?
    - Why are they travelling?
- *Structural* perspective:
    - How do they travel (what mode of transport (public or private) do they use)?

The findings from the analysis should provide an understanding of the situation. Typical answers might produce a number of findings including:

- There are too many vehicles for the capacity of the road.
- Deliveries and delivery vehicles are blocking commuter routes and causing congestion.
- The bulk of the travellers consist of commuters from the suburbs to the Central Business District (CBD) and students travelling to the university which is located in the CBD.
- Ways of moving people include cars, motor scooters, buses and light rail.
- Most of the congestion is in the morning between 0630 and 0930 and again in the afternoon between 1700 and 1900. However, the city still feels congested during daylight hours.

A good analysis would also provide quantitative information such as an estimate of the degree of the contribution by the scenario to the undesirable situation. For example, commuters make up approximately 70% of the traffic during rush hour, approximately 25% are students and the remaining 5% are other types of travellers.

The set of interrelated non-complex well-structured problems resulting from the analysis might include:

- How to reduce the number of individual vehicles on the roads?
- How to speed up traffic flow?
- How to reduce the need for travel?
- How to prevent the need for some travel, possibly by providing virtual meetings using information technology for students and even businesses?
- How to make travel by public transport more convenient and desirable?

The solution will depend on the vision of the FCFDS. If the vision is of traffic moving purposely at a reasonable speed from suburbs to CBD, efforts to realize that solution will depend on the meanings associated with ‘a reasonable speed’. If, on the other hand, the vision is stated as the city allows people to fulfil the purpose of their journey with a minimum amount of commuter traffic. The meaning of ‘minimum’ in this case is what the mayor wishes to assign to the term. This concept is often discussed as the need to define the correct problem.

After some analysis, the stakeholders produce a number of FCFDS that might include:

- Tolls or charges on the main routes into the CBD to try to persuade commuters to leave their vehicles at home and ride public transport.
- University extensions being located in the suburbs to localize student travel. These extensions might contain traditional classrooms or be linked via two-way teleconferencing technology to classrooms in the CBD campus.
- Offices (government and non-government) being located outside the CBD.
- Vehicular road traffic being moved in the most efficient manner using a computer controlled traffic system.
- New high-speed roadways with limited entrances and exits to move vehicles in and out of the CBD. These may be bidirection-

al the entire day, or allow traffic in different directions in the mornings, evenings and weekends.

- New light rail services.
- Additional buses and bus routes.
- A tax on ownership of private vehicles discouraging same.
- A ban on deliveries and delivery vehicles in the CBD during commuting hours.
- A ban on deliveries and delivery vehicles in the CBD during day-light hours.

The non-holistic approach problem-solving approach is to consider realizing these solutions as different single and possibly conflicting problems. Stakeholders talk about the remedy for the problem posed by the traffic congestion (undesirable situation) as being the realization of their specific FCFDS.

The holistic approach however, considers each FCFDS as a potential partial remedy to the whole undesirable situation. Thus the ill-structured problem posed by the undesirable situation of traffic congestion has been transformed into a number of well-structured problems for remedying part of the effects of traffic congestion, namely how to realize each (or at least a few of the) FCFDS listed above.

9.19.2. The Conceptual Solution Design State

The Conceptual Solution Design State is the same as in the traditional process except that more than one FCFDS is designed for each different stakeholder FCFDS. Each FCFDS is designed to the point where the feasibility, risks, costs, realization schedule, etc. are determined.

A generic *Big Picture* perspective of remedying the traffic situation in the city can be represented as shown in Figure 9.18. The gap analysis produces one or more solutions to well-structured conceptual problems (Section 9.12.3.1) such as ways of:

- Upgrading the current way of performing some or all of the functions.
- Acquiring new ways of performing the functions.
- Combining upgrading and acquiring functions.

The solution selection criteria are also developed during this State. Solution selection criteria might include:

- ***Cost:*** the city has a limited budget.

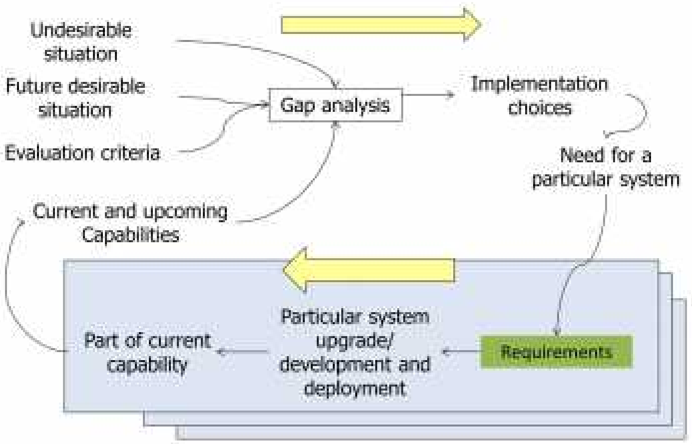

Figure 9.18 *Big Picture* perspective loop

- ***Schedule:*** how soon the FCFDS will be needed, when certain undesirable aspects of the current situation will become unbearable, etc.
- ***Political:*** the need to award development contracts to certain contractors for a variety of reasons or the need to tackle one aspect of the situation to satisfy the electorate.
- ***Performance:*** the degree that the FCFDS changes the undesirability in the current situation for the better.
- ***Robustness:*** the ability of the FCFDS to recover from a disaster, natural or man-made.
- ***Resilience:*** all foreseeable causes of future increasing congestion will also be remedied by the conceptual future solution.

9.19.3. The Solution Selection State

The solution selection state evaluates each FCFDS against the solution selection criteria. The problem-solving process for non-complex problems ends when a single FCFDS is chosen. In the problem-solving process for complex problems several FCFDS remedying different parts of the undesirable situation are chosen, prioritized and executed in a SDP sequentially with a reprioritization at the end of each iteration of the SDP.

9.19.4. The Solution Realization Planning State

This State:

- Contains the activities that plan the realization of the combination of FCFDS that need to be realized and integrated in an orderly manner with minimal, if any, disruptive impact on the current situation.

- Is where a gap analysis performed between the current undesirable situation and the FCDFS provides the information as to what is to be acquired for the FCDFS to become real in the future. The realization of each FCFDS is then planned as if it were a solution but within the context of the entire set of solutions as a time-ordered-multi-phased evolutionary process discussed in Section 9.18.1. The plan is created by process architecting the activities in the three interdependent streams of activities (Section 9.16.6) into the realization process to be implemented for the specific project in its time and place with its available resources.

  Some plans may have to consider additional problems due to constraints imposed by the infrastructure during the construction and transition phases. For example, if additional roads or railway lines have to be constructed, the effect on traffic in the existing infrastructure in those locations during the construction phase will have to be estimated and taken into account.

- Contains the activities that produce a set of realization plans for each partial FCFDS.
- Contains the activities that produce an integration plan for phasing in each FCFDS as it is developed to create the integrated FCFDS that will remedy the undesired situation.

9.19.5. The Solution Realization State

This State contains the three interdependent streams of activities (Section 9.16.6) that implement each of the plans developed in the preceding phase. The integrated FCFDS emerges from the combination of FCFDS. Unanticipated emergent properties may be discovered within each FCFDS as well as in the final integrated FCFDS and the undesirable emergent properties will need to be eliminated[22].

9.19.6. The Test and Evaluation State

This State

- Contains the activities that determine how many of the undesirable features of the situation current at the time the partial solution is realized[23] have been remedied in the FCFDS. The State

[22] The serendipitous ones can be presented to the customer as a bonus feature.

[23] Which may be different to those that manifested themselves at the time the project began.

begins with an evaluation of how much of a remedy is provided by the partial solution in the then current undesirable situation. The degree of undesirability of the changed situation drives the next iteration of the process.

Since the different systems elements of the various FCFDS are developed in parallel, the Test and Evaluation State of the complex problem-solving process covers all of the FCFDS under development. This means that the system may pass from the Test and Evaluation State for the first partial solution into the In-Service State and then revert to the Test and Evaluation State when the next partial solution needs to be tested and evaluation prior to integration.

9.19.7. The In-Service State

The FCFDS is no longer conceptual in the future since it has become the new current real situation. The In-Service State can be considered as one in which all the areas in Figure 9.7 are active at the same time on different parts of the system because changes take place at different rates. For example, some things wear out quickly while other things take much longer to wear out and new additions are always in process. Since each box in Figure 9.7 acts on a different aspect of the situation, the loop is not only endless it can be considered as a time-ordered multi-tasking set of parallel activities where each iteration is out of phase in time with the previous and following ones.

As time passes new undesirable features may appear and the problem-solving process is repeated for a further FCFDS. This State:

- Lasts:
    - For as long as the solution system remedies the undesirable.
    - Is affordable.
- Ends when the solution system is about to be taken out of service.

9.19.8. The Disposal State

This state contains the activities that dispose of elements of the situation when they are being replaced or upgraded.

9.20. The dynamic complex situational loop

Complex problems should be considered in the context of an undesirable current situation which needs to be changed. This traditional problem-solving approach treats the current situation as static. However, in the context of the complex problem-solving process, each current situation can be considered as being a part of the solution realization phase of a meta-problem-solving process. The approach for solving complex problems is to evolve a solution through the following endless loop:

1. Analyse the undesirability of the current situation.
2. Convert ill-structured complex problems to well-structured complex problems or FCFDS.
3. Elaborate the well-structured complex problem or FCFDS into a series of simple well-structured problems.
4. Solve one or more simple well-structured problem.
5. Go back to Step 1 as and when resources permit.

9.21. Summary

This Chapter:

1. Discussed problems and solutions, the assumptions behind problem-solving, ways to remedy problems and introduced a holistic approach to managing problems and solutions.
2. Began with the properties a of good problem statement in Section 9.1.
3. Discussed the problem posed by the different meanings of the word 'problem' in Section 9.2.
4. Discussed the initial reaction to a problem in Section 9.3.
5. Discussed the traditional problem-solving process in Section 9.4.
6. Provided some examples of the systems engineering approach in Section 9.5.
7. Examined the relationship between problems and solutions in Section 9.6.
8. Discussed the holistic extended problem-solving process in Section in Section 9.7.
9. Discussed the difference between problems and symptoms in Section 9.8.
10. Discussed the assumptions underlying formal problem-solving in Section 9.9.
11. Discussed the components of problems in Section 9.10.
12. Discussed a problem formulation template used in this book in Section 9.11.
13. Classified problems in four ways in Section 9.12.
14. Defined the problem classification matrix discussed in Section 9.13.
15. Described ways of remedying problems in Section 9.14.
16. Compared varieties of the problem-solving process in Section 9.15.

17. Discussed the System Lifecycle (SLC) as an example of a complex problem solving process in Section 9.16.
18. Discussed the real world including two examples of how people adapt it when problem solving often in unexpected ways in Section 9.17.
19. Discussed remedies for complex problems based on the structure of the problem rather than the complexity of the problem in Section 9.18.
20. Discussed the complex problem solving process perceived as being made up of multiple series-parallel iterations of the non-complex problem-solving process in Section 9.19.
21. Discussed the dynamic complex situational loop in Section 9.20.

9.22. Conclusions

The conclusions from this Chapter are:

- Simple problems generally have single causes and single solutions.
- Complex problems have multiple causes and hence have complex solutions.
- There is no simple solution to a complex problem.
- The problem-solving process is self-similar whether providing solutions to simple problems or converting ill-structured problems to well-structured problems.
- There are two basic problem-solving processes:

    1) The forward-looking research problem-solving process.
    2) The backward-looking intervention problem-solving process.

- Many problems can have more than one acceptable solution.
- Acceptable solutions can be achieved.

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Part III
Innovative solutions to complex problems

10. Examples of the application of the holistic thinking approach to problem-solving

Textbooks generally describe methodologies that were developed for use in specific situations. However in the real word, situations differ, sometime slightly and sometimes in a major way so the textbook and situation do not overlap 100%. You need to think about both the situation and the methodologies. You have a choice between:

1. Adapting a situation to the methodology.
2. Adapting a methodology to the situation.

If you go by the book and use the textbook example as a template, you are adapting the situation to the methodology. Your results will probably be less than optimal, and take an excessive amount of time, even if they succeed. If, on the other hand, you think about the situation and adapt the methodology to the situation, your results will probably be innovative and depend on the number and type of errors you make. This Chapter provides the following examples of the adaptation of the systems engineering approach to problem-solving mentioned in Section 9.15:

1. The Command, Control, Communications, and Intelligence (C3I) group morale issue discussed in Section 10.1.
2. The Multi-Satellite Operations Control Center (MSOCC) data switch replacement project discussed in Section 10.2.
3. Developing an optimal classroom teaching and learning environment discussed in Section 10.3.
4. Creating and guide a successful student software engineering project class when the instructor is halfway around the world discussed in Section 10.4.
5. The apartment dwellers' amateur radio antenna system discussed in Section 10.5.

Each example not only illustrates how the problem-solving process was tailored but provides examples of other aspects of finding innovative solutions to complex problems such as where things went correctly and where and how things can and did go wrong.

Use the process mentioned in Section 1.1 to study each anecdote, especially if you are not familiar with the domain and pick out the pertinent points from the details.

10.1. The Command, Control, Communications, and Intelligence (C3I) group morale issue

This Section tells the anecdote of how SSM (Checkland and Scholes, 1990; Checkland, 1993) introduced in Section 4.4.1 was adapted and combined with the systems engineering approach to problem-solving to investigate an organisational problem in a government organisation.

10.1.1. Background

In early 2000, the Defence Systems and Technology Department (DSTD) within the government of Engaporia[1] performed a variety of research tasks that was aimed at upgrading the national defence systems, and the acquisition and implementation of appropriate technology in the Engaporean defence environment. DSTD worked in close cooperation with the Engaporean Defence Forces (EDF). At that time, the members of the Command, Control, Communications (C3), and Intelligence (C3I) group within the DSTD were concerned about the effect an impending reorganization would have on their jobs. They were concerned because they had the impression that they were underperforming because DSTD wanted them to do more research than they were doing and because the group's Research Leader was not spending any time with the group. The members of the group were so concerned about these issues that their morale had suffered and key members of the group were seriously considering leaving the DSTD for other employment. The group's Research Leader and the DSTD Big Chief were so concerned about the situation that they asked the Systems Engineering Centre at Hypothetical University to investigate the situation as a task under an existing task-ordered research contract. This Section discusses the anecdote providing analysis and comments in the form of footnotes.

After receiving the task and analysing the situation, the plan[2] for the intervention investigation in the form of Hitchins' systems engineering

[1] A fictitious third world country, ex British Colony used to provide a context for Case Studies in classes in systems engineering.

[2] This Section focuses on the activities and products elements of the task. Cost, schedule and other resource information are omitted.

problem-solving approach to tackling a problem shown in Figure 9.2 This Section just covers:

- ***Task 2:*** understand the situation and define the root cause (problem) discussed in Section 10.1.2.
- ***Task 6:*** Perform trade-off to find the optimum solution discussed in Section 10.1.3.
- ***Task 7:*** Formulate strategies and plans to implement the preferred option discussed in Section 10.1.4.

10.1.2. Task 2: Define the problem

This task began with a review of the relevant documentation[3]. The documentation provided was sparse and mostly useless. However, what was gleaned was that:

- The situation had persisted for some time.
- The DSTD Big Chief was concerned about the situation.
- A consultant had been called in some months previously to analyse the situation and make recommendations with little apparent effect.
- This investigation would be the same type of activity that the C3I group performed on other groups with the EDF.

Once the information had been harvested from the documentation, preliminary discussions were held with the Research Leader to clarify points that were obscure in the documentation and receive an update on the situation. Then, after some consideration it was agreed that:

1. The systems engineering problem-solving process was an appropriate approach to resolving the situation since the task statement was a well-structured problem with a clear, singular objective.
2. The CONOPS for the solution system that would describe the activities performed by the C3I group would be part of the final report.

This was a people intensive situation; the solution system in the FCFDS would probably be a rearrangement of the work performed by the existing (and possibly) additional personnel. Consequently the intervention approach to gain an understanding of the situation was based on SSM (Checkland, 1993: pages 224 to 225) briefly discussed in Section 4.4.1. The CATWOE elements in this instance were:

[3] This is not an unusual first step.

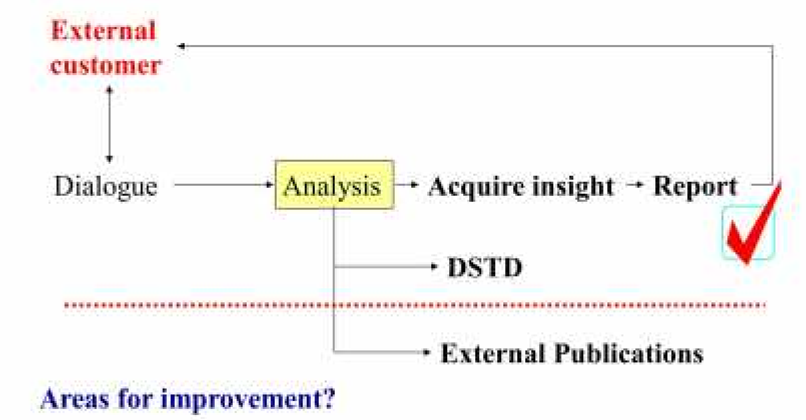

Figure 10.1 The transformation process

10.1.2.1. Customers

The C3I group had two distinct groups of customers, namely:

- ***External customers*** in the form of the EDF where a client element within the EDF perceived a problem which was reported to DSTD who tasked the C3I group to examine the situation and recommend improvements in a timely manner[4].
- ***Internal customers*** in the form of DSTD management and other groups within DSTD.

10.1.2.2. Actors

The actors were the members of the C3I group, the Research Leader and the Big Chief.

10.1.2.3. Transformation process

The then existing transformation process performed by the C3I group, which was based on scenarios describing the work performed by members of the C3I group gleaned from the documentation and the preliminary discussions, is shown in Figure 10.1. The group's goal was the improvement of the effectiveness of the EDF by performing organizational analysis tasks on elements of the EDF and then providing timely reports and recommendations to those elements (customers). The analysis subprocess was further broken out as shown in Figure 10.2. The transformation process was a 'standard' process in which the C3I group collected relevant data about the specific situation they were investigating, performed a comparison with a reference model and acquired insight as a

[4] Within two weeks or less.

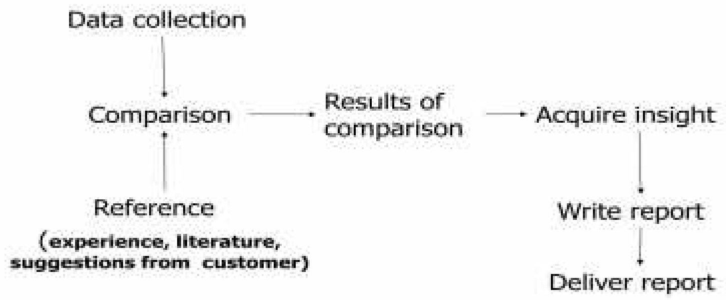

Figure 10.2 The analysis process

result of the analysis. The group then produced a timely report. At the same time the group reported the insight to DSTD and was expected to publish research papers in their field of expertise[5].

10.1.2.4. Weltanschauung

The first phase of the study quickly identified that the Big Chief, the Research Leader and the members of the C3I group all seemed to have a different Weltanschauung.

10.1.2.5. Ownership

The ownership resided in the DSTD.

10.1.2.6. Environmental constraints

The environmental constraints were external and internal as follows:

- ***External:*** military activities were changing; there was a revolution in military affairs under way and military organizations were changing, and consequently, their external customers were changing. The reports of the group's investigations needed to be made in a timely manner in this changing environment.
- ***Internal:*** within DSTD, namely the Research Leader and indirectly the Big Chief.

10.1.2.7. The apparent undesirable situation

The CATWOE information together with the domain knowledge pertinent to such situations provided sufficient information to formulate the preliminary hypothesis that the cause of the undesirable situation lay in the differences in Weltanschauungs exacerbated by a communications

[5] This study performed the same task on the C3I group as the C3I group performed on their customers.

breakdown between the Big Chief, the Research Leader and the members of the C3I group.

10.1.2.8. Supporting or refuting the preliminary hypothesis

The investigator had to study the C3I group with minimal interference to their on-going activities. This translated to planning and carrying out short interviews with selected people and a sample of the remainder. The algorithm for determining which members of the C3I group would be interviewed was as follows:

- Identify specific key persons who had to be interviewed. These turned out to be the Research Leader and the Big Chief.
- Sample the members of the C3I group. The sampling algorithm was simply to telephone each person for an appointment. If the phone was answered an appointment for an interview was made, if the phone was not answered the next person was telephoned.

10.1.2.8.1. The C3I group's Weltanschauung

After thanking the person for taking the time for the interview, and explaining the sampling algorithm[6], each interview began with the following five open-ended questions:

1. What does the individual like?[7]
2. What does the individual dislike?
3. What does the group do?[8]
4. What does the person feels group should be doing but isn't?[9]
5. What does the person feel the Big Chief wants the group to be doing?[10]

These questions and the subsequent short dialogue provided the maximum amount of information in the minimum time. The answers to the starter questions by the various members of the group were aggregated and are summarized below.

[6] The interview began with common courtesy, and explained the sampling algorithm to avoid upsetting members of the C3I group.

[7] This was an interview about the nature of the person's work. Like and dislike of work has an effect on morale. The first two questions were posed to determine if the nature of the work could have been a cause of poor morale and were also an icebreaker to start the conversation moving.

[8] This question was posed to determine if (1) there was a common vision of the purpose of the group, and (2) to confirm the transformation process shown in Figures 1 and 2.

[9] This question was posed to obtain ideas for improving the work and obtain buy-in to the results of the intervention.

[10] This question was posed to determine/confirm if there was a communications gap within the hierarchy of the DSTD.

10.1.2.8.1.1. *What the individual likes*

- The range of activities.
- Contributing to improvement of defence.
- Learning new things.
- Research.
- Interacting with co-workers.
- Making a difference.
- Being a change agent.

10.1.2.8.1.2. *What the individual dislikes*[11]

- Uncertainty of the future.
- Work overload.
- Changing directions.
- Political agendas.
- Nugatory work.
- Rushing through the process.
- Interfacing with customer[12].
- Working in a new area without an adequate foundation in the subject matter.
- Not being sure of what the Research Leader wants them to do.
- Conflicting instructions.
- Each task is different.
- Unsure how group fits into DSTD structure.
- Complexity.
- The shifting of the task from tactical to strategic.
- Research without a purpose.

10.1.2.8.1.3. *What the group does*

- Responds to client's demands.
- Goes into organizations and evaluates them.
- Analyse structures and processes.
- Analysis is not necessarily compared with a reference model.
- Research into group's own methodologies.
- Research into organizations.
- Assess impact of technology on capabilities.

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[11] Responses to these questions confirmed the presence of a communications gap between the members of the group and the Research Leader.
[12] This was from an individual whose job required meeting with customers!

- Gets additional work through satisfied customers.
- Considers aspects of:
    - Command, Control and Communications (C3).
    - Organizational analysis.
- Supposed to be in research context but is in evaluation context.
- Emphasis on current or short term.

10.1.2.8.1.4. *What the person feels group should be doing but isn't*

- Continue task to help implement recommendations (enterprise improvement).
- What ... if - simulations.
- Research.
- Removing uncertainty.
- Being more proactive in developing customers.
- Transition planning into new tasks.

10.1.2.8.1.5. *What the person feels the Big Chief wants the group to be doing*

- More or less the same.
- Apply more academic rigor.
- Quote "sources used" as basis for recommendations.
- Implement own research program.
- Continue to satisfy external client's needs.
- Publish more.
- Promulgate credibility by referencing underlying principles for recommendations.
- More research.
- "*No idea, I only hear things second and third hand*"[13].

10.1.2.8.2. Research Leader's Weltanschauung

The open-ended starter questions and findings are listed below.

10.1.2.8.2.1. *Questions to the Research Leader*

- What should the C3I group be doing?
- How well are they doing it?

The answers to the starter questions are summarized below.

10.1.2.8.2.2. *What should the C3I group be doing?*

[13] A definite communications gap

- Ultimate goal is to provide information to determine if the investment should be in C3 or in weapons systems.
- Need to work on these to show importance.
- Determine if C3 makes a difference.
- Operational and organizational analysis, synthesis and evaluation.
- Determine if people understand doctrine and equipment.
- Form Measures of Effectiveness (MOE) for C3.

10.1.2.8.2.3. *How well are they doing it?*

- Strengths:
  - Work together well as teams.
  - **Glowing reports** from external customers.
- Weaknesses:
  - The way in which the job is done.
- Is Management satisfied?
  - Yes and no.

10.1.2.8.2.4. *Research Leader's additional comments*

The Research Leader made the following additional comments:

- Not unhappy with rate of change.
- Does not want to interfere with a good group.
- Group needs to evolve faster than customers and add new skills.
- Research Leader is not spending time with group because there are more urgent problems elsewhere[14].
- Reduction of budget will have an effect.

10.1.2.8.3. Big Chief's Weltanschauung

The Big Chief was asked to:

- Comment on group.
- Define "research".
- Provide metrics for successful "research".

The answers to the questions are summarized below.

10.1.2.8.3.1. *Comments on group*

- Group performed a useful role.

[14] The Research Leader seems to be applying Management by Exception. However, the C3I group perceived it in a negative manner. There is a communication issue here.

- She recognized the strengths of the group.
- Group had credibility with customers.
- Group was evolving too slowly.
- Good use of empirical techniques in the group coupled with a lack of "scientific" theoretical background.
- Analyses seemed shallow.
- Needed to use a stronger research based methodology on what they did.
- Needed to add researchers to the group.
- Failed to communicate items of importance.

10.1.2.8.3.2. *Definition of "research"*

- **Was not** publish - publish - publish.
- Was:
    - Document in a manner consistent with Scientific Method (Section 9.12.2.1).
    - Use the Scientific Method in their work.

10.1.2.8.3.3. *Metrics for successful "research"*

- Needed to be convinced on authority of conclusions[15].
- Needed to quote from the literature to reinforce conclusions and justify methodology[16].

10.1.2.9. Conclusions from the interviews

The interview responses were analysed with the following conclusions about the nature of the undesirable situation.

1. There was indeed a communications issue, namely a lack of communications between the Big Chief, the Research Leader and the members of the C3I group. As a consequence, the group:
    1) Was uncertain about their future.
    2) Had an impression that the Research Leader perceived their work negatively.
    3) Perceived a conflict between performing their organizational analysis tasks for their customers and performing research.
2. There was an emphasis on short term or current problems.

[15] By citing references to the literature that support the conclusions
[16] An application of critical thinking

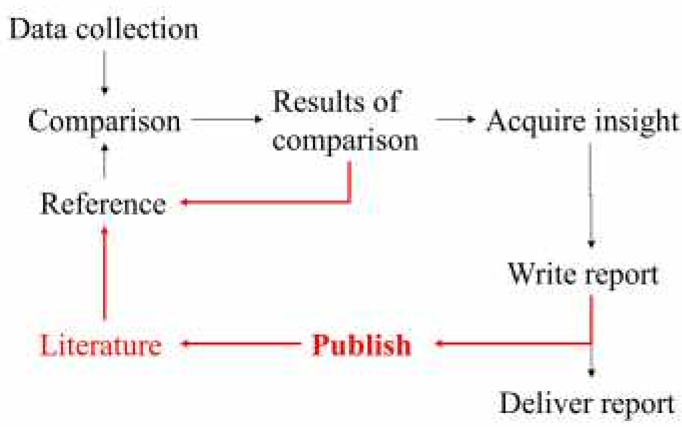

Figure 10.3 C3I group conceptual functional reference model

3. The group needed to consider the enterprise architectural framework in which the customer organization operated both in the present and future (*Temporal* perspective).
4. The work straddled the boundary between soft systems and hard systems which meant they were pushing the envelope but had an excellent 'name making' and publishing opportunity.

10.1.3. Task 6: select the preferred option

After considering several solutions[17], it was felt that the perceived conflict felt by the group between performing their organizational analysis tasks and publishing in the research literature could best be overcome by modifying the transformation model shown Figure 10.1 into the CONOPS (for what they should be doing) shown in Figure 10.3. The extra step in the modified process would be to take the same information in the report to the customer and reformat it for publication in a conference proceedings or journal.

10.1.4. Task 7: formulate strategies and plans to implement the preferred option

The strategies and plans to implement the preferred option took the form of a final report presentation containing an overview of the findings[18], a description of the study methodology, the recommendations and an Action Plan.

[17] Not described in this chapter since this chapter focuses on describing an application of SSM.

[18] Presented first and then amplified later in the presentation.

10.1.4.1. The recommendations to DSTD

The recommendations to DSTD were to open communications channels between the Big Chief, the Research Leader and the C3I group. Specifically the recommendations were for:

- DSTD Management to remove the fear of "research" and uncertainty about future.
- For the C3I group to:
  - Take continuing education courses[19] on how to do "research", Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) Architecture Frameworks and SSM as applied to Information Systems.
  - Develop personal career plans.
  - Modify their methodology by adding architecture issues to customer dialogue and considering medium and long term impacts.
  - Develop conceptual models based on the literature for appropriate customer organizations which would speed task completion[20], provide an objective basis for work and allow structured analysis of impact of technology to units and force structure.
  - Reorganize to match current and expanded functions to personal skills/likes dislikes.
  - Team within the group for publication in Journals and at the annual INCOSE Engaporean Chapter Systems Engineering Conference the following year.
  - Acquire mentors within DSTD on research methods, C4ISR Architecture Frameworks, and systems methodologies.
  - The Action Plan.

10.1.4.2. The Action Plan

The Action Plan contained the following four elements:

1. DSTD Management to remove uncertainty about the performance and future of group within 30 days.
2. Members of the C3I group to attend courses starting within two months.

[19] The intervention was performed by academics from Hypothetical University.
[20] By the use of pattern matching (*Generic* perspective).

3. Members of the C3I group to acquire mentors within DSTD within 3 months.
4. Create a target for acceptance for publication of at least three manuscripts within 12 months[21].

10.1.4.3. Preparation and delivery of the Final Report

With the agreement of the DSTD customer, the report was delivered in the form of a PowerPoint presentation[22]. The presentation was discussed with the Big Chief and then made to the Research Leader and members of the C3I group. The format of the presentation also provided an example of how to implement some of the recommendations and included:

- An explanation of the sampling algorithm, stating that there was not a 100% sample, and that not being sampled did not equate to unimportance.
- References to the literature for the methodology and conceptual models providing some academic rigour[23].

10.1.5. Comments

As discussed in Section 4.4.1, the *Big Picture*, *Operational* and *Functional* perspectives line up with CATWOE as shown in Table 4.3. In addition:

- The *Structural* perspective was used to develop the DSTD organisation chart to match the people into the hierarchy and identify which people had to be interviewed and who could be sampled.
- The 'to be' or reference model came from prior experience, namely going beyond systems thinking and using perceptions from the *Generic* and *Temporal* perspectives.
- The *Temporal* perspective provided the background information that an earlier intervention had not been successful which is why this intervention was invoked. This perception identified a need to find out the reason for the failure of the previous intervention.
- The conclusion from the analysis of the initial observations produced the hypothesis (*Scientific* perspective) that the situation was the result of a failure in the hierarchical communications path

[21] Acceptance is an output measurement. Specifying submissions for publications was useless because it did not require any academic standards and rigor to be applied to the manuscript.

[22] The intervention was performed within 40 man-hours. Creating a written report would have doubled the time and cost of the study. It was felt that a presentation would serve the purpose of distributing the findings of the intervention to the necessary personnel in the C3I group.

[23] As examples they could follow.

between DSDT management and the C3I group. The interview questions were then phrased to determine if the hypothesis could be supported.

- Perceptions from the *Continuum* perspective points out that each of the different SSM actors may have a different Weltanschauung which may need to be considered. And indeed this was the cause of the undesirable situation in this instance.

10.1.6. Lessons Learned

The lessons learned from the experience included:

- Perceptions are more important than the reality when dealing with people. It was the perception that the Research Leader was unhappy with the C3I group that drove their morale down.
- Communications is the key to success. The failure in communications between the C3I group and DSDT upper management was a major contributor to the situation.
- SSM needs to be tailored to the situation, like all methodologies.
- The HTPs were useful in scoping the intervention and determining the key interview questions.
- Hypotheses can be made based on a small data sample by experts who compare the situation at hand with similar situations that have been observed in the past (*Generic* perspective). However, the analyst performing the intervention has to make sure that if additional data does not fit the hypothesis, the extraneous data is not discarded but rather the data are verified and if found to be correct, the hypothesis is modified to fit the data.

10.1.7. Summary

This Section provided an example of how SSM was adapted and applied to investigate an organisational problem in a government organisation. The intervention investigation used the SSM within the systems engineering problem-solving approach as the approach to identifying and tackling the problem.

10.2. The MSOCC data switch replacement project

This Section is a Case Study describing a situation in which, a Soft Systems Methodology (SSM) similar to Avison and Fitzgerald's published interventionist methodology (Avison and Fitzgerald, 2003)[24] coupled with an object-oriented approach for viewing requirements was used in a tai-

[24] The MSOCC switch upgrade took place in 1989. Avison and Fitzgerald didn't publish their methodology until 2003.

lored version of the system engineering problem-solving process in a complex environment by a systems engineering team to solve the problem posed by the need to illicit and elucidate and achieve consensus on two sets of requirements. By considering the cost, priority, and risk attributes of the requirements, as well as clarifying the wording of the requirements for verifiability, both an optimal systems architecture and optimal SDP process were achieved in a relatively short period of time compared to using the standard systems engineering process. Moreover, the customer deemed the Systems Requirements Review (SRR) complete and comprehensive.

Use the process mentioned in Section 1.1 to study the Case, especially if you are not familiar with the data control centre domain and pick out the pertinent points from the details.

10.2.1. The current situation

In 1989, the NASA Goddard Space Flight Center (GSFC) Multi-Satellite Operations Control Center (MSOCC) was facing the problem of replacing the data switch that routed signals received from multiple Low Earth Orbit (LEO) satellites via the NASA Communication Network (NASCOM) to data processing computers. The MSOCC Switching System Replacement Project (MCSSRP) (Kasser and Mirchandani, 2005) provides the context. Framing the problem in the MSOCC situation:

- ***The undesirable situation:*** the perception that the MSOCC will not be able to cope with its anticipated future switching requirements coupled with some undesirable aspects of the current switching system that need to be eliminated.
- ***The FCFDS:*** an MSOCC that is able to cope with its anticipated future switching requirements.
- ***The problem:*** how to manage stakeholder expectations to gain consensus on a plan to transition from the undesirable situation to the FCFDS. The problem was compounded by the following conditions:
    - There was no physical space to locate a replacement switch in the MSOCC.
    - The data streams from the satellites could not be switched off.
    - Data could arrive at any time without warning.
    - Loss of LEO satellite scientific data would not be tolerated.
    - There was a plurality of stakeholders in the MSOCC.

- ***The solution:*** an upgraded higher performance switch operating within the context of the FCFDS.

Perceive the pertinent information about the MSOCC and its stakeholders from the HTPs as follows:

1. The *Big Picture* perspective discussed in Section 10.2.1.1.
2. The *Operational* perspective discussed in Section 10.2.1.2.
3. The *Functional* perspective discussed in Section 10.2.1.3.
4. The *Structural* perspective discussed in Section 10.2.1.4.
5. The *Quantitative* perspective discussed in Section 10.2.1.5.
6. The *Temporal* perspective discussed in Section 10.2.1.6.
7. The *Continuum* perspective discussed in Section 10.2.1.7.
8. The *Generic* perspective discussed in Section 10.2.1.8.
9. The *Scientific* perspective discussed in Section 10.2.1.9.

10.2.1.1. The Big Picture perspective

In 1989, the NASA GSFC MSOCC was facing the problem of replacing the data switch that routed signals from multiple Low Earth Orbit (LEO) satellites to data processing computers. At that time, the MSOCC was the major interface between the LEO data streams from NASCOM and the Telemetry Tracking and Control (TT&C) system at NASA's GSFC. There was minimal data capture and storage functionality in the ground stations and NASCOM.

10.2.1.2. The Operational perspective

The MSOCC received and forwarded data in several scenarios documents in the CONOPS. The data streams from the LEO satellites contained data telemetered from onboard experiments and instruments. These data were supplied to Principal Investigators (PI) who would be

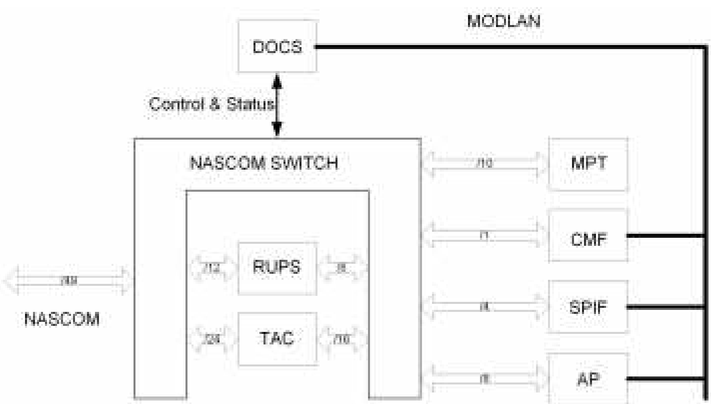

Figure 10.4 The MSOCC

very upset if they lost scientific data during the time period that the data switch was in transition. It was thus not acceptable to close down the MSOCC during the replacement of the NASCOM switch by the MCSS.

The then current MSOCC operational concept scenarios were categorized as Normal and Contingency modes where:

- The Normal mode scenarios were:
    - Spacecraft pass support scenarios: in which LEO data were ingested and processed.
    - Simulations and test scenarios: which were used for training.
- The Contingency mode scenarios were:
    - Trouble-shooting scenarios.
    - DOCS unavailable scenarios.
    - NASCOM line pre-emption scenarios.

10.2.1.3. The Functional perspective

The MSOCC used a switching system known as the NASCOM switch to route serial asynchronous digital data between NASCOM and the computer equipment within MSOCC and external facilities.

10.2.1.4. The Structural perspective

Perceptions from the *Structural* perspective of the MSOCC identified the architecture shown in Figure 10.4[25]. The NASCOM Switch shown as a single entity in Figure 10.4, really consisted of a number of subsystems including three separate switches controlled by a central Data Operations Control System (DOCS). The first switch connected some of the MSOCC equipment to the NASCOM lines and the second the remainder. The third switch handled connections between the Mission Planning Terminal (MPT), the Command Management Facility (CMF), the Deep Space Network (DSN), NASCOM and the Attached Shuttle Payload Center (ASPC). Each switch also contained a patch panel to allow the NASCOM lines to be manually tested, patched to another circuit, or looped back to NASCOM or to MSOCC equipment. To complicate the situation:

- The MSOCC forward link equipment sourcing uplink data to the LEO spacecraft did not generate the Send Timing (ST) signals (synchronizing pulses) to accompany the data. As a result, the ST

[25] In this situation, since the functions are mapped into the physical units on a 1:1 basis, the same figure can be used to represent both perspectives.

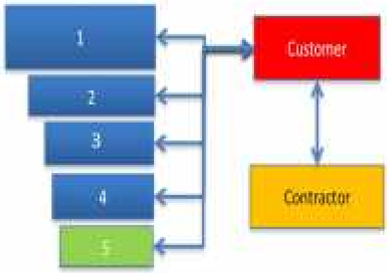

Figure 10.5 The contractual interface

for this data was generated by a timing signal generator called a Clock Buffer located in each switch.

- The NASCOM switch could not be removed during the replacement switch integration phase due to insufficient space in the MSOCC to hold both the NASCOM switch and the MCSS.
- The MSOCC was supported by two somewhat overlapping contracts, the Systems Engineering and Services (SEAS) contract and the Network Maintenance and Operations Support (NMOS) contract.

10.2.1.5. The Quantitative Perspective

The three switches were identical, each having a capacity of 62 full duplex 1.544 MHz serial asynchronous RS-422A digital data ports. The switches had been custom-designed for the MSOCC and were not commercially available. Crossovers were used to connect Switch numbers 1 and 2. Switch number 3 was independent of the other two. As a result of using ports for crossovers, only 112 duplex connections could be made through the first two switches.

The system could be taken out of service for pre-scheduled periods of up to 20 minutes at a time.

10.2.1.6. The Temporal perspective

Each of the three NASCOM switches had been added to the MSOCC over time in an incremental upgrade manner as the requirements for additional communications ports exceeded the number of ports available at the time the upgrade took place.

As a result of deficiencies perceived from the *Quantitative* perspective the need for a single switch to replace the three switches was recognized and the MCSSRP initiated. The new switch system was to be named the MCSS.

10.2.1.7. The Continuum perspective

Perceptions from the *Continuum* perspective identified a number of differences including:

- ***Differences in the stakeholder interests:*** different stakeholders have different areas of concern. As such, not every stakeholder is interested in all the aspects of the MCSS replacement project.
- ***Differences between stakeholders and customers:*** while the stakeholders may levy requirements on the MCSS, the customer[26] is the entity that funds the realization of those requirements. Consequently, the customer makes the decision to accept or reject requirements levelled by the stakeholders.
- ***Differences between the stakeholder communications and control interfaces:*** the communications interface passes information about stakeholder cares, concerns and needs between the contractor and MSOCC personnel. The control or contractual information first flows from the stakeholders to the customer and then to the contractor as shown in Figure 10.5. In this instance, the figure also provides information from the *Quantitative* perspective by using the size of the box to roughly represent the importance/influence of the stakeholder; information which can be used to prioritize the impact of the stakeholder needs on the project's decisions by adjusting the weighting on the decisions accordingly.
- ***Difference between "no loss of data" and "no downtime" during the transition:*** recognition of this difference allows for the switching system to be taken off-line for short periods of time with due prior notice.

10.2.1.8. The Generic Perspective

Perceptions from the *Generic* perspective indicate that the process to address the stakeholders' areas of concern and convert stakeholder's requests to requirements[27] is an instance of the change management process in an upgrade situation. In the change management process, requests for changes are made because something is undesirable due to the system:

1. Not doing what it should be doing, because:

[26] The customer was the NASA GSFC Associate Technical Representative (ATR) known as the Contracting Officer's Technical Representation (COTR) in other agencies.

[27] The term 'request for requirement' is used because the stakeholder's requests must not become requirements until the customer has agreed to accept the request and fund the realization of the request.

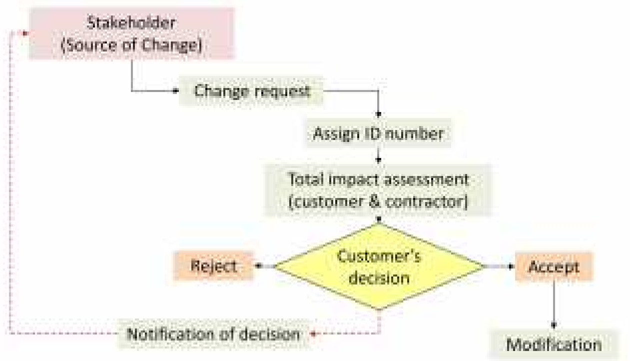

Figure 10.6 Functional view of the generic change management process

   1) Something is broken.
   2) Something does not have capability any more (it is overloaded).

2. Not doing something it could be doing.
3. Doing something, but not as well as it could be doing it.
4. Doing something it should not be doing.

The *Functional* perspective of the change management process shown in Figure 10.6 consists of the following activities:

1. Convert the stakeholder area of concern into one or more requirement(s)/change request(s).
2. Assign a unique identification (ID) number to the requirement(s)/change request(s).
3. Prioritize the requirement request(s) with respect to the other requirements/change requests.
4. Determine if a contradiction exists between the requirement(s)/change request(s) and existing accepted requirements/changes.
5. Perform an impact assessment which must:

   1) Estimate the cost/schedule to implement the requirement(s)/change request(s)[28].
   2) Determine the cost/schedule drivers: the factors that are responsible for the greatest part of the cost/schedule implementing the requirement(s)/change requests(s).
   3) Perform a sensitivity analysis on the cost/schedule driv-

[28] In this pre-SRR situation, there is no need to determine the cost and schedule for every requirement. Applying the quantitative perspective in the form of the Pareto principle, it can be perceived that the cost and schedule impact only needs to be determined for the most expensive and longest time to realize requests (Hari, et al., 2008).

ers.

4) Determine if the high cost/schedule drivers are really necessary and how much negotiating the requirement(s)/change request(s) with stakeholders can make modifications to the high cost/schedule drivers based on the results of the sensitivity analysis.

6. Make the customer's decision to accept, accept with modifications, or reject the request.
7. Notify the stakeholder of the decision.
8. Document the decision(s) in the requirement/change repository to provide a history in case the same requirement(s)/change request(s) are received at some future time.
9. If the requirement(s)/change request(s) is accepted, allocate the implementation to a specific future version of the system, modifying the documentation appropriately.

10.2.1.9. The Scientific perspective

After examining the situation from the eight descriptive HTPs, the conclusion was that the problem of how to transition the MSOCC from the undesirable situation to the FCFDS could be split into the following two well-structured problems, each having unique and shared stakeholders:

1. ***Determine the requirements for the MCSS:*** a well-structured non-complex problem since the CONOPS for the MCSS will be an upgraded version of the existing CONOPS; as is common in an upgrade situation (*Generic* perspective).
2. ***Convert the stakeholder plurality of opinions*** on the transition from the existing NASCOM switch to the replacement switch to a consensus on an approach. This was a well-structured complex problem with a prime directive of "*no loss of satellite data*" during the transition.

The FCFDS was an MSOCC containing a single switch replacing the three switches in the NASCOM switch. The replacement switch was to have at least twice the connection capability of the existing three switches combined. The new switch was to be configured to handle data and timing in the same direction for both uplink and downlink data, which would alleviate the current phase problem between data and timing. The switch was to be controlled by the DOCS, handle data at standard digital rates of between 1.544 and 6.312 Mbps, and have a capacity of 255 full-duplex connections. The new switch system was to be named the MSOCC Communications Switching System (MCSS).

10.2.2. The MSOCC Switching System Replacement Project (MCSSRP)

The description of the MSOCC Switching System Replacement Project (MCSSRP) herein is limited to the requirements elicitation state of the SDP up to and including the System Requirements Review (SRR).

10.2.2.1. The MCSSRP tasks

The MCSSRP took place in the context of the following sequential tasks:

1. Determination of lessons learned from past projects discussed in Section 10.2.2.1.1.
2. Determination of, and discussion with, stakeholders discussed in Section 10.2.2.1.2.
3. Determination of the areas of concern for the major stakeholders discussed in Section 10.2.2.1.3.
4. Identification of the operational scenarios for the MCSS discussed in Section 10.2.2.1.4.
5. Determination of the functional and performance requirements for the MCSS discussed in Section 10.2.2.1.5.
6. Pre-SRR architecting discussed in Section 10.2.2.1.6.
7. Identification of candidate switch architectures discussed in Section 10.2.2.1.7.
8. Evaluation of candidate switch architectures discussed in Section 10.2.2.1.8.
9. Identification and selection of candidate transition approaches discussed in Section 10.2.2.1.9.
10. Determination of test methodology for the MCSS upgrade discussed in Section 10.2.2.1.10.
11. Informing the Stakeholders how their areas of concern were addresses discussed in Section 10.2.2.1.11.
12. The Systems Requirements Review discussed in Section 10.2.2.1.12.

10.2.2.1.1. Determination of lessons learned from past projects

Lacking access to any corporate or customer information, we reviewed personal experiences and the literature in the domains of Quality and Management, researched factors that resulted in effective and ineffective systems engineering, and determined to make the project a success. We speedily identified that clear and concise communications were the key to the success of a requirements elicitation and elucidation project.

10.2.2.1.2. Determination of, and discussions with, the stakeholders

We identified the stakeholders by determining who was involved in the operations and maintenance of the MSOCC and actively involved the NASA GSFC Associate Technical Representative (ATR)[29] in the process of identification of stakeholders. We then determined the stakeholder concerns and their requirements for the MCSS. This necessitated arranging a number of meetings with the different groups of stakeholders at their offices at the GSFC. Since we were not located on the base, these meetings had to be formal and coordinated ahead of time.

Stakeholders were asked to provide two categories of requirements:

- Mandatory.
- "Wishes".

The "wish" category was one where if a decision had to be made to implement a mandatory requirement, and a "wish" could be implemented with little or no extra cost, the "wish" would be taken into account.

During the interviews of the stakeholders, the following key questions asked were from the *Operational*, *Functional* and *Structural* perspectives:

- What is good about the current system?
- What is bad about the current system?
- What would you change, and why?

When the responses from the different stakeholders to the questions were compared, we found that some of the answers were complementary and some were contradictory. We resolved the plurality by using a version of MVA and weighting the responses based on the relative importance of the stakeholders and then holding a second meeting with any stakeholder who had been overruled by one with a higher priority and explaining the situation and the reason for the overruling.

10.2.2.1.3. Determination of the areas of concern for the major stakeholder

The major areas of concern raised by MSOCC project management, the major stakeholder, are summarized as follows:

- The MSOCC requirements for a switch might not be completely supported by a Commercial Off-The-Shelf (COTS) switch.
- The estimated cost of the MCSS necessitated that the NASA procurement system should be used instead of the SEAS pro-

[29] Known as the Contracting Officer's Technical Representative (COTR) in other Agencies.

curement system to procure a COTS switch. This would delay the procurement.

- The transition of the ST modification would add complexity to the installation of the MCSS.
- The DOCS software had to accommodate the transition to the MCSS without changes.

10.2.2.1.4. Identification of the operational scenarios for the MCSS

The performance requirements for the MCSS were to be based on then current MSOCC operational concept scenarios categorized as Normal and Contingency modes discussed in Section 10.2.1.2.

10.2.2.1.5. Determination of the functional and performance requirements for the MCSS

Since this was a replacement or upgrade project, the CONOPS for the MCSS operating in the MSOCC would be almost identical to that of the NASCOM switch system. The MCSS functional and performance requirements were directly obtained or derived from the MSOCC Functional Requirements Document (FRD), based on the Normal and Contingency mode operations scenarios as well as the analysis of information obtained during interviews with MSOCC operations and maintenance personnel and other stakeholders. The non-functional requirements were those that ensured that the equipment power needs were within the capability of the building supply and others inherited from GSFC generic equipment specifications.

One set of these generic equipment specifications required that the MSCSS would be installed in standard Electronic Industry Association 19 inch racks. The paint colour for the racks was inherited when the grounding requirement was inherited from the Spacecraft Tracking and Data Network (STDN) Equipment Specifications-7. However, there was to be no requirement on the colour of the front panels of the MCSS to be installed in the racks. It was pointed out to the ATR that inheriting the colour requirement for the racks:

- Added unnecessary cost of the system since COTS racks were not painted in the specified colour.
- Made little sense since there was no requirement on the colour of the front panels of the equipment to be contained in the racks.

The ATR however would not waive the inherited requirement for the colour of the racks.

As the requirements were elicited and elucidated they were grouped into the following categories.

- ***Functional and non-functional:*** the requirements for the data stream throughputs, the ways of controlling the operation of the switch, and the requirements pertaining to the location of the equipment. The determination of the functional requirements was straightforward. The signal requirements for the replacement MCSS were to be compatible with, and improve on, the NASCOM switch in terms of numbers of inputs and outputs, data rates, data and synchronising pulse electrical voltages and currents as discussed above. The determination of the command and control requirements were more complicated because different stakeholders had different ideas of how the replacement switch would be controlled and the number of control points.
- ***Transition:*** the transition requirements were the major problem, because the prime directive was "no loss of data". The MSOCC was receiving data from a number of LEO satellites, and either the NASCOM switch or the MCSS had to be active and route the data to the appropriate destinations as and when data were received, and there were no long periods of time when no data was being received from at least one LEO satellite. To compound the problem, the MSOCC was full of equipment and there was no free space to install a complete MCSS without first removing the NASCOM switch. Moreover, in building temporary bypasses, the length of the cables to be used for the signals was limited, since the usable clock rate decreased as the length of the cable increased.

10.2.2.1.6. Pre-SRR architecting

Once the requirements for the data stream throughputs had been identified, we performed some risk management to alleviate the major stakeholder (MSOCC project management) concerns. As a result of that activity, we determined that COTS data switches could meet the data stream throughput requirements, but they might not meet the control requirements of all the stakeholders. Moreover, the COTS switches were supplied in modules that would have to be integrated either by the COTS vendor, or by a MSCOCC support contractor. This finding was communicated to the ATR.

10.2.2.1.7. Identification of candidate switch architectures

Three potential implementation architectures were identified. They were:

1. Buy a COTS switching system.

Table 10.1 The advantages and disadvantages of the three options

Option	Advantages	Disadvantages
1. Buy a COTS product	Low developmental risk	Provided COTS capability would not be exactly equal to the initial set of MSCC requirements
	Proven COTS switch technology	Large amount of customization would be costly
2. Build a new MCSS	Built to exact MCSS requirements	High developmental risk
	Could be built in a way to facilitate transition of the MCSS into the MSOCC	Long lead time
		High cost for lifetime support
		May have to customize control software
3. Build/Buy combination	Uses proven COTS technology for the data switching subsystem	Customization of software, either in the DOCS or in the MCSS
	Could be built in a way to facilitate transition of the MCSS into the MSOCC	
	Minimal developmental risk	

2. Build a new switching system.
3. Build/Buy combination. Buy some COTS elements and build add-ons to interface to the existing equipment in the MSOCC.

10.2.2.1.8. Evaluation of the candidate switch architectures

The advantages and disadvantages of the three conceptual implementation architectures were investigated and are summarized in Table 10.1.

The relatively low cost and implementation risk of the COTS switches as compared to the design and development of a custom product was examined and a decision was made to go with a COTS product for the switching subsystem. Cost was an important selection criterion with the need to keep the cost of purchased items within the SEAS procurement limit. However, this decision limited the range of the command and control requirements to the functionality of the COTS switches available from the vendors, and, as the data throughput switching requirements were of higher priority than the control requirements, the limitation was accepted.

This decision eliminated a major risk, and determined that the requirements for the replacement switch would be feasible, and achievable within budget. As a result of this decision, the recommended approach was the Build/Buy combination which would purchase the COTS switch components and other standard items such as the control terminals, and build small subsystems as required to interface the MCSS to the MSOCC. This choice also had the advantage of alleviating a major stakeholder concern, namely that the cost of the purchased components would be above the maximum allowed for the SEAS procurement process.

We tailored the systems engineering problem-solving process to evaluate the each option as it was being developed, not afterwards. Actually we performed a feasibility study early on. The overriding selection criterion[30] was cost; that was a given before the project began. Consequently, as soon as an option had been investigated to the point where it was shown to be too expensive, namely not feasible, work on that option ceased. The COTS option was risk free, available from multiple vendors and was within budget, so its selection was, as they say, a "no brainer".

10.2.2.1.9. Identification and selection of candidate transition approaches

The next step was to develop candidate alternative transition plans that met the constraints and the prime directive, based on our knowledge of the MSOCC and its operations. Going beyond systems thinking, we recognized that the prime directive of "*no loss of data*" did not equate to "*no down time*" (a perception from the *Continuum* perspective). There were short periods of time when no data were being received and these times could be determined in advance. Thus each candidate transition approach could incorporate some down time when data sources and sinks were being rerouted to the replacement MCSS. We met with the stakeholders again at their convenience and discussed each transition approach and their advantages and disadvantages. We then surveyed the stakeholders as to their preferences. Since the preferences of the stakeholders in the system, being a plurality, had different impacts, we identified a weighting scheme for prioritizing the preferences of the stakeholders by adapting MVA (Chapter 8). The survey requesting that the selection criteria be ranked by the respondent, both in the order of relative importance (i.e. which was more important than the other on a scale of 1-8, with 1 being the most important[31]) and standalone importance (how important each was in itself on a scale of 1-10) was sent to the MSOCC

[30] In this instance, it was a requirement but only as long as there was one option that could meet the cost requirement.

[31] We then transposed the 1 to an 8, a 2 to a 7 etc. to simplify the calculations on the responses.

operations, maintenance and engineering personnel. The weighting of the criteria from the survey results was summarized in both categories by adding the individual scores and dividing by the number of survey forms returned. No attempt was made to remind people to return the survey forms on the assumption that if they didn't return the completed survey form, they weren't interested in the matter. This assumption had one unfortunate effect. There was one late response to the survey by a curmudgeon who provided negative responses to all three transition approaches, with no additional positive suggestions. Since his responses arrived sometime after we had finished processing the timely responses, they were given all the consideration they deserved.

The transition approaches were evaluated against the weighted selection criteria and the option receiving the highest score was selected.

10.2.2.1.10. Determination of test methodology for MCSS upgrade

The test methodology determined the test and evaluation requirements. It was integrated into the transition plan to promote a low-risk approach based on the following goals:

- To verify that the MCSS was functional before transition to the MSOCC.
- To minimize the impact to the MSOCC.
- To ensure one tested change to the MSOCC at any one time during switch system transition.
- To establish transition state milestones to provide both a measurement of progress and contingency fall-back positions.
- To always have two control hosts for each switching system at any time during the transition (i.e., DOCS for the current switches, and the new Local Control Terminals for the MCSS).
- To minimize interdependencies between the different transition activities.

10.2.2.1.11. Informing the stakeholders how their areas of concern were addressed.

Once the areas of concern of the stakeholders had been identified and their concerns translated to requirement requests, two sets of meetings with the stakeholders allowed us to discuss their concerns and in a few instances how their concerns contradicted other stakeholders' concerns and more importantly, why their concern was noted but not acted upon.

Where the stakeholders' requirement requests for MCSS command and control functions contradicted other requirements requests, we met with the stakeholders, discussed and resolved the contradictions well before the SRR. From the *Generic* perspective this is a standard negotiating technique where the persons involved in the negotiations do not meet directly but pass their concerns through a middleman or negotiator.

Informal meetings to report on stakeholder concerns should be held between the formal milestone reviews in all states of the SDP.

10.2.2.1.12. The Systems Requirements Review

We combined all the relevant information into a single draft System Requirements Document (SRD) (NASA/GSFC, 1989b) and an overview SRR presentation. The draft SRD contained:

- The performance requirements for the replacement switch.
- The candidate MCSS architectures.
- The recommended architecture and the rationale for the recommendation.
- The transition requirements.
- The alternative transition plans.
- The transition survey results.
- The recommendation for transition from the existing NASCOM switch to the replacement MCSS, based on the weighted evaluation criteria.

We circulated the draft SRD before the SRR for stakeholder review and then presented the SRR. After summarizing the requirements, the candidate alternatives for transition, and the evaluation criteria for selecting the recommended approach, we presented the recommended transition plan as a high-level sequence of activities (process).

Since consensus had been gained in the informal meetings, when the SRR was held at GSFC and covered both the requirements for the MCSS and the transition plan, all requirement requests were accepted and became requirements without a single Review Item Discrepancy (RID)[32].

10.2.2.2. Analysis and commentary

Consider the following aspects of the Case Study:

1. The clear and common vision of the purpose of the project discussed in Section 10.2.2.2.1.
2. Stakeholder involvement in requirements elicitation discussed in Section 10.2.2.2.2.
3. Process architecting discussed in Section 10.2.2.2.3.

[32] Which we were informed was unprecedented. Perceptions from the *Continuum* perspective indicate that either we did a good job, or nobody cared.

4. The object-orientated approach discussed in Section 10.2.2.2.4.
5. The completeness of the SRR as a result of applying lessons learnt from other people's experiences discussed in Section 10.2.2.2.5.
6. What we did correctly discussed in Section 10.2.2.2.6.
7. Supply chain requirements discussed in Section 10.2.2.2.7.
8. Decision makers need the authority to make the decisions discussed in Section 10.2.2.2.8.
9. The modified MVA approach to decision-making discussed in Section 10.2.2.2.9.

10.2.2.2.1. The clear and common vision of the purpose of the project

The clear and common vision was the major contribution to the success of the project. The replacement MCSS was an upgrade of a functioning facility. There was a clear vision or CONOPS for what the MCSS would do; it would be a bigger and better NASCOM Switch performing the same functionality. Most of the requirements engineering effort was spent on developing transition options in the form of a FCFDS for each transition solution option, identifying the selection criteria and performing the solution selection. An additional contributor to the success of the project was that the requirements did not change during the period of performance of the project.

10.2.2.2.2. Stakeholder involvement in requirements elicitation

There were two categories of requirements for the MCSS. The first dealt with the performance and control of the MCSS, the second dealt with the transition process for upgrading the NASCOM switch into the MCSS in an MSOCC that didn't have space to install the entire MCSS in one go. Consequently, a staged upgrade would have to be planned, and designed in such as manner to ensure that the downtime of a switch would not impact the prime directive and satisfy all the stakeholders.

The stakeholders who were involved in both aspects of the requirements elicitation process were the:

- ***MSOCC operators:*** identified from the *Functional* perspective.
- ***NASA managers:*** identified from the *Big Picture* perspective.
- ***NASA facilities personnel:*** identified from the *Structural* perspective.
- ***SEAS and NMOS managers:*** identified from the *Operational* perspective.
- ***Hardware and software developers and testers:*** identified from the *Functional* perspective.

- ***NASCOM personnel:*** identified from the *Operational* perspective.
- ***Experiment PIs:*** identified from the *Big Picture* perspective.

We used a soft systems methodology similar to Avison and Fitzgerald's published interventionist methodology (Avison and Fitzgerald, 2003) to determine both sets of requirements by discussing the needs of the stakeholders based on the operations scenarios. Opening the communications channels and providing an understanding of the needs of the various other stakeholders usually resolved any issues immediately.

The stakeholders were also included in identifying the transition approaches and in developing the selection criteria for the transition approach. This is the holistic approach since their knowledge of the MSOCC domain was much greater than the knowledge in the systems engineering team.

10.2.2.2.3. Process-architecting

Theoretical traditional wisdom in systems engineering teaches that the steps in the SDP are:

1. Develop a complete set of requirements.
2. Develop alternative candidate designs that meet the requirements.
3. Develop the evaluation criteria to be used to select the optimal candidate.
4. Select the optimal candidate.
5. Build the system.

Had we followed the standard process, we would have had to elicit, elucidate, and document requirements for a MCSS that could have been met by all three candidate architectures. The command and control requirements would have been interesting and probably too expensive to implement since the stakeholders had no idea of the cost of implementing their requirements. After some reflection, we architected the elicitation and elucidation process (Kasser, 2005) which was coupled with an object-oriented approach, to rapidly identify the build/buy approach as the optimal one. The process was similar to Avison and Fitzgerald's published soft system interventionist methodology (Avison and Fitzgerald, 2003).

10.2.2.2.4. The object-oriented approach

The object-oriented approach to requirements engineering goes beyond systems thinking because it considers that a requirement is more than just the imperative statement of the form "the system shall something"

(Kasser, 2003). The object-oriented approach not only includes the concept of inheritance (*Generic* perspective) but also draws its roots from Total Quality Management (TQM) and contains attributes of the requirements that affect the production process (Kasser, 1995a). Thus, at the same time as the product (functional and non-functional) requirements were documented, their attributes in the process dimension, namely risk, priority, and cost, were also discussed with the ATR.

The initial set of functional requirements for the MCSS was inherited from the existing NASCOM Switch; the non-functional requirements from the generic requirements for equipment installed at the GSFC. These requirements were then tailored (improved) by considering the stakeholder responses to the three key questions:

- What is good about the current system?
- What is bad about the current system?
- What would you change, and why?

The weighting of the responses was such that responses from those direct stakeholders who interacted with the NASCOM Switch were allocated a higher priority than the responses from the indirect stakeholders who managed it.

The data switching requirements had the highest priority. By considering the cost and risk attributes at the same time as the performance attribute, risk management was built into the requirement elicitation and elucidation process. Thus the implementation risk in building the data switching subsystem of the MCSS led to the early decision to purchase COTS products for that subsystem. Cost was an important selection criterion with the need to keep the cost of purchased items within the SEAS procurement limit. However, the decision to purchase a COTS switch limited the range of the command and control requirements to the functionality provided by the COTS switches[33], and, as the switching requirements were of higher priority than the control requirements, the ATR and other stakeholders accepted the limitation.

10.2.2.2.5. Completeness of the SRR

At that time, each project at the GSFC held Milestone Reviews in the form of presentations to stakeholders. In the case of a SRR, feedback, suggestions, omissions, and comments took the form of Review Item Discrepancies (RID) in which written comments were made about some perceived deficiency in the requirements, documents or presentation

[33] Which actually did everything it needed to do in this case.

graphics. These RIDs were tracked, assessed, and reported on, at the following milestone review.

Kasser and Schermerhorn discussed the following two metrics for reviews (Kasser and Schermerhorn, 1994a):

1. The number of RIDS generated by a review.
2. The amount of rework to be performed following a review.

Consider each of them.

- ***The number of RIDs generated by a review:*** perceptions from the *Quantitative* perspective indicate that since reviews with the same name (i.e. SRR) for different projects have different levels of complexity depending on the size of the system being reviewed, comparing numbers between different projects may not be useful. However, measuring the number of RIDs does provide a metric for the degree of customer involvement in the process. The assumption being, the larger the number of RIDs generated, the lower the involvement of the customers, because the RIDs would have been pre-empted by the pre-review dialogue.
- ***The amount of rework to be performed following the review:*** includes the amount of work that has to be scrapped and replaced. In percentage terms, the metric can be used to compare the effectiveness of the systems engineering team across different projects. The MCSS SRR did not generate any RIDs so in this case there was no scrap and no rework was needed.

10.2.2.2.6. What did we do correctly?

What did we do correctly? Several things actually, including:

1. We applied TQM to systems engineering, "*TQM is the application of systems engineering to the work environment*" (NASA, 1992). Thus as we started the task, we researched factors that determined project successes and failures, namely looked at the lessons learned from experience and the literature[34].
2. We applied some critical thinking; we researched the literature to verify our approach and located a survey of quality implementation in 100 different companies (BBP, 1990; 1991) which showed that the single most important factor for project success was a common vision of:

[34] While not relevant to the anecdote, we even published the results (Kasser and Schermerhorn, 1994b; Kasser, 1995a).

- What the system was supposed to do.
- Who the customer was.
- The implementation plan for achieving the goals.

3. We speedily identified that clear and concise communications were the key to the success of a requirements elicitation and elucidation project.
4. We determined that our direct customer was the ATR, but there were important indirect customers, namely the stakeholders. Our identification of the customers and their concerns, the communication of the vision of what the MCSS was supposed to do and the implementation or transition plan were the major factors in achieving an outstanding SRR which resulted in no RIDs being generated, something which was unprecedented at the time[35].

Alas the follow-on realization activities fell into the grey area of overlap between the SEAS and NMOS contracts. NASA perceived the NMOS contractor as being cheaper than the SEAS contractor, so the implementation task was awarded to NMOS[36]. Lesson learned: contractors who want to obtain follow-on work should not complete tasks in US Government contracts. Another example of this situation (*Generic* perspective) was Kirtland Air Force Base's sole source follow-on award to CTA Inc. in 1995. The reasons for that sole-source follow-on contract were stated in the Commerce Business Daily (CBD) as being lack of documentation and insufficient existing data for a different contractor to economically take over the contract from the incumbent (CBD, 1995).

10.2.2.2.7. Supply-chain requirements

The transition requirements fell into the categories of supply chain requirements or constraints. They were not concerned with the functionality of the MCSS; they were concerned with the supply (installation) of the equipment to the MSOCC. Many procurements tend to overlook supply chain requirements. Apocryphal legends abound about the delivery of equipment to submarines, in which the equipment is constructed in such a manner as to require a hole to be cut in the hull to take the equipment aboard; or the failure to consider launch vibration conditions when building spacecraft. In the object-oriented paradigm, inheriting requirements from the class of equipment can reduce the number of 'forgotten' requirements. Thus for example, spacecraft can inherit launch vibration,

[35] Since RIDs can also be considered as metrics for the completeness of a review, we either did an outstanding job, or nobody cared about the MCSS (*Continuum* perspective, the situation is discussed in Section 3.2.7.1).

[36] I know, when my children complained, "it wasn't fair", my response was often, "*nobody said that life was fair*".

and thermal vacuum requirements. The same concept of inheritance can be applied to classes of non-functional requirements such as environmental requirements.

10.2.2.2.8. Decision makers need authority to make the decisions

When the inherited requirement for the colour of the racks was identified as adding cost and being illogical, the ATR made an informed decision to keep the requirement. Or so we thought. Actually he didn't make a decision. The appeal to the ATR to waive the requirements for painting the 19 inch racks to the STDN-7 colour was an appeal to the wrong person. We assumed the ATR had the authority and would be willing to waive the requirement. We should have first identified who had the authority and made sure they were included in the discussions on the colour requirement and the effect of not waiving the requirement on cost and schedule. By the time we realised this, it was too late to do so without appearing to be attempting to overrule the ATR, so we didn't, and just noted the lesson learnt.

10.2.2.2.9. The modified MVA approach to decision-making

The selection approach discussed in Section 10.2.2.1.9 used a stakeholder survey. The survey requesting that the selection criteria be ranked by the respondent, both in the order of relative importance (i.e. which was more important than the other on a scale of 1-8, and standalone importance (how important each was in itself on a scale of 1-10). The weighting of the criteria from the survey results was summarized in both categories by adding the individual scores and dividing by the number of survey forms returned. The traditional MVA approach would have been to multiply the relative by the absolute importance to develop the weighting value.

- In this instance, adding or multiplying the relative and absolute importance of the criteria provides the same result. The difference is that multiplication expands the differences and seems to show a wider variance as shown in Table 10.2.
- None of the relative criteria scored a perfect 8 which is an indication that there was plurality of stakeholder opinions.

10.2.3. Lessons learned

The lessons learned from this anecdote are summarized as follows.

- Stakeholder participation is critical to the success of any project especially when a plurality is involved (Kotonya and Summerville, 2000; Flood and Jackson, 1991). Everyone gets their needs addressed, and if they are not met, they understand the reasons why they were not met. This addressing of stake-

Table 10.2 Scoring and weighting the selection criteria

Selection criteria	Relative	Absolute	Addition	Multiplication
Minimal impact to MSOCC	7	10	17	70
Minimize number of equipment moves	6	9	15	54
Visibility of BEDs in DOC room	5	8	13	40
Schedule	4	8	12	32
Facilities	4	7	11	28
Replacement switch accessibility	4	7	11	28
Colocation of common functions	4	5	9	20
Proximity of MCSS to current switch location	3	5	8	15

holders needs was ensured by involving the stakeholders in determining both the requirements for the MCSS and how the transition from the NASCOM switch to the MCSS would occur.

- Decisions should be discussed with those who have the authority to make the decisions and are willing to do so.
- Domain knowledge is key to success.
- In US government contracts, always leave something undone. In this instance it was don't solve the entire problem, or the competing (cheaper) contractor will get the follow-on (implementation) task.

10.2.4. Summary

This Section is a Case Study about a situation in which a Soft Systems Methodology similar to Avison and Fitzgerald's published interventionist methodology (Avison and Fitzgerald, 2003) coupled with an object-oriented approach for viewing requirements was used in a tailored version of the SEP in a complex environment by a systems engineering team to solve the problem posed by the need to gather two sets of requirements. The functional and performance requirements were relatively simple to identify. The control requirements were more difficult since there was a plurality of stakeholder needs. However, the most important requirements were the supply chain requirements pertaining to the actual transition from the NASCOM switch to its replacement MCSS rather than the performance of the MCSS. The tailored soft system intervention approach was crucial to the success of the task.

10.2.5. Conclusions

The following conclusions can be drawn from this Case Study:

- While the performance requirements are mandatory, sometimes the supply chain and process requirements are just as, or even more, critical.
- The context in which the system is being implemented must be considered when determining the system requirements, namely the importance of the *Big Picture* perspective.
- Systems engineers involved in the elicitation and elucidation of requirements need to add soft systems methodologies to their toolboxes.
- The interpersonal skills of the systems engineering team were a critical factor in the project success.

10.3. Developing an optimal classroom teaching and learning environment

Use the process mentioned in Section 1.1 study the anecdote especially if you are not familiar with the education domain and pick out the pertinent points from the details.

This Section:

- Provides an example of how easy it is to make the wrong decisions if there is insufficient information or lack of domain expertise in the project team.
- Begins by stating the need[37] to provide postgraduate students in systems engineering with an optimal classroom teaching and learning environment, namely a system[38].
- Demonstrates the development of conceptual alternative solutions to meeting the need by introducing and considering a sam-

[37] Notice the need was stated not explored.

[38] Unstated and/or implied constraints or assumptions can have a great deal of influence on the solution system often planting the seeds of doom which lead to realization of the wrong solution system. There are at least two unstated and/or implied constraints or assumptions in this situation, these being that:

1. The solution system is limited to the classroom environment and online distance mode and other non-traditional options are out of scope.
2. The content of the course meets the requirements for the knowledge components.

ple of the factors that affect the solutions in Section 10.3.1.2. Sketchy concepts of the solutions are shown, discussed, and a few representative risks associated with the solutions are identified.

- Describes the development of a set of solution selection criteria in Section 10.3.1.3.
- Illustrates an example of decision making in a situation where the choice is unclear and more information is needed in Section 10.3.1.4[39].
- Moves on to discuss the formulation of strategies and plans for implementing the solution system after having selected the conceptual solution in Section 10.3.1.5 and Section 10.3.1.6.
- Provides examples the following factors or mistakes that contribute to solving the wrong problem:
    - Using solution language rather than functional language.
    - Drawing incorrect conclusions from data.
    - Insufficient data.
    - Not understanding the situation.
    - Lack of critical thinking.
    - Lack of domain knowledge.
    - Use of single perspectives, e.g. a focus on perceptions from the *Operational* or the *Functional* perspective and ignoring the *Temporal* perspectives.
    - Failure to admit mistakes which leads the project in the wrong direction, discussed in Section 12.5.6.

Throughout the discussions, the factors affecting the solution in the educational environment should be considered as being representative, not complete.

10.3.1. The sequential tasks

The Case Study is discussed in the context of the flowing sequential tasks according to Figure 9.2:

1. ***Task 2:*** defining the problem space discussed in Section 10.3.1.1.
2. ***Task 3:*** conceiving conceptual solution options discussed in Section 10.3.1.2.
3. ***Task 4:*** identifying ideal solution evaluation criteria discussed in Section 10.3.1.3.

[39] Commonly known as operating under conditions of uncertainty.

4. ***Task 5:*** performing the trade-off to find an optimum solution discussed in Section 10.3.1.4.
5. ***Task 6:*** selecting the preferred option discussed in Section 10.3.1.5.
6. ***Task 7:*** formulating strategies and plans to implement discussed in Section 10.3.1.6.

10.3.1.1. Task 2: defining the problem space

The first task in the systems engineering approach to tackling a problem is to explore and define the problem space. Once the aspects of the situation that makes it undesirable have been identified, the problem then becomes how to create the FCFDS. If the problem can be expressed as a function, the solution becomes a system that performs the needed function namely the solution is the inverse of the problem[40]. In this anecdote, the customer stated:

- The problem[41] as, "the need to provide postgraduate students studying systems engineering in a classroom[42] with the necessary knowledge and skills components in an optimal manner". This bounded problem statement results in a target optimal solution that is a system in the form of a classroom that provides postgraduate students studying systems engineering with the necessary knowledge and skills components in the optimal manner[43]. The optimal manner is defined in this situation as the best way which allows the students to ingest, retain, understand and be able to apply the required amount of knowledge in the time allocated to learning[44].

[40] Similarly if the problem can be stated as a function that is present but not needed, then the solution becomes a system that no longer performs the function.

[41] The customer has presumably explored the problem space and determined the problem (sarcasm intended). The customer is using solution language rather than functional language.

[42] This is an example of how unchallenged assumptions can lead to poor solutions. For example, challenging the assumption, one could ask is it self-evident that the solution consists of a classroom? Could it be instead, a learning laboratory, an online environment or some other alternative? Is it possible that the root problem has yet to be identified? And does 'using a classroom' preclude learning in an optimal manner?

[43] This may also be an example in which the customer states the problem in solution language.

[44] Is this definition valid? Surely, the value of a systems engineering course can be judged only by outcome, that is by the quality of the students, perhaps 3 or 4 years down the road, when they have jobs in the business and they can look back and reasonably determine what the course gave them that has proved useful. So, outcome is more valuable than output.

- That factors affecting the solution shall include the domain knowledge that postgraduate students are generally employed full-time, studying part-time, and have families and other demands on their time. Consequently, the time they can allocate to their education is limited, hence the need to optimize the learning experience (Kasser, et al., 2004). At the time, the most commonly used method for transferring knowledge[45] from the instructor to the student still seemed to be the lecture-based approach.

10.3.1.2. Task 3: conceiving conceptual solution options

A good conceptual solution is one that provides a complete solution to the whole problem. Consequently, it is essential to delineate the *whole* problem first and then show that the conceptual solution would remedy (solve, resolve or dissolve) that *whole* problem. Conceptualising solutions takes the form of visualising two or more FCFDS located in different points on the:

- System solution implementation continuum (Section 4.3.2.6.2.2).
- Continuum of change (Section 4.3.2.6.2.4). Each FCFDS can be adaptive, namely minor or incremental changes to an existing system or situation, or the FCFDS solutions can be innovative (Kirton, 1994) but either way they shall solve, resolve or dissolve the whole problem.

One process of identifying potential candidate solutions takes the form of asking questions about the problem and potential solutions from each of nine HTPs using Active Brainstorming (Section 6.1.3).

The undesirable situation or context for the problem/solution in this situation is a classroom[46] which can be expressed as a system containing the professor, and the students. Moreover, the students can be arranged in groups or teams as shown in Figure 10.7. Two sets of interactions take place in the system[47], the primary interaction being communications between the professor and the students, and the secondary interaction being communications between the students and the students. For simplicity the secondary actions are only shown between two student/teams, in

[45] Knowledge or understanding?

[46] The customer had insisted upon the classroom context. In this case it demonstrates a real-world situation in which the seeds of doom (providing the wrong solution) can be planted into the project at its beginning.

[47] Different teams take on individual characters/exhibit emergent properties, indicating that they are complex subsystems in their own right. This important relationship was not considered in this case, illustrating the need for domain experience as well as expertise in the problem-solving team when examining a situation.

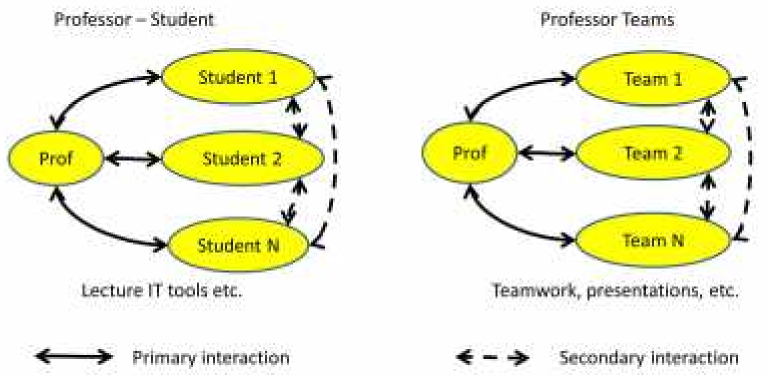

Figure 10.7 Two of the relationships in the instructor-based classroom system

reality there is interaction between each student/team and all the other student/teams[48].

Three candidate conceptual solutions were identified from processing the following questions from the *Operational* and *Generic* perspectives.

10.3.1.2.1. Operational perspective

The questions from the *Operational* perspective were:

- What is the current approach?
- How can it be improved?

Due to the implicit assumptions discussed above, two critical *Operational* perspective questions were not posed. These questions being, "*what topics are being taught?*" and, *"what topics should be taught?"* the lack of these questions focused the problem-solving effort on the pedagogy of the classroom and incorporated the assumption that the knowledge content met an unstated implied set of requirements. This situation provides a demonstration of how easy unstated and implied assumptions can influence the development of the solution system in undesirable ways unknown to the participants.

10.3.1.2.2. Generic perspective

The questions from the *Generic* perspective were:

- What does the literature have to say about more effective ways of teaching and learning?

[48] This in accordance with the methodology to reduce the apparent complexity of a situation by optimizing the interfaces discussed in Section 7.8.7.

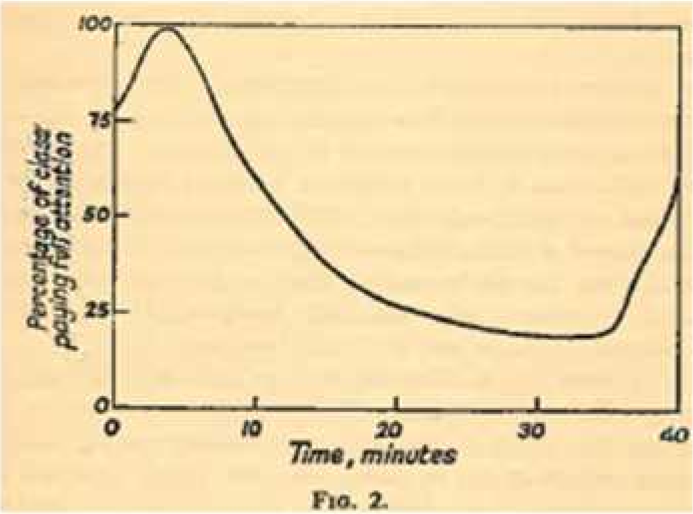

Figure 10.8 Attention span (Mills, 1953)

- What lessons can be learned from other people's teaching/learning experiences?
- How can those lessons learned be used to solve this problem?
- What is this problem similar to?

The answers were not readily apparent so a review of the literature in the education domain was undertaken, a process of research in the manner described in Figure 7.12. This research produced three candidate FCFDS which were:

1. A somewhat modified current lecture-centric classroom discussed in Section 10.3.1.2.2.1.
2. A classroom using pedagogy based on active learning discussed in Section 10.3.1.2.2.2.
3. A classroom environment which matches student learning styles to instructor teaching styles[49] discussed in Section 10.3.1.2.2.3.

10.3.1.2.2.1. *A somewhat modified current lecture-centric classroom.*

Modifying the current approach is an obvious (intuitive?) and not necessary optimal approach which leads to a FCFDS based on making adaptive changes. This solution is the traditional format in which the instructor is the speaker, while students are the audience. It is similar to a conference presentation session but lasts longer. It is the most familiar teach-

[49] Is Candidate 3 clearly different from the others? Candidate 1 might be said to match student-learning styles to conventional didactic teaching styles.

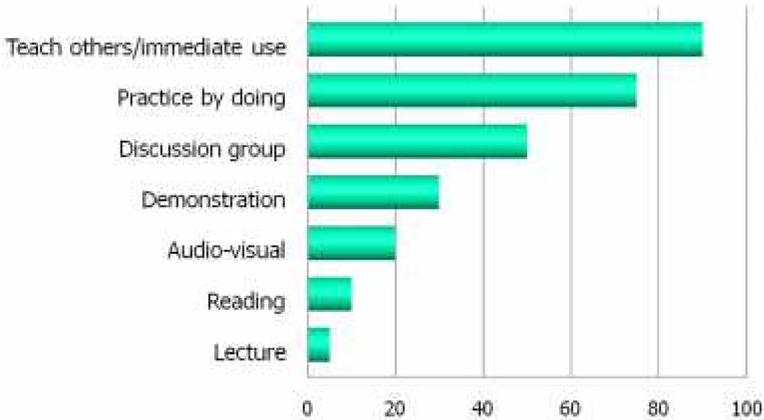

Figure 10.9 Claimed effectiveness of different learning techniques (Kasser, et al., 2008)

ing style for students since[50] they have experienced that format in the classroom since they began their education in the first grade[51]. Modifications could start by putting the emphasis on deep learning (Biggs, 1999) and taking into account the effect of the 'attention span' of the students. Students seem to have limited attention spans (Mills, 1953: page 32). They tend to be more attentive at the start of a lecture and the effectiveness of the lecturing decreases over time as shown in Figure 10.8[52]. This means that a break should be taken after an hour or so. If one is not taken, after an hour and half, there is a good probability that at least one person will need to answer the call of nature. If they are counting down the seconds till the break because they do not wish to disturb the class, they are not learning.

10.3.1.2.2.2. *A classroom using pedagogy based on active learning*

This candidate FCFDS is based on active learning which engages the students in the learning process rather than allow them to passively receive information from the instructor. Active learning is more than the instruction to, "*read, learn and inwardly digest*" given out in Dame Alice Owens Grammar School for Boys in the 1960's by a teacher whose real name is long forgotten but whose nickname was "Cheyenne". Active learning has its roots in the often quoted learning pyramid developed in the 1960's at the National Training Laboratories, Bethel, Maine (Lowery, 2002), which lists the effectiveness of seven teaching methods and in the

[50] Students, note this example of critical thinking in the supporting part of the statement following the word 'since'.

[51] The students were in Singapore.

[52] Conference sessions may have been originally limited to 20-40 minutes for this reason.

earlier Dale cone of experience[53] (Dale, 1954: page 43). The meaning of the term 'active learning' covers a broad spectrum of team work exercises ranging from 20-minute problem-solving exercises to the way in which postgraduate business schools tend to work, i.e., where a lecturer introduces a subject, sets the class a problem based in the subject, and the class then splits into their teams to work on the problem[54], perhaps for a week, finally presenting their solutions in competition at the end of the week. The learning pyramid and Dale's cone have been redrawn in Figure 10.9 (Kasser, et al., 2008) which shows that listening to lectures is the worst way of learning something, while any of the forms of active learning is better. However, many students favour the lecture style class because they are used to it and can multi-task other activities such as dealing with their emails, surfing the Internet, watching a sports broadcast or playing a game, while listening to the lecture.

This candidate FCFDS uses an active learning approach set in the middle of the 'active learning' spectrum and is also the proven approach used in the world's first immersion course in systems engineering which was developed at Cranfield University funded by a grant from the Leverhulme Trust in 2007 (Kasser, 2007a). The immersion course format produced better results in the university classroom than previous lecture-based semester mode classes delivered in the intensive block mode format[55].

10.3.1.2.2.3. *Match student learning styles to instructor teaching styles*

"*Students learn in many ways - by seeing and hearing; reflecting and acting; reasoning logically and intuitively; memorizing and visualizing and drawing analogies and building mathematical models; steadily and in fits and starts. Teaching methods also vary. Some instructors lecture, others demonstrate or discuss; some focus on principles and others on applications; some emphasize memory and others understanding. How much a given student learns in a class is governed in part by that student's native ability and prior preparation but also by the compatibility of his or her learning style and the instructor's teaching style. Mismatches exist between common learning styles of engineering students and traditional teaching styles of engineering professors. In consequence, students become bored and inattentive in class, do poorly on tests, get discouraged about the courses, the curriculum, and themselves, and in some cases change to other curricula or drop out of school*" (Felder and Silverman, 1988). This conceptual candidate solution looks promising. However there are many problems related

[53] Which does not have any numbers associated with the cone.

[54] Creating the knowledge and applying it to solve the problem

[55] The class ran for four consecutive days in the first three iterations and five consecutive days in the last iteration. Students then had up to 60 days to complete the assignments. Communications with the instructor during those 60 days was encouraged.

to matching learning and teaching (Dunn and Dunn, 1979). Among others, the following questions should be answered[56].

- What are the problems in matching teaching and learning styles?
- How to design a matching teaching and learning system?
- Should the matching be done before or after students select a course?
- What should be the speed of the match, gradual or sudden?

Each of these questions must be answered. Research and various types of analysis and modelling/simulation tools may have to be employed. If the questions cannot be completely answered the elements of the solution they influence must be monitored.

Notice that at this time the descriptions of the three conceptual FCFDS are just sketchy concepts of operation at different levels of detail with few if any details as to how the FCFDS would actually function: just enough to conceptualize and determine the feasibility of the concept. At this point in time a milestone review takes place. Once the conceptual alternatives are accepted as being feasible, each conceptual FCFDS would then be developed further developing an understanding of the relationships between the instructors, students and teams and how those relationships are affected by various parameters to produce a CONOPS which describes in greater detail how the conceptual solution system will operate in its future environment. Models and simulations might be developed and experiments might be carried out[57]. However, should a 'show stopper' that indicates that the solution is not feasible show up at any time, work on that solution should stop immediately. Any further effort pursuing an infeasible solution is a waste of resources.

10.3.1.3. Task 4: identifying ideal solution evaluation criteria

An initial but incomplete set of solution evaluation criteria can often be extracted from personal experience and the literature during the same literature search performed to generate ideas for the conceptual solutions[58]. However in this case the literature review on systems engineering educa-

[56] These questions are broad and may require substantial analysis to determine the pertinent parts of the findings of research performed in generating the answers to the questions.

[57] These activities are really beneficial to gaining an understanding of the nature of both the problem and the solution and are a tried and tested method of developing understanding in other applied sciences - physics in particular, as well as electronics, conflict management, psychology, ecology, business management, etc.

[58] This section of the chapter represents the development of selection criteria and the presentation of information to help making the decision as to which of the alternative conceptual solutions to choose.

tion and curriculum design showed that publications tended to focus on the body of knowledge for systems engineering and tended to ignore pedagogical issues, namely how systems engineering classes should be taught (Kasser, et al., 2008). Valerdi believes that it is plausible that engineering students may prefer different learning styles to the styles of other types of students depending on the content and the kind of assessment expectations which are placed upon them with respect to the abilities that they will be able to demonstrate as a result of the their study (Valerdi, et al., 2009).

Some evaluation criteria can also be derived from the student experience in a postgraduate class on systems engineering at the National University of Singapore (NUS) in early 2009 which employed three instructors, Profs A, B and C, teaching sequentially one after the other, teaching different topics at different levels of abstraction using different teaching styles. Student perceptions of the amount they learnt from each instructor and the differences between the instructors, the types of knowledge and the topics taught were examined and analysed to determine if the results of the analysis could provide evaluation criteria as described herein[59]. The variables/parameters in the course included:

- Types of knowledge taught discussed in Section 10.3.1.3.1.
- Topics and level of abstraction of the course content discussed in Section 10.3.1.3.2.
- Instructor teaching styles discussed in Section 10.3.1.3.3.
- Student learning styles discussed in Section 10.3.1.3.4.

10.3.1.3.1. Types of knowledge taught

Woolfolk described the following three types of knowledge (Woolfolk, 1998):

1. ***Declarative knowledge:*** knowledge that can be declared in some manner. It is "knowing that" something is the case. Describing a process is declarative knowledge.
2. ***Procedural knowledge:*** knowing how to do something. It must be demonstrated; performing the process demonstrates procedural knowledge.

[59] But should students be the only source? Is it reasonable to judge relative merits of courses and instructors on the basis of student perceptions? Are students able to judge how much they have learned (and understood?), and are they able to separate their judgment from their emotions? Is this situation is akin to design departments making decisions on what they think the customer would want without actually asking the customer. Is it also similar to a group only using items they have invented or developed in-house or have direct experience?

3. ***Conditional knowledge:*** knowing when and why to tailor and apply the declarative and procedural knowledge.

Prof A:

- Provides knowledge using lectures, readings and problem-based active learning.
- Uses a teaching style that emphasizes conditional knowledge more than declarative and procedural knowledge which affects the students in three ways. It:
    1) ***Improves the thinking skills of the students:*** Prof A:
        i. Provides the outlines and abstracts or overviews of knowledge, and asks open-end questions expecting the students to find the answers and explanations by themselves or in groups.
        ii. Watches student teams at work and gently nudges them along the path of learning rather than leading the way.
    2) ***Builds team-working spirit:*** the different group exercises following the introductory lecture ***are*** designed for 'learning by doing' in every class.
    3) ***Enriches their experience in receiving the knowledge:*** Prof A uses multi-media (audio, video and reading materials) as additional knowledge sources for students.

Prof B:

- Provides the students with the traditional and familiar lecture using PowerPoint presentation graphics.
- Teaches the declarative knowledge and demonstrates procedural knowledge in the daily examples within the lecture. All the key information (e.g. concepts, methodology, examples, etc.) is clearly written.
- Enunciates 'word by word' the content of the slides[60]. This traditional method has been widely accepted by the students and makes most of them feel comfortable.

Prof C:

[60] To many of the students, English, the teaching language, is a second language, so they appreciated the dual delivery modes.

Table 10.3 The topics, teaching styles and level of abstraction of the course content

	Coursework Topics	Level of Abstraction
Prof A	Critical thinking Problem-solving Context of system engineering SDP and SLC Requirements engineering	High
Prof B	Risk Management System Real Options	Low
Prof C	Business Process Reengineering (BPR) concepts Process mapping and analysis Process validation BPR practice	Medium

- Teaches procedural knowledge in class.
- Delivers knowledge using a combination of the traditional lecture followed by immediate group work.
- Gets involved in the group work and personally interacts with the students and the groups as a consultant and facilitator. At the end of the exercises depending on the available time, the groups make presentations and share learning.

In summary, there is a difference in the type of knowledge taught by the instructors. Prof A delivers declarative and procedural knowledge but focuses on conditional knowledge, while Prof B and C focus on declarative and procedural knowledge, which make students feel more comfortable (Kasser, 2009). Some students can't get used to the problem based learning method in Prof A's class because the highly abstract lecture makes them feel unclear about what they have learned. On the other hand, Prof B and Prof C deliver the typical lecture-based class with concrete information in the slides. This delivery format helps the student understand the basic concepts. Prof A and Prof C both employ some forms of active learning. Besides those methods, Prof A's class also involves more up-front investment in teaching resources and methods, such as identifying and creating readings, videos, etc.

10.3.1.3.2. Topics and level of abstraction of course content

The topics, teaching styles and level of abstraction of the course content were different as shown in Table 10.3.

Table 10.4 Approximate percentage of time each instructor spent in a teaching method

Teaching Method	Learning Pyramid effectiveness	Prof A	Prof B	Prof C
Lecture	5%	30%	50%	50%
Reading	10%	15%	--	--
Audio visual	20%	25%[1]	--	--
Demonstration	30%	--	50%	--
Discussion group	50%	30%[2]	--	50%[2]
Practice by doing	75%	30%[2]	--	--
Teaching others/ immediate use	90%	--	--	50%[2]

10.3.1.3.3. Teaching styles

The teaching styles and type of content were different for each instructor. The Learning Pyramid values for the degree of retention of information of the student after two weeks for each of the teaching methods (Lowery, 2002) illustrated in Figure 10.9 and the approximate percentage of time allocated by the three instructors to each of the teaching methods is shown in Table 10.4. Two of the three instructors performed a self-assessment of their teaching styles using an online Grasha-Riechmann (Grasha, 1996: pages 127 and 128) test[61] in May 2009. The results are shown in Table 10.5[62].

Notes:

1. One class session used the movie 'Pentagon Wars' (Benjamin, 1998) as the basis for a Case Study.
2. The activities in the two rows in the column happened simultaneously.

[61] Available at http://www.longleaf.net/teachingstyle.html in May 2009.

[62] Further research will have to be done to determine the significance of the differences if the information is deemed pertinent to providing the solution. This is illustrative of a situation in which analysis data is incomplete. In such instances if the solution system may be affected by the incomplete information, then the missing information becomes 'risks' and shall be managed appropriately. The unplanned self-assessment was done because the Web site showed up on a search and the test was simple and fast. This situation illustrates that while systems engineers measure and perform analysis it is very easy for analysis-paralysis to set in. For example, questions such as, "*did the test provide any useful data?*" and even, "*why are we measuring this characteristic*?" should be asked and answered. Analysis shall only be done if pertinent to conceptualizing the solution, not because the data is available.

Table 10.5 Grasha-Riechmann Instructor self-assessment results

	Prof A		Prof B	Prof C	
Expert	3.50	Moderate	No data	4.375	High
Formal authority	4.25	High	No data	3.625	High
Personal model	4.25	High	No data	3.627	High
Facilitator	4.25	High	No data	3.750	Moderate
Delegator	3.87	High	No data	3.500	High

10.3.1.3.4. Student learning styles

There were about 30 students in the class. Using a tailored version of grounded theory (Glaser, 1992), a representative eight of the students were interviewed about the class and their learning styles using face-to-face and telephone discussions when the semester was over. Each interview lasted about 30 minutes. The student responses were grouped into three types according to the Myers-Briggs's personality research (Myers and Myers, 1980) where:

- ***Type 1 students*** are introvert thinkers. They:
    - Prefer a quiet environment for learning and listening rather than talking and interacting in class.
    - Make decisions and work directly with data, rather than with feelings, emotions and personal values.
    - Are objective decision makers, who like to get opinions based on established facts, known procedures and linear presentations.
    - Tend to have stronger skills in memorizing details rather than in understanding abstract pictures.
    - Prefer concrete language and working directly with data.
    - Tend to reserve judgement until all the data has been processed.
- ***Type 2 students:***
    - Are more likely to make decisions based on emotions, personal values or vague intuitions.
    - Value group harmony and feel less comfortable with personal conflicts.
    - Tend to have stronger skills in memorizing details rather than in understanding the whole picture.
- ***Type 3 students:***
    - Feel more comfortable interacting with others.
    - Like talking aloud in public.

  - Believe data and evidence, but most of the time make immediate decisions and draw premature conclusions based on initial inputs.
  - Feel comfortable with accepting abstract knowledge and get the big picture of things first. They then look inside at the internal components, items such as the connections between seemingly random sets of data, and fill in the details later.

Student comments on the instructor's teaching styles, by Type, included:

- ***Type 1 students:***
  - I felt puzzled when I attend Prof A's class. There were too many class activities that made learning experience complex. My team members and I always feel stressful and find it hard to enjoy the class.
  - The content of Prof's B's class was also not easy, but I am quite familiar with this traditional teaching method. So it is not a problem for me to grasp the knowledge.
  - Prof C's class made us feel easy to catch up and the number of activities was neither too much nor too little, which even inspired our interest in learning more after class.
- ***Type 2 students:***
  - Prof A's teaching style was quite new for most of us. We didn't have enough psychological preparation and needed time to adapt to the teaching method.
  - Though the organization of the teaching style is simple in Prof B's class, the demonstration and lecture notes have enough detail for us to understand the knowledge. Moreover, the active individual presentation skill kind of balances the boring teaching method.
  - Prof C's class is fun. I like the immediate practice in class, which make me feel effective learning and inspires my interest.
- ***Type 3 students:***
  - Prof A's lecture is at a higher-level abstract for the topics, which make it hard for most of us to grasp them in the short time. But after the module, I felt I learned more and my thinking ability improved in Prof A's ses-

Table 10.6 Summary of evaluation of alternative solutions

	Solution 1	Solution 2	Solution 3
Conceptual Solutions	The somewhat modified current lecture-centric classroom	A classroom using pedagogy based on active learning	A classroom environment which matches student learning styles to instructor teaching styles
Criteria			
Teaching styles	Does not allow much variation	Multiple styles but not matched	Matched to student learning styles
Types of knowledge	All	All	All
Topics	All	All	All
Degree of abstraction of the course content	Suitable	Suitable	Suitable
Student learning styles	Does not take student learning styles into account	Variation in activities seems to allow for different learning styles at different times in the class.	Takes student learning styles into account.

sion, though it is still hard for me to connect it with our daily experience.

- We are used to Prof B's way of teaching. Though it is a little boring, I feel it doesn't depress our learning effect. What's more, his active personal presentation skills kind of balance the boring teaching method.
- Prof C's class makes us feel that it is easy to understand the knowledge through the immediate practice. Moreover, it makes everyone perform actively, because there are more chances to consult with Prof C personally in class during the team project.

In this classroom example, from the random sample[63], the majority of the students:

- Are introverts and thinking students, perhaps because of their prior engineering background.
- Agreed that classroom interaction and being an extrovert are also good for learning.
- Hoped they could be more extroverted and sociable in the light of their perceptions of the types of students in the business school.

The surveyed students would like to become managers in future, managers who can perform decision-making and risk management at the business level, rather than remaining as a person who can only deal with data. As the content of their degree program is positioned between engineering and business, and given their prior major engineering background, their preference for subjective and objective decision making is relatively equal.

10.3.1.4. Task 5: performing the trade-off to find an optimum solution

The analysis identified variables and data that could have an effect on the solution but the results of the analysis are inconclusive[64]. When the results are summarised as shown in Table 10.6 the data does not appear to be useful and there is no data upon which to make an objective decision as to which of the conceptual alternative solutions to select[65]. The selection criteria in this case had been determined using student provided data. But are the students a good source of selection criteria? There are other stakeholders – instructors, employers and the academic institution (Kasser, et al., 2008). Students can only evaluate the way in which they were taught, they cannot evaluate that they were taught what they need to

[63] It needs to be mentioned that the survey results may be biased and limited. This is because people tend to complain during evaluations and sometimes blame others subjectively rather than cite good points. In addition, students get used to relying on the teacher actually teaching in class, and not having to do it themselves or self-learn. Moreover, students are reluctant to change their learning styles. Resistance to change is an important element that has to be taken into account when introducing change into any context.

[64] How much of the data is pertinent and how much is not? This is where experience is used to separate signals (pertinent data) from noise (data that is not pertinent).

[65] Had there been domain experts in the problem-solving team the results of the analysis might have been different. This result is meant to illustrate the need to have problem domain expertise and experience during the problem-solving activities.

know (at least not immediately after the class ends)[66]. Other selection criteria need to be identified and employed.

Looking out of the box by posing the *Generic* perspective question, *"What is this problem similar to"* one answer is a digital radio communications system where the 'ability to apply the knowledge in various situations' is the message, the instructor is the transmitter, the student is the receiver and the amount of received signal represents the learning. Maximising the received signal requires that the transmitter and receiver be on the same frequency, use the same modulation, compatible data rates and the message is transferred in an environment with minimal interference. If this analogy holds then the selected solution should be one which matches instructor teaching styles to student learning styles unless a thorough search of the education literature and the opinions of cognizant personnel in the education domain would confirm that in the last 20 years or so, research has shown that matching teaching and learning styles makes no significant difference in the effectiveness of learning systems engineering. Or should it?

The accuracy of the *Generic* perspective analogy is critical to the success of the project; in this analogy the message is akin to the 'ability to apply the knowledge in various situations'. This analogy would drive the pedagogy towards producing innovators who have both problem formulating and problem-solving competencies (Section 5.3.5). Had the analogy stated the message as just being akin to the 'knowledge', the analogy would tend to drive the pedagogy towards producing systems engineers who can follow a process which seems to be common practice (Kasser, et al., 2009) since much of systems engineering seems to be taught as declarative and procedural knowledge. To be fair, this focus on declarative and procedural knowledge is not unique to systems engineering (*Generic* perspective). For example, Peter Drucker wrote, *"Throughout management science - in the literature as well as in the work in progress - the emphasis is on techniques rather than principles, on mechanics rather than decisions, on tools rather than on results, and, above all, on efficiency of the part rather than on performance of the whole"*(Drucker, 1973: page 509).

Notice that the conceptual alternative solutions have been developed without regard to cost and implementation constraints. At this stage in the systems engineering problem-solving process these constraints should be two of the selection criteria and not part of the FCFDS. The only time the constraints are to be considered in the development of a conceptual solution is if they become a 'show stopper' and indicate that

[66] And will not pick up or question the implied assumption that the knowledge component is correct and complete.

the solution is not feasible as discussed above such as in the MCSS Case Study in Section 10.2.

10.3.1.5. Task 6: selecting the preferred option

The next task in the systems engineering problem-solving process is to select the preferred option. While the findings of the analysis are not firm, the preferred approach from the literature and the digital radio analogy is to choose an option that incorporates matching teaching to learning styles. However, the amount of work to implement the solution is unknown since the cited work was published in 1988 and systems engineering classes were still in the main lecture-based in 2007[67]. On the other hand, the change from the lecture-based style to the matching teaching and learning styles constitutes a paradigm shift and has experienced resistance to change. Unwillingness to unlearn something is a major cause of resistance to change. Peter Drucker stated that a paradigm shift in management takes about 25 years, namely the time it takes for the 'unwilling to unlearn' proponents of the old paradigm to retire (Drucker, 1985). Kuhn also mentions the generational delay in making a paradigm change. (Kuhn, 1970). A simple calculation on the back of an envelope shows that (2015–1988)=27. There is hope that perhaps the time to complete the paradigm change is approaching. However, hoping for a solution does not guarantee success. The reasons for the resistance to the change need to be investigated, and become a prime candidate for risk determination and mitigation. Other risks to be monitored and mitigated might include those associated with matching teaching and learning styles mentioned above and issues arising from the following questions.

- Does the type of content affect the desired learning style (*Functional* perspective)?
- Is an individual learning style fixed or does it vary in some manner (*Continuum* perspective)?

10.3.1.5.1. A fourth option?

There may even be a fourth option in situations where the alternatives have been developed by different teams. Each team will generally have different degrees of expertise in different domains and produce conceptual solutions containing useful ideas. It is then likely that a fourth option could be put together based on integrating the best concepts from the set of alternatives. Should this situation show up, then the process must iter-

[67] When this anecdote was written

ate back to the start and develop the fourth conceptual solution[68]. For example, Option 1 was the somewhat modified current lecture-based classroom. It was a generic conceptual solution that would teach all students in the same way. The detailed conceptual design based on further research identified eight factors for a growing and expanding teaching system (Fitzgerald, 2005). The following four factors were incorporated into the instructor's notes in the conceptual design for Option 1:

1. Plan the competencies you want students to develop.
2. Prepare the learning options and choices. This can be a school-wide program in which students learn about different learning styles and talent choices and how to use their strengths.
3. Give students a choice of teaching styles which means provide different ways for students to receive information in the manner of Prof A. Examples would be auditory, visual, somatic and reflective experiences.
4. Check and adjust. For example, if formative assessment shows that teaching technique X did not work for a student, you might try technique Y as an "adjustment".

The other four factors[69] listed by Fitzgerald were considered out of scope in this classroom system because those factors were deemed to affect the Metasystem namely the doctrine, institutional characteristics, or-

[68] Unless the problem is in a well-understood domain, the schedule should always be planned to contain at least one iteration cycle. What would the number of iteration cycles depend on?

[69] The other four factors (Fitzgerald, 2005) that were not considered in this Case Study, are listed herein for further discussion:

1. Begin with motivation or connection (to real life) activities. Show students how the lesson(s) will give them power and how the instructor will help them (anchor). Give them a unique, question-generating introduction (hook) to the lesson topics.
2. Provide different tasks so that students can use talent or intelligence preferences and develop other talent strengths to demonstrate learning. Here there are tasks that let them "construct meaning", the true measure of learning. This is the area of multiple intelligences.
3. Promote mastery with some different re-teaching where necessary. Some of this might come after formative assessment. The goal is student competence, i.e. not "20% missed is good enough!"
4. Celebrate success. Document competencies achieved or not achieved so that the next teacher can follow-up properly. Remember that congratulations help students take pride in learning.

ganizational goals, resources, etc. in the academic institution rather than in a single classroom[70].

Research also discovered that other factors such as teacher beliefs, teacher understanding of their roles, the syllabus time available, the textbook, the topic, preparation and the available resources, and the language proficiency of the students also need to be considered in the design of a classroom (Carless, 2003)[71]. The goal of the solution is to optimize the teaching and learning system. This means that the pertinent factors should be incorporated into the instructor's notes in the design of the selected conceptual alternative even if they were not part of the original conceptual solution[72].

10.3.1.6. Task 7 formulating strategies and plans to implement

The next task in the process is to formulate strategies and plans for the implementation of the preferred solution. The preferred conceptual option is to match teaching and learning styles; the findings from the analysis show that the students have to be prepared for any teaching style that is not lecture-based. As such some sort of training will have to be provided. The new problem becomes how to provide both the course and the training without extending the classroom time? This is where the recursive nature of problem-solving is illustrated, because the approach to providing a solution to this new problem is the exact same six systems engineering problems solving tasks shown in Figure 9.2 even though they all take place inside this task as sub-tasks. In this situation conceptual solutions might include:

- Providing training to instructors teaching in the programme.
- Providing training to the students at the start of every class in the degree programme.

[70] Factors that affect the meta-system need to be addressed in the context of the meta-system configuration control and not just noted in the single system and ignored/forgotten!

[71] However, this research was performed in a primary school in Hong Kong and the relevance of factors affecting primary school teaching in that culture to those factors affecting postgraduate systems engineering teaching in this culture needs to be determined and if, and only if, applicable, incorporated into the preferred conceptual solution. This anecdote illustrates a serious issue. Lessons learned from one context shall not be incorporated into another context without a full understanding of the context from which those lessons were learnt and how much of that context is applicable on the current project.

[72] Similarly in any project, serious consideration should be given to incorporating factors contributing to the success of one conceptual alternative solution into the preferred solution if those factors are solution independent.

- Providing training to the students at the start of the degree programme.
- Don't provide training to the students but identify individual student learning styles and stream the students in classes taught by different instructors using different teaching styles (either for the entire degree programme or individual classes) which match the learning styles of the students.

The feasibility of each of these alternatives would have to be determined, evaluation criteria established, a solution chosen and the appropriate CONOPS and implementation plans developed. Given that there is a high degree of uncertainty, the solution classroom system should be implemented in phases using an evolutionary approach such as the one described in Section 9.19.

10.3.2. Iteration required

Hold everything! New information has come to light[73]. Further research found a report addressing the issue of the relationship between instructor's learning style, student style and the impact that the degree of instructor commitment to a particular mode may have on student achievement in students enrolled in freshman English (Davis, et al., 1988). The method used to assess student learning styles was based on Kolb's work (Kolb, 1984). The results in the report stated that there was no significant difference in course grade point averages among students who were matched or partially matched with, or held opposite styles to, their instructors. The Davis report provided several reasons for the inconclusive results and recommended further research. These findings need further research. However, if the findings are valid then a new alternative may become feasible (*Scientific* perspective).

As mentioned above, the majority of students in the sample are introverts. This situation is supported by a newly discovered statement in the ongoing literature review (McClure, 2004) who when reviewing Laney (Laney, 2002) began the review with, "*Are you an introvert? Only a quarter of the general population is, but more than half of engineers are*". Another set of conceptual alternative solutions for classes teaching systems engineering

[73] This paragraph demonstrates that changes in the state of the art as well as the customer can provide new information or describe a new need anytime in the development of the solution system and sometimes that new information means that the work already done is no longer valid and the process has to start again, from the beginning of the appropriate earlier state. In practice this restart delays the completion of the project by the amount of time taken to get back to the point at which the iteration began (schedule delay) and incurs costs due to the resources expended in the unplanned iteration (cost escalations). Good project planning should allow for a number of iterations.

Table 10.7 ILS Learning and teaching styles

Learning Style	Teaching Style
Sensory, intuitive-perception	Concrete, abstract-content
Visual, auditory-input	Visual, verbal-presentation
Inductive, deductive-organization	Inductive, deductive-organization
Active, reflective-processing	Active, passive-student participation
Sequential, global- understanding	Sequential, global-perspective

could be based on (1) verifying a hypothesis that systems engineers, as a subset of engineers, tend to be introverts and then (2) creating a classroom teaching and learning system based on the learning styles of introverts as the norm rather than on matching individual teaching and learning styles. The literature on learning styles contains a number of different ways of expressing and evaluating learning styles including:

- The VARK (Visual, Aural/Auditory, Read/Write, and Kinesthetic) learning style instrument which divides learning styles in response to the input forms of 'visual', 'aural/auditory', 'read/write' and 'kinesthetic' forms (Fleming and Mills, 1992).
- The Grasha-Reichmann model developed in the early 1970's and used for more than two decades to identify the preferences learners have for interacting with peers and the instructors in classroom settings (Grasha, 1996: pages 127 and 128).
- The Index of Learning Styles (ILS), (Felder and Soloman, 2008), a model which classifies instructional methods according to how well they match the teaching and learning styles shown in Table 10.7.

The documents would be reviewed and data extracted and correlated to the needs of introverts and a new set of conceptual alternative solutions conceived. These conceptual solutions could even provide a lower cost more effective solution than those already identified and minimise or even eliminate the need for training students and instructors, both of whom are engineers.

This new information changes the rules[74] and means that the problem-solving activity returns to the start of the Task 2 and Task 3 boxes in Figure 9.2

[74] When doing research (for a dissertation or grant) the literature review has to be ongoing (a background task) since new findings may change or even invalidate the research in process.

10.3.3. Yet another iteration?

The introduction to the Case Study mentioned that there was an unstated and implied constraint or assumption that the solution system was limited to the classroom environment and online distance mode options were out of scope. If the customer changes her mind and distance mode options become allowable or even desirable, the process must iterate back to the beginning to examine conceptual distance mode alternatives and compare them with the already developed solutions, with corresponding cost increases and schedule delays.

10.3.4. Challenging assumptions

The eighth of Jenkins' twelve roles of a systems engineer was, "*He challenges the assumptions on which the optimization is based*" (Jenkins, 1969: page 164)[75]. None of the problem-solving systems engineers on this project did so, specifically with regard to challenging the solution stated by the customer. Perhaps that was because they had already experienced how challenging the solution stated by the customer can lead to undesired consequences in the real world. For example, in the mid 1980's, a data processing facility at the NASA GSFC was in the middle of a facility upgrade project. The facility processed data downlinked from low earth orbiting spacecraft and was running out of capacity. Working on the project were NASA, contractor and subcontractor personnel. In a brainstorming session during an early project meeting the NASA facility project manager drew an optical Fiber Distributed Data Interface (FDDI) ring architecture on the white board and issued a fiat that he had just drawn the system architecture. "*FDDI has a 100 Megabit data rate, it's a neat technology to use, so we are going to use it*" he said as he completed the sketch and sat down. The members of the contractor's organisation said nothing. The subcontractor's lead systems engineer politely suggested that perhaps they needed to do an analysis of the data rates[76]. The NASA project manager firmly restated that the decision had been made and the matter was

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[75] Using the critical thinking component of holistic thinking.

[76] He felt but did not state that the concept of using fiber optic connections was valid, but there were viable alternatives to a ring structure (such as a matrix or cross point switch approach), especially as they would be dealing with:

- Receiving and processing real-time data.
- A number of spacecraft providing the data.
- Incoming data rates of up to 10 Megabits.
- Several input data processing elements (workstations).
- Several output data processing elements (workstations).
- Output data rates of between 5 and 10 Megabits.
- Data transfers between the input and output processing elements.

closed[77]. Two weeks later the subcontractor's lead systems engineer was removed from the project at the request of the NASA project manager. The stated reason was that the subcontractor's lead systems engineer was '*too arrogant*'. In this situation the lead systems engineer had politely questioned the assumptions without any conscious thought of the decision to perform the questioning[78]. Things went well during the facility upgrade design phase and at no time during this process did any of the contractor or subcontractor personnel disagree with, or question, the NASA project manager[79]. Several months later, when data flow problems became apparent, another non-holistic thinking rethink by the NASA personnel determined that the system would use two FDDI rings in series; one for input data and one for output data[80].

This anecdote has been an example of how, in some situations, the customer inserts a fundamental flaw into the solution system at the start of the process and the problem solvers get the blame when as a result of that flawed solution in which:

- The solution system does not meet the need or remedy the undesirable situation
- The implementation suffers from technical problems and cost and schedule escalations.

10.3.5. Summary

The Case Study in this Section provided an example of tackling the problem of providing postgraduate students with an optimal learning environment as an example of the many types of factors that need to be considered in the conceptual phases of solving the problem, showing the need for subject matter or domain expertise on a project as well as showing how the seeds of doom can be planted into a project in the early stage.

10.3.6. Conclusion

The problem-solving approach in this Case Study was sound in that the process was done by the book. However, the seeds of doom had been planted[81] before the process began since the customer initially stated the problem as the need to provide postgraduate students studying systems

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[77] He had read about it in a magazine and so was the subject matter expert!

[78] However in other situations, conscious recognition of the need to question the assumptions can sometimes lead to an ethical dilemma (Kasser, 1995a: pages 237 to 251).

[79] Either they didn't want to upset him and get transferred, or they knew that NASA would later pay them to fix the problems since it was a Cost Plus Contract.

[80] Notice they were still locked into a ring architecture solution.

[81] And pointed out in the text or in footnotes.

engineering in a classroom with the necessary knowledge and skills components in an optimal manner. Accepting that statement, the problem solvers addressed the pedagogy limited to the classroom environment and ignored the knowledge and skills components due to the implied assumption that the knowledge and skills component in the class were adequate.

As a consequence, the project has a high probability of failure. That is, the subsequent processes for engineering the solution system will deliver the wrong solution system!

10.3.7. Lessons learned

There are lessons to be learned from this anecdote that apply to a broad range of projects in many domains. Lessons learned include:

- Identification of the correct problem is critical. If the wrong problem is identified, the wrong solution system will be produced.
- Implicit and unstated assumptions potentially comprise seeds of doom.
- Solution systems can be adaptations of exiting systems or new and innovative systems.
- Good holistic thinking in the early stages of a project is vital.
- The choice of process to tackle the problem and implement the solution is as important as the choice of solution system.
- Following a perfect process can still produce a poor product. This is commonly known as Garbage-In-Garbage-Out (GIGO).
- Analysis of a prospective solution should stop once the solution is deemed to be infeasible.
- Experience, excellence and knowledge in both problem-solving and the three domains are needed in a project.
- Iteration needs to be built into a project schedule, the higher the level of uncertainty, the greater will be the number of iterations required. Building iteration into the schedule reduces cost and schedule overruns due to unplanned iteration.
- Use appropriate views of project data to minimise misunderstandings. Gantt charts for schedules (*Temporal* perspective), functional flow charts for functional views, etc. A single view does not fit all purposes.
- Challenging assumptions can be an ethical challenge in itself.
- Going beyond systems thinking to perceive the situation as a whole from the perspectives perimeter is necessary throughout the whole problem-solving process.

- Students shall not be the sole evaluators of good teaching. This can be generalised to state that users of a system shall not be the sole evaluators of conceptual replacement systems[82].

10.4. Creating and guide a successful student software engineering project class when the instructor is halfway around the world

This Case Study:

- Describes the experience of going beyond systems thinking when converting a traditional face-to-face synchronous class into a format to allow the instructor to guide the class into producing useable software within the 14-week semester from a location half way around the world.
- Summarizes a number of lessons learned that are applicable to other classes in engineering management and systems and software engineering when using distance education techniques.

Use the process mentioned in Section 1.1 to study the case, especially if you are not familiar with the education face-to-face and distance learning domains and pick out the pertinent points from the details.

10.4.1. Perceptions from the HTPs

Perceive the situation from the following HTPs:

1. The *Big Picture* perspective discussed in Section 10.4.1.1.
2. The *Operational* perspective discussed in Section 10.4.1.2.
3. The *Functional* perspective discussed in Section 10.4.1.3.
4. The *Continuum* perspective discussed in Section 10.4.1.4.
5. The *Scientific* perspective discussed in Section 10.4.1.5.

10.4.1.1. The Big Picture perspective

University of Maryland University College (UMUC) inaugurated its Master of Software Engineering (MSWE) degree in 1999. However, from the beginning, the success of the degree was contingent on having all subjects available via web-based distance learning within two years from the inauguration. This factor was taken into account when creating the degree. The content of each class were configured such that the students[83]

[82] Because their focus is too narrow

[83] These students were employed in the workforce and earned their degree by studying part time, mostly in the evenings. Their employment positions ranged from programmers to project managers. Some also had up to 20 years of experience in their respective fields.

would be able to perform any "laboratory" work on their own personal computers. The only risk to the web-based degree was the final project class (MSWE 617) which was designed to be the capstone class in the program. MSWE617 may be considered as a comprehensive examination covering the application of the tools, skills and techniques the students have acquired in the course of their studies. This class provided experience in applying software-engineering techniques by giving the students an opportunity to produce software working in teams under the schedule constraints commonly experienced in industry. The students had to produce the appropriate documentation for the SDP as well as the working software, although the grading was designed so that the students could pass the class if the scope of the software development effort was such that the students could not complete the software by the end of the semester.

The class was a collaborative learning environment. The instructor was not present in a teaching role, but was only supposed to emulate the vagueness shown by typical customers in describing requirements and serves as a guide and mentor. The students were expected to have acquired the knowledge of what to do and how to do it from the prerequisite classes. It was up to the students to form their own teams (organization) and schedule their work to meet the deadlines imposed by the contract (syllabus).

The distance mode web-based class would be taking place in UMUC's web based distance learning environment (WebTycho). This was a constraint imposed by the institution.

10.4.1.2. The Operational perspective

Perceptions from the *Operational* perspective included the class was designed so that the class would only meet at the following formal milestone reviews:

- Kick off.
- Operations Concept Review (OCR).
- Systems Requirements Review (SRR).
- Preliminary Design Review (PDR).
- Critical Design Review (CDR).
- Delivery Readiness Review (DRR).

However, the students were free to meet in between times, as and when, they decided to do so.

10.4.1.3. The Functional perspective

Perceptions from the *Functional* perspective included:

- Audio lectures by the instructor using PowerPoint graphics. This wasn't a problem. The technology had already been used in other WebTycho based classes in the program (Kasser and Kerby, 1999).
- Public (class-wide) and private communications between the instructor and the students. This wasn't a problem. The technology had been used in other WebTycho based subjects in the program. The rule of thumb for these communications had been as follows. If it was:
    - ***Public:*** a question that in the classroom would be asked aloud in front of other students in the class who would benefit by the reply, post it in the appropriate thread or on the Listserver.
    - ***Personal:*** as in asides after class, or during the break in the classroom, use E-mail, fax, voicemail or synchronous communications (telephone or Voice over the Internet (VOIP)).
- Students presenting PowerPoint presentations with recorded audio. This wasn't a problem. The technology had been used in other WebTycho based subjects in the program.
- Transfer of documents between the instructor and students. This wasn't a problem. The capability was built into WebTycho.
- Students sharing documents. This wasn't a problem. This capability was built into WebTycho.
- An effective web-based collaborative learning environment for the students. This was the highest risk. Students were already collaborating on simpler projects in WebTycho to produce single documents with what appeared to be the usual mixed results of students working in teams. The WebTycho version of this class would require that the students produce a suite of documents as well as a working software product.

Thus, the reuse of techniques from other WebTycho classes provided most of the functionality needed for the WebTycho version of MSWE 617. The only risk remaining was to determine if the students could complete a software development project in the WebTycho environment.

10.4.1.4. The Continuum perspective

Perceptions from the *Continuum* perspective include postgraduate seminar classes are spread out along the spectrum of synchronicity discussed in Section 4.3.2.6.2.1. The difference between teaching in the synchronous (face to face) style of the traditional classroom and the asynchronous web classroom may be as great at the difference between the theatre and television in the entertainment industry (*Generic* perspective). This means that techniques that work in the synchronous classroom may not work, or may have to be modified to work, in the asynchronous classroom. Consider some of the differences:

- ***Dialogue:*** unlike the face-to-face classroom, the asynchronous classroom has to use non-visual and non-verbal dialogue. Mechanisms such as the requirement for regular task completion, evaluation of frequency and depth of interaction (i.e. making it 'count') and hooks such as regular postings requiring student responses can be used effectively in classes where dialogue constitutes a significant learning resource.
- ***Attendance:*** unlike the face-to-face classroom with its fixed meeting times, the asynchronous classroom is available for longer periods of time in which both the student and instructor appear at sporadic or periodic time intervals. This requires specific time management skills.
- ***Lecturing:*** unlike the face-to-face classroom where lectures are interspersed with question and answer discussions as shown in Figure 7.17, the asynchronous classroom is multi-threaded not single-threaded as shown in Figure 7.18 since the instructor cannot wait for a few days before continuing the lecture. Asynchronous pauses can, however, be advantageous to the learner who (depending on learning style and language proficiency) can benefit from the time available for reflection before responding to or asking questions.
- ***Technical limitations:*** there are things that can be done in the face-to-face classroom that as of the moment cannot be done in the on-line classroom. Designing the optimal asynchronous classroom requires going beyond systems thinking and perceiving the capabilities and limitations of the entire communications link between the students from the perspectives perimeter.
- ***Team building:*** unlike the face-to-face classroom in which a team can begin to form in a few minutes as the prospective team members sit and talk, forming successful teams in the asynchronous on-line class requires a completely different approach. However, once developed, this approach can be retrofitted to the synchronous classroom to facilitate team building in that environment.

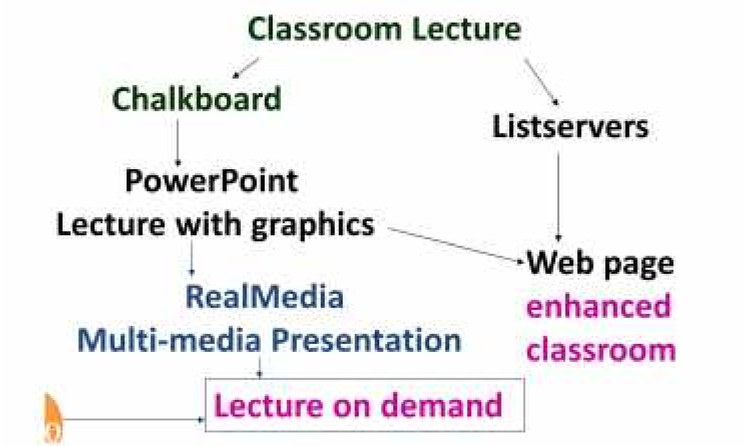

Figure 10.10 The evolutionary online transition process

10.4.1.5. The Scientific perspective or the solution system design

The class (system) was designed as two subsystems, the instructor and the classroom. The classroom contained further subsystems, the student teams and the teaching assistant. Location and technology was interchangeable. The problem-solving approach taken was an evolutionary transition approach building on integrating working concepts following the evolutionary transition from the synchronous to the asynchronous classroom methodology shown in Figure 10.10.

10.4.2. The evolution from asynchronous to synchronous lecture formats

The evolutionary process was designed so that each step along the way provided a meaningful capability in itself as well as a baseline, so the conversion could take place at a comfortable pace. Consider the evolution from asynchronous to synchronous lecture formats. Moreover, since the development of the online version of MSWE617 was taking place in parallel to developing and delivering other asynchronous classes, each step was tested in the asynchronous classroom environment.

The starting point was the face-to-face class where in many instructors lecture from notes, and write and draw on the whiteboard in real time to enhance the spoken lecture. The first step in the transition is to put what would have been written on the whiteboard into presentation graphics that can be handed out to the students before the lecture begins. The time that the students spent on drawing and copying can then be spent on discussion and constructive learning.

At the same time, there are many instances when there is not enough time in the classroom to cover all the topics, or the discussion gets involved and has to be prematurely terminated because the three hours are up. Listserver technology[84] was used to enhance the discussions in 1999 by continuing them on-line in an asynchronous manner via e-mail. We could even use the Listserver to introduce new topics that were not covered in the classroom. Another use for the Listserver was to allow students who were shy about speaking in the synchronous face-to-face class, to post comments via the anonymity of the written communications medium. The presentation graphics for each lecture were also posted on the class web site. This saved sending files via e-mail and their possible rejection by e-mail host software as being too large for the system. It also provided an archive for students who lost their copy and to potential students the following semester who wanted to know about the class before enrolling.

The next major step of the transition process was to record the sound. This is simpler than it sounds[85]. Several readily available low cost software packages provide that capability[86]. The approach for recording a lecture is the same approach as that used for making it in the classroom. You go through the presentation and record what you would have said in the classroom. Unlike in the classroom, you can then review and edit it before the students get to experience it. The presentation is then placed on the web site for downloading, truly a lecture-on-demand.

10.4.2.1. The original plan

The plan was that the first and second iterations of MSWE617 would be traditional face to face-sections in the classroom; and the WebTycho class be designed using the lessons learned in those iterations. However, by the time the second iteration ran, several students in the programme had moved out of the local area and needed the class to graduate. Had the original plan been followed, those students would have had to delay their graduation by at least year while waiting for the WebTycho class to run. To avoid this situation, the plan was changed to allow the second iteration to be modified into a hybrid class[87].

A hybrid class proved to be an excellent way to mitigate the risk invoked by a totally WebTycho based class as it provided an opportunity

[84] Today's technology offers several options to transfer text messages between students and instructors.

[85] Pun intended.

[86] These days the recording functionality is built into cell phones and hand-held MP3 music players.

[87] We should have thought of this ahead of time.

for a side-by-side experiment between the face-to-face student teams and the distance mode student teams. The hybrid class was designed as follows:

- There would be several teams of four to five students, depending on the enrolment. At least one team would be a distance mode team accessing the class purely via WebTycho to cater to the students who had moved out of the area.
- Each milestone review would be presented using a mixture of synchronous and asynchronous techniques. The formal presentations would be done asynchronously, via WebTycho. This approach would allow all the teams to preview the presentations before the reviews.
- The discussions would be face-to-face and via WebTycho. This, and the asynchronous reviews for all teams, would allow the WebTycho teams to feel part of the entire class.
- The face-to-face teams had the choice of meeting face-to-face or using WebTycho and other non-face-to-face techniques.
- The WebTycho teams were prohibited from meeting face-to-face even though some team members would be in the local UMUC service area.

All students enrolling in the class that semester were offered the opportunity to select between the WebTycho and face-to-face sections and were assured that there would be no assessment penalty if the experiment failed. While there were really too few distant students to make up a viable team[88], enough local students chose the WebTycho option to form one WebTycho team.

10.4.2.2. Expect the unexpected!

After the plan had been finalised the instructor decided to relocate half way around the world. This meant that not only would there be distance-students; there would also be a distance-instructor. While distance-instructors were commonplace in the WebTycho classes, there hadn't been a distance-instructor in a face-to-face class: a major risk to the success of the class.

Drawing on the results of on-going research mitigated the risk. While in the process of converting other subjects in the MSWE programme from face-to-face to WebTycho and employing asynchronous PowerPoint enhanced audio lectures, it had been perceived, that from the *Generic* perspective there was very little difference between a classroom and a conference session. Distance mode conference presentations had been

[88] Was it worth the effort for those few students? Yes, the students came first.

made with the aid of the session chair (Kasser, 2000a). Using this perception, it was hypothesized that if the instructor was considered as a distance mode presenter, all that was required was a session chair to be present in the classroom to facilitate the face-to-face milestone review meetings. So a session chair was appointed in the guise of a teaching assistant acting in the two areas of activity associated with the class. The first area was in the running of the hybrid classroom. The second area was in the continual development of the class to make it function entirely in the WebTycho environment in future. In particular, the teaching assistant had the following duties:

- Help develop the student project ideas by interviewing potential clients within the University.
- Act as a single customer interface between students and university staff to minimize impact on staff workload while students were developing the software.
- Assist with recording student presentations as necessary.
- Represent the instructor in face-to-face meetings as appropriate.
- Monitor the class with the goal of being able to assume the role of (back-up) instructor in the following iteration.
- Assist in developing and testing techniques for use in WebTycho classes in conjunction with UMUC research grant applications.
- Assist in developing a model for future instructor/teaching assistant roles in the hybrid classroom.

The modified plan for the hybrid class was that the instructor would "lecture" in the asynchronous mode as planned. However, instead of attending the face-to-face meeting in person, he would do it via distance mode, either using VOIP, or the telephone. He would phone in at a prearranged time and talk to the students.

10.4.3. The results

The results exceeded expectations. After some early equipment problems with the communication links at UMUC, the class was a success. The project products were produced on schedule just as in the prior face-to-face section of the class and there was little difference between the performance of the WebTycho team and the other teams.

The session chair did a great job both as a teaching assistant and as an "IT Technician". We both put in many extra hours to make the class work, some planned, and many not planned. After an initial high volume of e-mail to clarify the situation to all concerned, the volume settled down to a thin trickle and the pressure was off[89].

With respect to the milestone review meetings, the distance instructor's feelings after the first one were that he was not needed; the session chair had everything well in hand. After the second session, he really was not needed. When he telephoned in, the main question the students had was deciding when the class would meet next. He stayed on-line at the end of the VOIP link for a while, but was not needed. Since it was a hybrid class, the WebTycho team were asked if they wanted the Milestone reviews to be live on-line (synchronous) using chat room technology. Their response, in the main, was negative. They preferred the asynchronous approach, in which questions and points raised at the face-to-face meeting were posted in WebTycho after the meeting had ended. There became no need for the instructor to "attend" the meetings, and then when the technology failed for a short period of time, his absence didn't seem to make any difference.

The software produced by the students was not just an academic exercise. The software performed useful functionality. The most difficult aspect of creating the class was to size the problem so the software to provide the solution could be created during the course of a single semester. The UMUC administrative and teaching staff were the customers for the standard projects, however students could propose their own programs if they could talk their team into working on it. Software projects in the first two iterations of the class (1999 and 2000) included those whose descriptions, as provided to the students, are quoted herein. They were:

1. The Farleyfile discussed in Section 10.4.3.1.
2. The Webconference discussed in Section 10.4.3.2.
3. Deskcopy discussed in Section 10.4.3.3.
4. The supply order system discussed in Section 10.4.3.4.
5. Student evaluations discussed in Section 10.4.3.5.
6. The Webforum which ran twice and produced two operationally equivalent web sites using two fundamentally different software technologies discussed in Section 10.4.3.6.
7. The Advance Team Scheduling System (ATSS) discussed in Section 10.4.3.7.

When reading about the examples, remember that the software was produced in 1999 and 2000 when the software was innovative.

[89] When things go as planned and no issues arise, then nobody realized how much effort was put into preventing those issues from arising in the first place.

Figure 10.11 MSWE617 celebration cake

One other innovation was produced by the students. The last class session was also a small celebration and the students produced the cake emulation of a computer shown in Figure 10.11. The innovation however was limited to the students in the classroom since the distance students and distance instructor were unable to partake of the cake.

10.4.3.1. The Farleyfile

The description provided to the students was as follows:

- Faculty advisors need an online information system to document communications with students. This package needs two databases.
  - A common database on a server accessible to all faculty advisors. Each advisor would be able to read and write but not delete information in the database.
  - A private database located on the faculty member's own computer.
- The functionality needed in the program is the ability to store student photographs, email and telephone contact details, import and send emails, accept manual entries, automatically tag entries by advisor's name and date, and access student information by name and student number.

10.4.3.2. The Webconference

The description provided to the students was as follows:

- Distance education is becoming increasingly important. While much of the work in on-line classes is done in an asynchronous mode, often times, students and instructors need to talk in a synchronous mode while in the virtual classroom. This project is to develop the software that will allow a specific named group of people to talk to each other using VOIP in a synchronous mode. Each software package will contain two lists of contacts: one for the other people or students the person running the package wishes to connect with, and the second list of those people whose calls will be accepted. When a connection is initiated and accepted, the two people can talk over the Internet.

10.4.3.3. Deskcopy

The description provided to the students was as follows:

- The graduate school is always looking for new textbooks to keep its classes current. In addition, each semester we need to ensure that the instructors have current copies of the books well ahead of the semester. Given that each department may require 50-100 books for each semester, the co-ordination of this process is cumbersome and currently a manual process.
- The way the current system works is that when a Program Director locates a potential book, he informs the Book Monitor by means of a form stored on the Local Area Network (LAN). The form is completed manually and then delivered to the Book Monitor's office. The book monitor then faxes an order to the publisher. When the book is received, it is passed on to the Program Director, who may examine it, or in turn pass it on to the instructor of the class. Each semester the list of books that will be used for the given semester need to be complied via a desk copy request. We also request any other supporting texts such as solutions manuals etc. be forwarded at that time.
- The issue is that the Program Directors do this process manually. Often times, they fail to update the information when a new edition or International Standard Book Number (ISBN) number is released. Also, currently there is no tracking system in place, so we have no idea what the status of a particular book is, whether it has been ordered, if it is on its way, or if it has actually arrived. This project is to build a web accessible book database to gather the most recent book information via links to the publishers, create an electronic desk copy form, and devise a mechanism to monitor the status of the books ordered.

10.4.3.4. The supply order system

The description provided to the students was as follows:

- Currently there is a manual system in place for ordering supplies. When a department needs supplies, the administrative assistant looks the supply information up in a catalogue that is distributed each semester to the various departments within the graduate school. The needed list of supplies is then communicated to the Dean's office via a form, a post-it note, or a trip down to the office.
- We believe we need to automate this process. We need to have a way for the departments to be able to quickly access and order the supplies they need. In addition, the departments would be asked to review their supplies every month via an inventory sheet that will be made available on the web. The supplies will need to be tracked to determine an optimum on-hand supply list. Once this is determined, the supplies can then automatically be ordered based on their liquidation rates.
- A special mechanism would need to be in place for special orders as well.

10.4.3.5. Student evaluations

The description provided to the students was as follows:

- We strongly believe in using feedback gathered from the students in order to evaluate instructors. Currently, this presents a problem in the on-line environment. Students complete the evaluation; the evaluation information is then downloaded by our Information Technology department. Once this occurs, the information is emailed to an administrative assistant who runs the data through statistics analysis software. The problem is the format in which the data comes through creates an arduous process of reformatting the information to distribute to the departments in usable form. This information is critical and needs to be made available in days, not weeks to the Program Directors so that they can make staffing decisions. A more powerful reporting function should also be included to track and report on past semester information.
- This project would require an examination of the current process, suggestions of change that would accomplish what we need it to do in a timely manner. The final component is the sensitivity of the information related to the instructor's privacy. This in-

formation cannot be easily accessible by anyone other than Program Directors.

10.4.3.6. The Webforum

The description provided to the students was as follows:

- Methods of publishing new ideas have serious lag time associated with the delivery of information. Not only does it take a long time to get something published, the information is often outdated by the time the information is published. Technology has afforded an alternative to this situation. The innovation is the WebForum (Kasser, 2000b), a web site that hosts the publication of papers, asynchronous presentations, and discussions on topics of interest pertaining to the forum participants on a continuous basis. The WebForum is based on the WebConference (Section 10.4.3.2) (developed in MSWE 617 in Spring 1999 and used in CSMN 648 in Summer 1999) that operates continuously. Submissions are posted as and when received, rather than by a certain date as in the traditional conference. When the participant finds a presentation or paper on the topic of interest, they look at the ratings it received from participants who have already read or viewed it. They make a somewhat informed choice and download it. They then review it off-line. Next time they log into the WebForum, if they wish, they can add their rating and follow the discussion threads based on the presentation or paper. If they wish, they can then add a comment or pose a question to the participants.
- This project is to develop a WebForum for an upcoming conference. Students will be given sample papers to post. The project will require the design and implementation of such a WebForum.

10.4.3.7. The Advance Team Scheduling System (ATSS)

The Advance Team Scheduling System (ATSS) was a student-generated project for the Secret Service in the White House. The problem they faced was that scheduling of agents to accompany dignitaries on travel was performed on a white board. This software was to replace the white board and add functionality to remote access over a LAN via a web browser interface. The software would allow trips to be scheduled and edited, sites to be added, edited and deleted, and historical data to be archived and viewed. The students brought the server and client hardware into the face-to-face classroom at UMUC for the final session to demonstrate the working software.

10.4.4. Conclusions

The lessons to be learned from this anecdote are:

- Preparation and team work works wonders.
- A well-designed system runs itself.
- Students can achieve remarkable results.
- Distance mode can be used in the classroom in a hybrid style. This opens up opportunities for remote guest speakers and instructors.

The system was optimized at the interfaces for low coupling between the subsystems and high coupling within the subsystems as recommended in Section 7.8.7. This provided a great deal of flexibility and successful speedy adaptation to the changing circumstances.

The hybrid section of MSWE 617 pushed the envelope, not only in the teaching area, but also in the area of on-line collaborative working in geographically distributed groups. The success of the experiment resulted in a template for a WebTycho only section of MSWE 617, as well as a potential solution to UMUC and other postgraduate institution's universal staffing problem in the area of software engineering.

10.5. The apartment dwellers' amateur radio antenna system

This anecdote is an example of how adapting the problem-solving process is but the first step in creating the best FCFDS. The anecdote starts with a non-holistic thinking approach which satisfices the undesirable situation, the anecdote then looks at the situation from the perspectives perimeter and shows how holistic thinking produced a better solution.

This is another anecdote about Fred whose hobby is amateur radio. Unfortunately he lived on the top floor of a low-rise apartment building and couldn't install a decent antenna on the roof which to him was an undesirable situation. He wanted to transition to a FCFDS which he defined as being able to operate his station and make contacts with other radio amateur stations around the world.

Use the process mentioned in Section 1.1 to study the anecdote, especially if you are not familiar with radio communications, to pick out the pertinent points from the details.

10.5.1. The non-holistic thinking approach

Using the non-holistic thinking approach, Fred defined his solution as installing an antenna[90] that would allow him to contact other amateur radio stations around the world and his problem as choosing the best antenna possible given the constraints of his situation.

10.5.1.1. Solution options

The first problem-solving activity was to determine what kind of antennas could be used from a window. This activity provides the solution options. After some research in the literature he identified the following candidate antennas:

1. Mobile whips which are designed for cars and work reasonably well.
2. Fiberglass fishing poles which can be used to support vertical wires at night if the balcony is high enough. A length of wire can also be wrapped around the fishing pole for daytime use.
3. Loops which are directional broadside to the loop.
4. Random lengths of wire which work well for local contacts but don't work too well for long distance contacts.

10.5.1.2. Constraints

The following constraints apply to all of the options so cannot be used as selection criteria.

- All of the solutions options require an Antenna Tuning Unit (ATU) to match the impedance of the antenna to the radio[91].
- The directions in which he will be able to transmit and receive signals will be constrained by the building. Fred can also expect that the building will absorb some of the radio signals.

In addition:

- Fred's apartment is not high enough to use the fishing pole solution, so he struck that option from the list.
- The loop would be fixed in window in the direction facing the window. This solution would be fine if Fred wanted to talk to people in that direction. But since it did not meet his initial desire for contacts in as many directions as possible, he struck that option from the list as well.

[90] Fred always works back from the solution.

[91] While a mobile whip can be tuned to match the radio and eliminate the ATU, it is much easier to use ATU to perform the matching when operating on a wide range of frequencies.

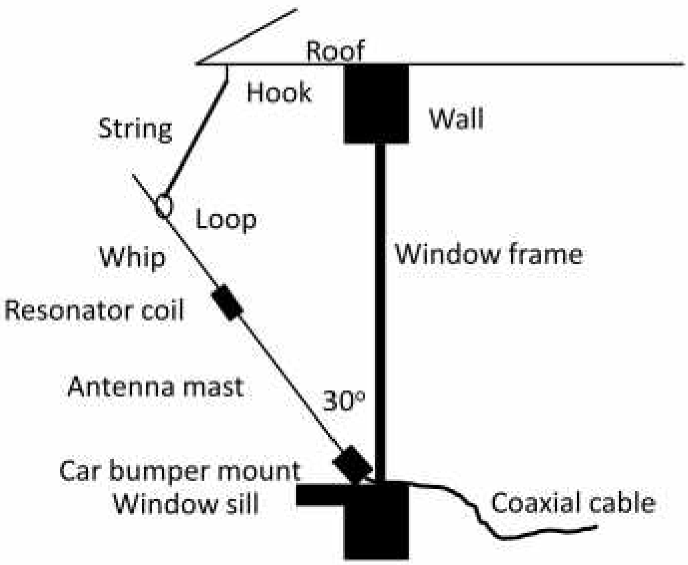

Figure 10.12 Fred's window antenna system

10.5.1.3. Solution selection criteria

Fred's solution selection criteria were:

- ***Invisibility or unobtrusiveness:*** a constraint imposed by his understanding landlord.
- ***Cost:*** the antenna had to be affordable.
- ***Easy to assemble and dismantle:*** if not a permanent fixture.
- ***Radiation pattern:*** Fred wanted an antenna that radiated the strongest signal to as many different local and distant locations as he could achieve under his circumstances. This criterion eliminated random lengths of wire from the list of candidate solutions.

Fred looked into the costs of the remaining option. He had a mobile whip car antenna which he used on vacation trips so using this antenna would only incur any additional cost of the mounting hardware. So he decided to try the mobile whip mounted on his windowsill before spending any money, in engineering terms, to prototype some experiments. He began by screwing a small hook into the underside of the roof and tying a length of string with a loop on the other end to the hook. He inserted the mobile antenna (mast, resonator coil[92] and whip) through the loop and rested the bumper mount on the windowsill. He adjusted the length

[92] Which provides the resonance for the various amateur radio bands.

of the string until the antenna was leaning at an angle of about 30 degrees away from the vertical position and cut the string to that length. Lastly he connected the antenna mount to the window frame using a clip lead and ran the coaxial cable connection via the ATU into radio into the room[93]. The window components of the system are shown in Figure 10.12. When he tried to make a few contacts with other radio amateurs, he found that the antenna worked and Fred was satisfied.

10.5.1.4. Discussion

Fred had adapted the problem-solving process. He identified the undesirable situation, the FCFDS and a solution. He then identified a number of options for the solutions, developed the solution selection criteria and discarded solutions that failed the selection criteria as soon as that fact was established. He made his selection, and was satisfied. Was his solution correct? The answer is, it depends! The solution worked so it was acceptable (Section 9.6), but was it the best solution he could have implemented? He did not know. Holistic thinking would have helped him answer these questions as discussed in the next section.

10.5.2. The holistic thinking approach

The holistic thinking approach takes a wider perspective by perceiving the antenna as part of a system[94]. Perceive the situation from the following perspectives on the perspectives perimeter.

1. The *Big Picture* perspective discussed in Section 10.5.2.1.
2. The *Operational* perspective discussed in Section 10.5.2.2.
3. The *Functional* perspective discussed in Section 10.5.2.3.
4. The *Structural* perspective discussed in Section 10.5.2.4.
5. The *Quantitative* perspective discussed in Section 10.5.2.5.
6. The *Scientific* perspective discussed in Section 10.5.2.6.

10.5.2.1. The Big Picture perspective

Perceptions from the *Big Picture* perspective indicate that amateur radio is a worldwide hobby pursued by more than 1,000,000 people[95] whose activ-

[93] He connected a grounding wire to the radiator in the room, assuming the hot water pipe would provide a connection to ground.

[94] A similar approach was used to dissolve the Pacor panic attack described in Section 11.1.

[95] The number was obtained from the *Quantitative* perspective but fits into the *Big Picture* perspective in this instance to quantify the description.

ities include talking to other radio amateur stations around the world via short wave radio[96].

10.5.2.2. The Operational perspective

Perceptions from the *Operational* perspective indicate that there can be many conversations on any amateur band at any time of the day when the ionosphere refracts sky wave radio signals back to earth on that band. The factors that limit the establishment of a conversation include the strength of the received signal and the amount of man-made (QRM) and natural noise (QRN) interference at the other end of the radio link as shown in Figure 10.13.

10.5.2.3. The Functional perspective

Perceptions from the *Functional* perspective indicate that the functional system can be split into three subsystems, a:

1. Transmitting function which generates and transmits the radio signal.
2. Propagation function which conveys the radio signal from the sending station to the receiving station.
3. Receiving function which receives the radio signals and converts them to sounds.

10.5.2.4. The Structural perspective

Perceptions from the *Structural* perspective allocate functions to the physical components as follows where the:

- Transmitting function is performed by the radio transmitter and the antenna[97].
- Propagation function is performed by the ionosphere.
- Receiving function is performed by the radio receiver and the antenna[98].

Most amateur radio stations use antennas that are fixed at a height above ground; a height that is determined by the placement of the antenna, either mounted on a tower or supported in some way from poles, buildings etc. This means that the antenna radiates at a specific vertical angle which might not be the optimum for a specific contact at a specific

[96] Other activities include technical experimentation and research, as well as providing communications functionality during and immediately after emergencies such as earthquakes, tsunamis and volcanic eruptions.

[97] For this simple analysis, the Antenna Tuning Unit (ATU) is considered a part of the antenna subsystem.

[98] The same antenna is generally used for both transmitting and receiving.

distance due to the geometry of the path of the link. Fred's antenna is mounted on the windowsill and supported by a string from the roof which means that he can change the vertical angle of radiation by changing the angle of the antenna with respect to the vertical. For example, if he lowers the antenna until it is horizontal it will radiate straight up. If he raises the antenna until it is vertical it will radiate horizontally. The antenna has:

- ***Directivity:*** depending on its length, shape and height above ground. The directivity is in both the vertical and horizontal planes and can be positive, that is increase the signal, or the directivity can be negative, that is decease the signal in any direction.
- ***Polarization:*** radiates/receives vertically or horizontally polarized signals depending on its alignment with the horizontal ground.

10.5.2.5. The Quantitative perspective

Perceptions from the *Quantitative* perspective indicate that the transmitted or radiated power is a function of the combination of the transmitter power and transmitter antenna gain. In the radio amateur context radiated power is measured in decibels (dB) and 'S' units where one 'S' unit is 6 dB of Power. The relationship between dB, Power and 'S' units is shown in Table 10.8. A well-equipped radio amateur in many countries can operate a kilowatt transmitter using a directional antenna with a forward gain of perhaps 6 to 9dB. Assuming Fred has a well-equipped station and he can hear signals from another well-equipped radio station at S9 he can expect the other station to hear his signals at the same signal strength under normal circumstances. However, since Fred had a low powered station running less than 100 Watts to a mobile whip on his window frame, he would have a weaker signal at the other end of the link. What would the strength of Fred's signal be at the well-equipped station at the other end of the link? Consider the information in Table 10.9. 100 Watts is 10dB down on the 1000 Watts and the mobile whip antenna is also about a generous 10dB down on the directional antenna, so Fred's signals would be about 20dB down or about 3.5 'S' units which works out to about S6. If Fred's S6 signal can override the natural and man-made noise at the other end of the link, as shown in

Table 10.8 Relationship between dB, Power and 'S' units

dB	Power	S units
3	2 x	
6	4 x	1
9	8 x	
10	10 x	
12	16 x	2
15	32 x	
18	64 x	3
20	100x	
21	128 x	
24	256 x	4

Figure 10.13, Fred will be able to speak to the station at the other end of the link which is why Fred's prototyping experiment worked.

However, there are other factors that affect the signal strength at the other end of the link, including:

- The antennas at each end of the link have some directivity and polarization.
- The geometry of the propagation path between the two stations.
- The rotation of polarization of the signal in the ionosphere.
- The amount of interference from natural (QRN) and man-made (QRM) sources.

Table 10.9 Power and 'S' units

Power	'S' units
1024 Watts	S9
256 Watts	S8
64 Watts	S7
16 Watts	S6
4 Watts	S5
1 Watts	S4
0.25Watts	S3

10.5.2.6. The Scientific perspective

Without going into the details which are available in the relevant domain text books, Fred ought to be able to change the directivity and polarization of his signal by raising and lowering his antenna (the hypothesis). He can do this by changing the length of the string[99], and instead of tying it to the hook in the roof as shown in Figure 10.12, he can run the string through the hook and into his operating position. When he raises and lowers the antenna, if he is lucky[100], he increases his signal strength at the other end of the link and improves the probability of making a contact and speaking with the other station.

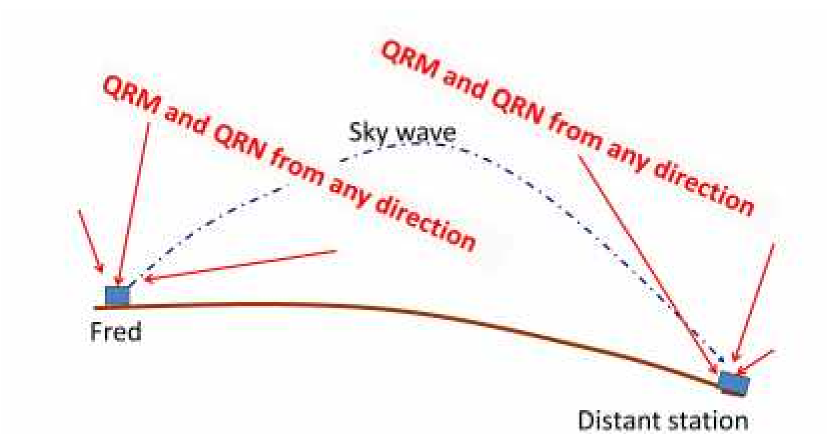

Figure 10.13 Factors affecting radio communications links

10.5.3. Testing the hypothesis

Meanwhile Fred was getting a little frustrated. He was able to contact a few stations but much of the time, when he called someone else, they answered a call from a different person. So Fred could hear many other stations but could only speak to a few of them. Eventually Fred decided to do something about increasing the number of contacts he could make. He realized that the only thing he could change was the angle of the mobile whip with respect to the vertical window and so he extended the string and converted his workable solution to a better one. In many instances the angle made a difference and Fred was able to talk to many more people than before. Had he practiced holistic thinking, he would have arrived at his better antenna sooner. In this instance, Fred lucked out; all he had to do was change the angle of the mobile antenna with respect to the window.

10.5.4. Lesson learnt

Fred's non-holistic thinking solution, a typical engineering solution, provided a solution that worked (satisficed) but was not as good as it could have been had Fred initially used holistic thinking and an understanding the radio communications domain (domain knowledge) to build a better antenna.

10.6. Summary

This Chapter provided the following examples of the adaptation of the systems engineering approach to problem-solving mentioned in Section 9.15:

1. ***The C3I group morale issue*** discussed in Section 10.1 is an application of how SSM was applied in the context of the systems engineering problem-solving approach to identify an organizational problem in a government organisation and recommend an appropriate solution. The last part of the Case Study showed that SSM is a useful tool for gaining an understanding of certain aspects of situations but needs to be used within the context of holistic thinking.
2. ***The Multi-Satellite Operations Control Center (MSOCC) data switch replacement project*** discussed in Section 10.2 documented the way a soft systems approach was used to go beyond systems thinking and achieve a consensus on the system requirements in a situation with multiple stakeholders holding a plurality of views. The anecdote also described two sets of trade-off studies; the first for the solution system and second for the transition approach to upgrade the facility.

3. ***Developing an optimal classroom teaching and learning environment*** discussed in Section 10.3 provided an example of how easy it is to make the wrong decisions if there is insufficient information or lack of domain expertise in the project team.
4. ***Creating and guide a successful student software engineering project class when the instructor is halfway around the world*** discussed in Section 10.4 used the evolutionary build-a-little-test-a-little process coupled with optimising the interfaces between the subsystems to provide a great deal of flexibility and a successful agile adaptation to the changing circumstances.
5. ***The apartment dwellers' amateur radio antenna system*** discussed in Section 10.5 is an example of how adapting the problem-solving process is but the first step in creating the best FCFDS. The anecdote started with a non-holistic thinking approach which satisficed the undesirable situation, the anecdote then perceived the situation from the perspectives perimeter and showed how holistic thinking produced a better solution.

Each Case Study/anecdote provides examples of aspects of finding innovative solutions to complex problems such as where things went correctly and where and how things can and did go wrong. The common denominator in each of the examples is that rather than follow the book, in each Case Study/anecdote the methodology was adapted, or should have been adapted, to fit the situation.

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11. Innovative insights and solutions

This Chapter provides macro and micro examples of perceiving several issues/systems from various points on the perspectives perimeter for different purposes, the insights obtained and the resulting innovative solutions. While the *Functional* and *Operational* perspectives provide an understanding of the situation, the ideas behind the innovative solutions generally came from the progressive perspectives. The perceptions from the perspectives perimeter trigger key questions that require domain knowledge to provide the remedy to the problem. The issues/systems discussed in this Chapter are from a number of domains in different degrees of complicatedness and complexity to help you to relate to one or more of the stories and provide knowledge that may be applicable in your "box".

1. The NASA GSFC Pacor Panic Attack discussed in Section 11.1.
2. An alternative teaming approach for Small and Small Disadvantaged Businesses in certain types of government contracts discussed in Section 11.2.
3. Redrawing the contractor-sub-contractor boundaries in certain types of Defence contracts discussed in Section 11.3.
4. Addressing the problem of vertically integrating Taiwan's small and medium sized enterprises discussed in Section 11.4.
5. Determination of a set of risk-indicators to predict project failure discussed in Section 11.5.
6. Dealing with the ALSEP Command Verification Word (CVW) Failure discussed in Section 11.6.

Use the process mentioned in Section 1.1 to study each anecdote, especially if you are not familiar with the domain and pick out the pertinent points from the details.

11.1. The NASA GSFC Pacor Panic Attack

Once upon a time, actually in the mid 1990's the Packet Processor Data Capture Facility (Pacor) at the NASA GSFC was in the middle of a facility upgrade. Pacor's mission was collection and storage of data received from spacecraft in near Earth orbit. Pacor's architecture was in transition from a minicomputer-based system to a client-server open architecture network system.

Pacor contained two systems Pacor 1 and Pacor 2. Pacor 1 was the operational system containing two minicomputer-based systems, Pacor A and Pacor B, where Pacor A was the operational system and Pacor B was the spare and used for software maintenance. Pacor 2 was the new open architecture network based system under development. The plan for support of spacecraft on orbit was:

- Current spacecraft to be supported by Pacor's 1 and 2.
- Future spacecraft to be supported by Pacor 2.

One day Pacor's management personnel identified a risk that Pacor might not be able to support the then operational spacecraft before the transition would be completed. The risk had to do with the aging minicomputer hardware in Pacor 1. The reliability data projected a statistical probability of a permanent failure of Pacor 1 within 12-18 months (*Quantitative* perspective), while Pacor 2 was not scheduled for completion for at least another 24 months (*Temporal* perspective). Moreover, the manufacturer had discontinued the production of the minicomputers several months earlier[1] so spares were unobtainable (*Big Picture* perspective). Pacor's manager was thus faced with an estimated probability of a temporal window of 6-12 months in which Pacor could fail to meet its spacecraft support requirements; definitely an undesirable situation.

11.1.1. The non-holistic thinking approach

The non-holistic thinking approach to dealing with the undesirable situation produced two options:

1. ***Absolve the problem or do nothing:*** the prediction that Pacor 1 might fail to meet its spacecraft support requirements if enough of the system hardware were to fail was based on statistics and there was a probability that the hardware would in fact not fail. However, if nothing was done and Pacor 1 failed, the Principal Investigators (PI) would lose their experimental data and become exceedingly unhappy with dire consequences for the Pacor manager.
2. ***Begin crash development of a Pacor 1 temporary replacement:*** this would be
    1) ***Costly:*** estimated at about $2,000,000, and would only be a temporary solution.

[1] This was a time when minicomputers were being replaced by cheaper and faster microcomputer based workstations.

2) Risky: it might not be completed in time, and since it would compete with resources for the Pacor 2 development, it would delay the Pacor 2 development.

11.1.2. The holistic thinking approach

The holistic thinking approach went beyond systems thinking considered the problem in context as a part of a Metasystem[2] and produced the following key questions:

- "What is the expected lifetime of the spacecraft currently supported?" (*Temporal* perspective)
- "What external sources of spares are there for Pacor 1?" (*Big Picture* perspective)

The answers provided the insight for the innovative solution. After some research, it was found that:

- The orbits of the spacecraft supported by Pacor 1 were expected to decay to the point where the spacecraft re-entered the Earth's atmosphere within 12 months. The orbital physics were such that the 12 months was a maximum value and excessive solar activity would shorten the lifetimes.
- There were a number of minicomputers of the type used in Pacor 1 available in the secondary (pre-owned or used) computer market suppliers.

These findings meant that there was no need to panic. The recommended innovative solution was to purchase a previously owned computer (to be designated Pacor C) for about $500,000. Pacor C would be used as an operational spare and for maintenance software development. The availability of Pacor C would also relax the Mean Time To Repair (MTTR) the minicomputer in Pacor 1 in event of a hardware failure in Pacor A or Pacor B and provide support in the very unlikely situation that the current spacecraft operational lifetime would stretch beyond the predicted maximum of 12 months. This recommendation produced an estimated cost saving of $1,500,000 in hardware costs alone.

In addition, there was no need to support the current spacecraft in Pacor 2 which serendipitously reduced the scope of the Pacor 2 software development effort which would contribute to an earlier completion date.

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[2] Similar to the approach described in the apartment dwellers' antenna system in Section 10.5.2.

11.2. An alternative teaming approach for Small and Small Disadvantaged Businesses in certain types of government contracts

This Section shows how going beyond systems thinking provided the key questions that were instrumental to the success of a doctoral research study and also provided some innovations.

Use the process mentioned in Section 1.1 to study the anecdote, especially if you are not familiar with the domains and pick out the pertinent points from the details.

Systems Engineering and Technical Assistance (SETA), Business Process Reengineering (BPR), software and hardware engineering, and other consulting, advisory and assistance types of contracts are low-capital-cost knowledge-intensive types of work. In the early 1990's the US government tended to award these contracts under the terms of 'full and open competition' to large businesses. Perceiving the situation from the *Generic* perspective many Small and Small Disadvantaged Businesses (SDB) had the capability to perform these types of activities and could have formed strategic alliances in the form of virtual corporations to compete for these low-capital-cost knowledge-intensive awards against the large contractors (*Structural* perspective). Such alliances or virtual organizations could provide lower cost products coupled with the socioeconomic benefits of the Set-Aside programs. However, as these strategic alliances were not being formed at the time, the research question investigated was *why weren't they teaming?* (Kasser, 1997a).

The literature review and preliminary research identified 13 hypotheses (answers) to the research question (*Scientific* perspective), so applying the *Quantitative* perspective, there would have to be 14 questions on the survey asking if the responder agreed (supported) or disagreed (refuted) the statement (hypothesis)[3]. In addition the survey would be at least two-pages long since the SDBs were being parameterized in the following categories:

- Size in several ranges.
- Revenues in several ranges.
- Age of company in several ranges.
- 8(a) or non 8(a) where 8(a) is a Federally-certified minority and woman-owned businesses.
- Woman or non-woman owned.
- Prior or no prior government contracting experience.

[3] The option for 'other' to be filled in by the recipient made up the 14th question.

- Member of the Armed Forces Communications and Electronics Association (AFCEA).

11.2.1. The difficult problems

When scoping the effort to provide an answer to the research question, the difficult problems identified included the following:

1. How to get responses from US Government and contractors (Large, Small and Medium Enterprises) discussed in Section 11.2.1.1.
2. How to get sufficient responses from the survey discussed in Section 11.2.1.2.
3. How to deal with expected small sample sizes due to few responses[4] discussed in Section 11.2.1.3.

11.2.1.1. How to get responses from US Government and contractors (Large, Small and Medium Enterprises)?

The personnel were busy and could be expected to ignore doctoral students. This was a potential showstopper because if the cognizant personnel would not respond to questions, the research could not take place.

The key question came from the *Generic* perspective and was, "*Who do contracting officers and contractors speak with?*" The answer was 'Small and SDBs'. The way to tackle the problem was to become a Small Business. So the researcher formed a Delaware Corporation electing Subchapter C of the Internal Revenue Service Code. The approach allowed the researcher to receive the Commerce Business Daily (CBD), request copies of government issued Requests for Proposals (RFP) and bid as an individual and as part of a team in response to RFPs in Small and SDB Set Aside opportunities.

11.2.1.2. How to get sufficient responses from the survey?

A that time, a normal response was estimated as being <=3% (*Quantitative* perspective).

The key question came from the *Generic* perspective and was, "*what communications media is viewed as important (responded to)?*" Being 1996, the answers were facsimile (FAX) and face-to-face personal contact. These answers suggested the way to distribute the survey and resulted in[5]:

[4] Conventional statistics does not work with small sample sizes.
[5] Without follow up reminders to non-responders.

- ***Sending surveys by Fax:*** 391 sent, 81 received, for a 21.5% response rate. Some faxed responses were received within 24 hours; the first response came within 2 hours.
- ***Personal contact:*** 45 handed out at association meetings, 30 responses were received for a 66% response rate.
- ***Serendipity:*** cost savings. Since a fax cost the same as a local telephone call[6], the cost to fax a two-page questionnaire was significantly less than the cost of paper, a dollar as token of appreciation, envelopes, postage stamps and self-addressed stamped envelopes for return post.

11.2.1.3. How to deal with small sample sizes due to few responses?

Normal statistics are not valid for small sample sizes so an alternative approach would have to be found. **The key questions** which came from the *Quantitative* perspective were:

1. "Do the 13 hypotheses need to be ranked?" discussed in Section 11.2.1.3.1.
2. "What is the required level of confidence in the data?" discussed in Section 11.2.1.3.2.
3. "What is the relationship between sample size and level of confidence?" discussed in Section 11.2.1.3.3.

11.2.1.3.1. "Do the 13 hypotheses need to be ranked?"

The answer was negative because of the way the research was framed (boundary). Framing the research problem to avoid ranking the hypothesis simplified the survey by eliminating the need for the respondent to do Pair Wise Comparisons (PWC) or other ranking approaches.

11.2.1.3.2. "What is the required level of confidence in the data?"

Research into statistics indicated that the answer was 0.95 for standard statistics (Downie and Heath, 1959).

11.2.1.3.3. "What is the relationship between sample size and level of confidence?"

This question provided the key to the innovation. Research into statistics indicated that the relationship is expressed in the following equation (Downie and Heath, 1959):

$$n=(z^2 * \sigma^2)/H^2$$

Where:

[6] The cost was zero because the monthly telephone service charge included unlimited local calls.

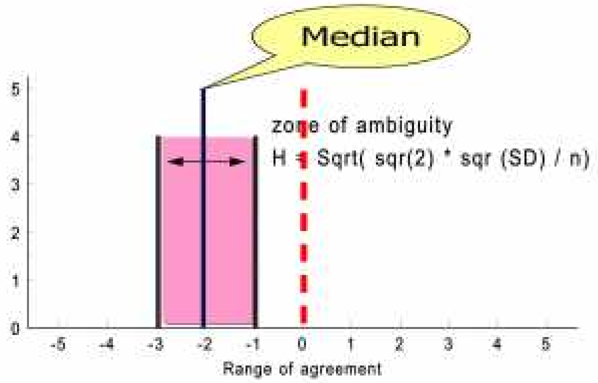

Figure 11.1 Zone of ambiguity

n = sample size.
z = level of confidence factor (for a 95% level of confidence, z = 1.96).
σ = estimated Standard Deviation (square root of the variance) of the data.

H = accuracy of the estimate (±).

The equation was rearranged to provide a zone of ambiguity (± accuracy) on the median (the innovation) namely:

$$H=\sqrt{(z^2 * \sigma^2/n)}$$

Since the sample size is the number of responses to the questionnaire, the equation could provide three results for each hypothesis.

- ***Supported:*** if value of the Median is positive and the zone of ambiguity does not overlap the zero line, i.e., (Median>0) and (Median-H)>0.
- ***Refuted:*** if value of the Median is negative and the zone of ambiguity does not overlap the zero line, i.e., (Median<0) and (Median+H)<0.
- ***Ambiguous (no clear result):*** if the value of the Median is zero or the zone of ambiguity overlaps the zero line when overlaid on the median, i.e., (Median=0) or (Abs(Median)<H).

For example, as shown in Figure 11.1 where for a given sample size H=2. If the Median of the responses is more positive than +2 the hypothesis is supported. If the Median of the responses is more negative than -2 the hypothesis is refuted. If the Median of the responses is somewhere between -2 and +2 then there is no clear result. In the figure the zone of ambiguity around the median does not overlap the zero, so

Company age	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13
1991 - 1996	S	S	S		S	E	S	S	S	S	S		S
1986 - 1990			S	S	S	S	S	S	S				R
1981 - 1985		S	R	R	E	R	S		S	S		R	R
Pre 1981	R	S	E	S	R		S	R	R	S	R		R

Primary	
S	Support (>50%)
R	Refute (>50%)
	Ambiguous
Secondary	
E	Even [S=R] (±2%)
C	Complacent [0] (>50%)

- Q1 Government regulations are too complex
- Q2 The Government is not interested in dealing with a team of small businesses
- Q7 Government "bundling of contracts" excludes Small and SDBs from competing, so why waste resources
- Q11 My company can handle the whole contract Q12 The right opportunity has not come along
- Q13 We never thought about it

Figure 11.2 Results by Company Age

Employee size	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13
1-10	S	S	S	S	S	S	S	S	S		R		R
11-25	S	S	S	S	R	R	S	S	S	S	R	R	R
26-50	E	S			S	S	S		S	S		E	R
51-100		S					S		E	R			R
101+	R	S	R	R	R	R	R				E	E	R

- Q5 Teams of small businesses will not be perceived as being credible, so why bother
- Q7 Government "bundling of contracts" excludes Small and SDBs from competing, so why waste resources
- Q9 The time delay between submitting the proposal and the award date
- Q10 Other Small and SDB owners are not easy to work with
- Q11 My company can handle the whole contract
- Q13 We never thought about it

Figure 11.3 Results by Company Size

the result is unambiguous on the negative side of the X-axis, namely the hypothesis is refuted.

The results showed trends in the data even though there were no clear results in some parameters. Typical results are shown in Figure 11.2 and Figure 11.3. Support (S) and Refute (R) can be clearly seen for some of the hypotheses (questions) and subsets of the Small and SDBs while the grey areas show no clear results. Even then, changes in the responses as a function of the subsets can be clearly seen in some instances. For example, the response to Q1 in Figure 11.2 changes from support for new companies to refute for companies that have been in business for more than 15 years. Since Q1 was 'Government regulations are too complex', we can infer that the findings reflect that a learning curve may be in operation. Other results such as the responses to Q4 in Figure 11.2 and Q8 in Figure 11.3 need further data. In the event that such further information had been needed about a question or subset of the SDBs, a follow up survey could have been performed.

11.2.2. The outcomes

The responses to the key questions allowed the research to continue and provided an innovative way of obtaining usable data from small sample sizes.

11.3. Redrawing the subcontractor boundaries in certain types of Defence contracts

This Section contains an example of using holistic thinking in the mid 1990's to go beyond systems thinking and develop a hypothesis (*Scientific* perspective) that redrawing business boundaries (*Structural* perspective) could simplify and lower the cost of the Small and SDB Set Aside contracts (*Quantitative* perspective) in the US Government contracting process while retaining the socio-economic benefits to society for certain types of contracts.

Use the process mentioned in Section 1.1 to study the anecdote, especially if you are not familiar with the domains and pick out the pertinent points from the details.

11.3.1. Framing the problem

The problem was framed as follows:

- ***The undesirable situation:*** providing socio-economic benefits to Small and SDBs was increasing the cost of government contracts[7].
- ***The FCFDS:*** providing socio-economic benefits to Small and SDBs <u>without</u> increasing the cost of government contracts.
- ***The problem: was to create the FCFDS.***
- ***The solution:*** was to be conceptualised or hypothesized.

11.3.2. Perceptions from the perspectives perimeter

Perceive the situation from the perspectives as follows:

[7] However, contractors on cost plus contracts did not find the situation undesirable since they received a percentage of the costs passed through to the Small and SDBs.

1. The *Big Picture* perspective discussed in Section 11.3.2.1.
2. The *Operational* perspective discussed in Section 11.3.2.2.
3. The *Functional* perspective discussed in Section 11.3.2.3.
4. The *Structural* perspective discussed in Section 11.3.2.4.
5. The *Generic* perspective discussed in Section 11.3.2.5.
6. The *Quantitative* perspective discussed in Section 11.3.2.6.
7. The *Temporal* perspective discussed in Section 11.3.2.7.
8. The *Scientific* perspective discussed in Section 11.3.2.8.

11.3.2.1. The Big Picture perspective

Perceptions from the *Big Picture* perspective indicate that a Defence contractor performing SETA and other low-capital-cost knowledge-intensive activities constitutes a complex system. In the US, in 1995 or so, the system was even more complex due to the Federal Acquisition Streamlining Act (FASA) of 1994 which had established a 5% Small and SDB Set-Aside goal for civilian agencies[8]. However, the socio-economic benefits of these goals were hard to achieve.

11.3.2.2. The Operational perspective

Perceptions from the *Operational* perspective indicate that while the agencies required prime contractors to propose subcontracting plans, overall they did not seem to follow up on the plans and require compliance. In such circumstances, the plan was an element to be checked off for the proposal and subsequently forgotten.

11.3.2.3. The Functional perspective

Perceptions from the *Functional* perspective indicate that there are overlaps between the functions performed by the contractors and subcontractors.

11.3.2.4. The Structural perspective

Perceptions from the *Structural* perspective indicate that:

- The traditional Multiple-Award-Task-Ordered (MATO) contract award pool scenario is as shown in Figure 11.4 Several contractors bid on the Government's RFP and a selected subset qualifies for the award pool. The subset that qualifies then competes for individual tasks within the contract. Each contractor has its Small and SDB subcontractors as required by the contract. This arrangement:

[8] The situation today is unknown.

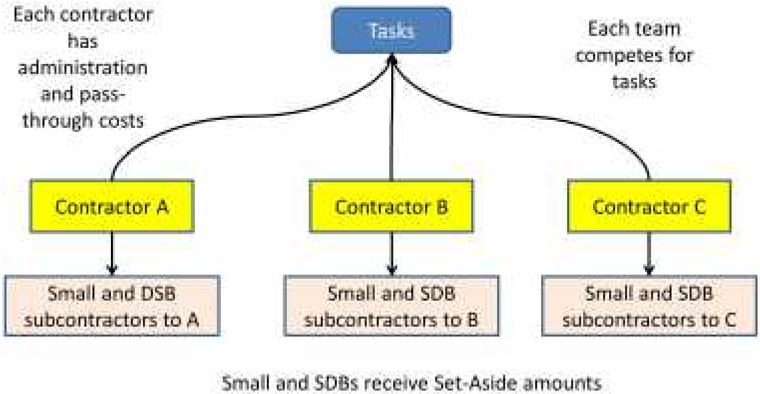

Figure 11.4 Traditional multiple award Set-Aside scenario

- Allocated the Small and SDB funding goals in a vertical manner. The Small and SDBs are below the large prime contractors in the hierarchy of the contract.
- Is a way of providing socio-economic benefits to the Small and SDB community.
- Loads the cost of the contract with the overhead to plan and administer the regulatory required Small and SDB subcontracts as well as the subcontract pass-through costs.
- Considers each contractor as a subsystem of the MATO contract (system), and the Small and SDBs as subsystems of the Contractor subsystems.

- The organizational structure of a consortium or strategic alliance of Small and SDBs performing these activities would be practically the same as the organizational structure of a large Defence contractor.

11.3.2.5. The Generic perspective

Perceptions from the *Generic* perspective indicate many Small and SDBs did the same kind of low-capital-cost knowledge-intensive types of work namely SETA, technical assistance, business process reengineering, software engineering, and operations support activities as the large contractors as mentioned in Section 11.2. Thus when large companies identified subcontracting partners there tended to be a degree of overlap between the activities each performed on the contract. This overlap provided the large prime contractor with the opportunity to squeeze the subcontractor out of as much work as possible.

11.3.2.6. The Quantitative perspective

Perceptions from the *Quantitative* perspective indicate that according to the US Small Business Administration (SBA) in 1982, studies had shown that small companies were more cost effective and innovative than large companies[9].

11.3.2.7. The Temporal perspective

Perceptions from the *Temporal* perspective indicate that by the mid 1990's:

- Concerns had been raised regarding the quality of the products provided by Set-Aside contracts. These concerns were so serious that the whole Set-Aside program had been questioned. As a result, the DOD went as far as suspending its (rule of two) SDB Set-Aside program in October 1995.
- The US Government had begun to award MATO contracts in an attempt to obtain quality products at reduced cost by removing the monopoly effect present after a single contractor won a multiple year award.

11.3.2.8. The Scientific perspective

Insight from the *Scientific* perspective infers a hypothesis that one conceptual FCFDS would be for Small and SDBs to form strategic alliances in a MATO contract environment to compete for these contracts. Such strategic alliances could provide socio-economic benefits to Small and SDBs while reducing the cost of government contracts by:

- Providing the Small and SDB team partners with more work than the overall Small and SDB set-aside percentage.
- Reducing the need for Small and SDB Set-Asides.
- Reducing the complaints of "unfair" by non-SDBs.
- Providing the Government with lower cost work of equal if not better quality than large companies for these types of contracts.

As discussed in Section 11.2 with these apparent reasons to form strategic alliances, consortiums and teams, most Small and SDBs still, in general, tended to:

- Attempt to team with large companies in a prime-subcontractor relationship to meet the contractual Set-Aside requirements.

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[9] In 1982, there were 2.4 times as many small firm innovations as large firm innovations per employee according to the (SBA, 1982)

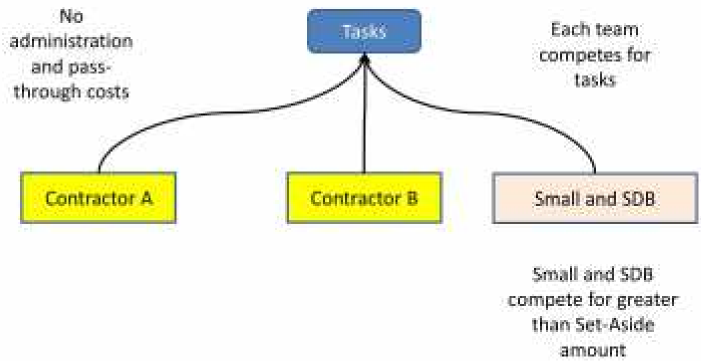

Figure 11.5 Alternative MATO Set-Aside scenario

- Concentrate their marketing efforts on Small and SDB Set-Aside contracts.

11.3.3. Redrawing the boundaries

Consider redrawing the organizational boundaries between the contractors making a change from the contractor-subcontractor relationship to a structure in which Small and SDBs joined in a strategic alliance to form a virtual large contractor with the following contractual changes:

- Make the guaranteed minimum for the procurement to the strategic alliance of Small and SDB contractors equal to the Small and SDB Set-Aside dollar amount.
- State that one or more awards will be made to a Small or SDB or alliance thereof.
- Completely remove the legal Small and SDB subcontract requirements from the RFP.
- Consider each contractor large or Small and SDB strategic alliance as a subsystem.

In this situation, arrangement of the large contractor and the Small and SDB contractors is the alternative arrangement shown in Figure 11.5.

11.3.3.1. Benefits of the alternative approach

The alternative approach reduces costs by eliminating the:

- Overhead costs to plan and administer the then current regulatory required Small and SDB subcontracts.
- Subcontract pass-through costs.

The alternative approach would also seem to provide the Government with a win-win situation from two perspectives, namely:

1. The Small and SDB perspective discussed in Section 11.3.3.1.1.
2. The large business perspective discussed in Section 11.3.3.1.2.

11.3.3.1.1. The Small and SDB perspective

Their performance would affect the cost of the contract as follows. If they were to be:

- ***Outstanding:*** Their technical approach and low cost would win them a larger percentage of the work. The Government would get more value added for each dollar spent, and the total amount spent on Small and SDBs would increase, helping the Agency meet its Small Business dollar goal in a cost-effective manner.
- ***Mediocre:*** They would receive the Set-Aside minimum percentage of the contract and some help in improving their performance.

11.3.3.1.2. The large business perspective

The cost of work would be lower for reasons which include reducing:

- ***Proposal preparation costs:*** by eliminating the need for the large companies to develop a subcontracting plan.
- ***Contract performance costs:*** by reducing duplicate management structures in each company, and eliminating the prime contractor's subcontract management functions.

In addition, outstanding Small and SDB performance would drive down the cost of the contract, with no reduction of quality, because either the Small and SDBs would capture all the work, or, the large businesses would have to improve to remain competitive.

11.3.4. Summary and conclusion

By going beyond systems thinking and perceiving the government contracting situation from the perspectives perimeter, one can infer that redrawing MATO contract contractor boundaries into an alternative set-aside approach may be a way to provide the socio-economic benefits to Small and SDBs without giving up quality or incurring additional costs in carrying out the Small Business regulations. Implementation of this approach would require a change to the Federal Acquisition Regulations.

11.4. The problem of vertically integrating Taiwan's small and medium sized enterprises

This Section goes beyond systems thinking by providing an example of Active Brainstorming the problem of vertically integrating Small and Medium Enterprises (SME) in Taiwan in 2008, to provide a recommended FCFDS that can be adapted for vertically integrating SMEs in any part of the world. While addressing a similar issue to that in Section 11.3, this example:

- Documents some of the key questions and responses.
- Conceptualizes a whole functional and purposeful solution to the problem of vertically integrating Taiwan's SMEs with minimal disruption to the working of individual SMEs.
- Develops a hypothesis for a conceptual solution.
- Provides recommendations for a pilot scheme to test the feasibility of the conceptual solution.

Use the process mentioned in Section 1.1 to study the anecdote, especially if you are not familiar with the domain and pick out the pertinent points from the details.

11.4.1. Framing the problem

The problem was framed as follows:

- ***The undesirable situation:*** In 2000 Taiwan's SME produced various products and services, many of them hi-tech items that were incorporated in the increasingly complex technical systems that underpin society. The SMEs were facing increasing local and global competition and had a desire to vertically integrate.
- ***The FCFDS:*** Profitable vertically integrated consortia of SME's.
- ***The problem:*** Since vertically integrated organizations need knowledge, skills and competencies that SMEs may not have, the problem was to:
    - Figure out a way of vertically integrating these SMEs and providing any missing knowledge and competencies.
    - Conceptualize a way of profitable quality products and services once vertically integrated.
- ***The solution:*** the FCFDS.

11.4.2. Perceptions from the perspectives perimeter

Go beyond systems thinking by perceiving the situation from the perspectives perimeter when this study was performed in 2008 and consider-

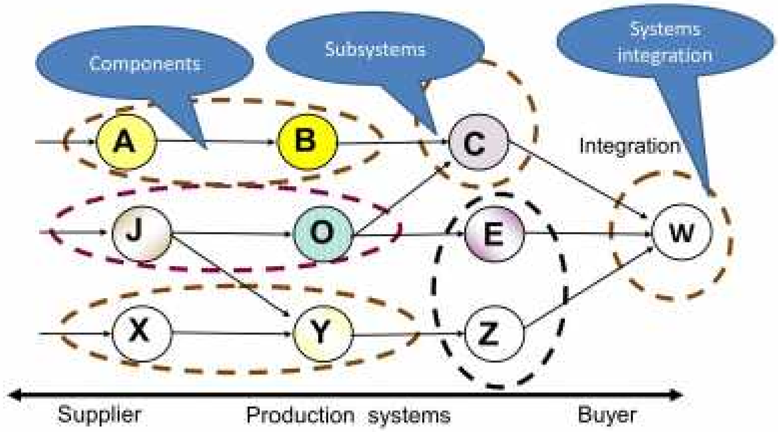

Figure 11.6 The value chain

ing the key questions and their responses to gain an understanding of the situation from the following perspectives:

1. The *Big Picture* perspective discussed in Section 11.4.2.1.
2. The *Operational* perspective discussed in Section 11.4.2.2.
3. The *Functional* perspective discussed in Section 11.4.2.3.
4. The *Structural* perspective discussed in Section 11.4.2.4.
5. The *Generic* perspective discussed in Section 11.4.2.5.
6. The *Continuum* perspective discussed in Section 11.4.2.6.
7. The *Quantitative* perspective discussed in Section 11.4.2.7.
8. The *Temporal* perspective discussed in Section 11.4.2.8.
9. The *Scientific* perspective discussed in Section 11.4.2.9.

11.4.2.1. The Big Picture perspective

The key questions and responses from this perspective are:

- ***What is driving the need for vertical integration?*** The desire to increase revenue share of total system production by performing systems integration.
- ***What is the total system?*** The production company and its suppliers. As such, the Value Chain in the system crosses company boundaries. For example, consider the Value Chain drawn in Figure 11.6 across six SMEs. The functions performed in the value chain are represented by letters and are grouped into the SME organizations (i.e. functions A and B are performed in one SME, functions J and O in a second, etc.). Value is added as the products move along the chain from supplier to buyer. The initial functions produce components, the next set integrates those

components into subsystems and the highest level (furthest to the right) integrates the subsystems into systems.

11.4.2.2. The Operational perspective

The key question and response from this perspective is:

- ***What do SMEs do?*** They produce components and provide services.

11.4.2.3. The Functional perspective

The key question and response from this perspective is:

- ***What functions do SMEs perform?*** Production, sales, service, marketing, research, etc.

11.4.2.4. The Structural perspective

The key questions and responses from this perspective are:

- ***How can the organizational structure be improved?*** Organizations evolved into the current hierarchical format due to issues related to "span of control". These days flattening of the hierarchy can be achieved by a combination of:
    - Process using the management by exception approach, only looking at situations where actual results differ significantly from planned results, and the
    - Products of Information Technology (Rodgers, et al., 1993).

11.4.2.5. The Generic perspective

The key questions and responses from this perspective are:

- ***Who else performs the same functions?*** Large companies.
- ***What is happening in Taiwan?*** A number of things. First, the Corporate Synergy Development Center (CSDC), a non-profit organization established in 1984, by the Industry Development Bureau (IDB) of Ministry of Economic Affairs (MOEA) provides technical services for SMEs. Second, SMEs in Taiwan already seem to be working together in consortia as shown by the following examples:
    - ***Bicycle Industry:*** A-Team, started in 2003, led by Giant and Merida with more than 20 SMEs participating, formed a cluster in Taichung, in the central part of Taiwan (Liu and Brookfield, 2007).

- T***ool Machine:*** another example from the Taichung area industry cluster. The current success of Taiwan's machine tool industry is due to the competitive advantages achieved through flexibility, delivery, and price by the user-producer interaction of the factory satellite network system in the industry cluster in the Taichung area. The success of the diffusion of technology from bridging institutions to industry has also been an important factor (Ching-Chiang Yeh and Pao-Long Chang, 2003).
- ***M-Team:*** established for machine tool industry in Sept. 2007 under the IDB and The CSDC assistance, (Liu, 2008).
- ***Fastener Industry:*** S-Team established, FPD Industry and Hand-Tool Industry are examples of SMEs working together.

11.4.2.6. The Continuum perspective

The key questions and responses from this perspective are:

- ***What is happening elsewhere, for example in the US?*** Many SMEs do the same kind of SETA, software and hardware engineering, operations support activities as do the large corporate contractors (Kasser, 1997a) as discussed in Sections 11.2 and 11.3.
- ***What is the difference between large companies and SMEs?*** The resources of SMEs are more limited. They lack the deep pockets and "spare" personnel of the large companies.
- ***What are some alternative organisational structures?*** The traditional systems engineering approach to organizational design allocates functions to physical elements or departments within the same organization. However, one can visualize an alternate arrangement with separate functional and organizational boundaries so that the functions can be performed by different SMEs working together as a consortium as discussed in Section 11.3. This concept is similar to a temporary project organisation within a large corporation and in this context seems to be an application of the reengineering concept (Hammer and Champy, 1993). Thus, back to the *Big Picture* perspective, the structure of a large corporation and the structure of a consortium of SMEs performing the same functions looks the same from the outside as shown in Figure 11.7. The difference as discussed below is that to ensure the quality of the final system/product, all the functions except enterprise management are performed by more

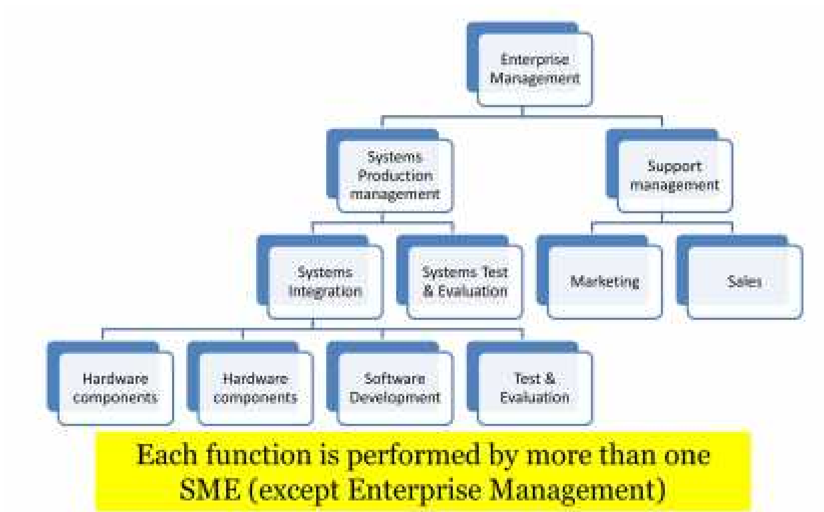

Figure 11.7 Structure of consortium (virtual corporation)

than one SME in an internal (to the consortium) MATO contracting environment.

- ***What lessons can be learned from the concept of alliances or teams of organizations in other countries***? Applicable lessons learned from the US include:

    - There is a considerable payoff if a new team can take a short period of time at the beginning of its life to examine collaboratively how it is going to work together, what its methods, procedures, and work relationships will be, and what the priority concerns of its members are. Then the team works more effectively, has fewer interpersonal problems, is more productive, and is more meaningful to its members (Beckhard, 1969).
    - The following six issues need to be resolved for the alliance before an opportunity arises (Drucker, 1993), pages 289 to 291), all parties must:

        i. Define their own objectives.
        ii. Agree on the objectives of the alliance.
        iii. Agree on how the alliance should be run.
        iv. Agree on who should manage the alliance.
        v. Define the formal organizational relationship between the alliance and its own organization, including the responsibility and accountability.
        vi. Agree on how to resolve disagreements.

11.4.2.7. The Quantitative perspective

The key questions and responses from this perspective are:

- ***How has consistent quality been guaranteed by a single entity in the past?*** The International Standards Organization (ISO) 9000 set of standards were developed to ensure that consistent quality of the process and products of parts suppliers would be verified by a single impartial entity.
- ***How many top-level functional subsystems are there in a production company?*** Two subsystems; production (mission) and support (Section 7.6).

11.4.2.8. The Temporal perspective

- ***Where did systems development and integration begin?*** It began in SMEs since the large corporations evolved from SMEs. One prominent example is the way Henry Ford vertically integrated the Ford Motor Company to ensure quality, timeliness of delivery and reliability of parts (subsystems) (Ford and Crowther, 1922). However, as time went by, vertical integration tended to produce poor quality and high inventory stocks (sometimes of poor quality parts).
- ***How is modern supply chain economics addressing the issues of quality and timelines of delivery of components?*** In the form of consortia of companies working together rather than using Ford's vertically integrated single company approach.
- ***What about inventory costs and timeliness of delivery?*** Outsourcing of parts manufacturing by large companies to SMEs is common and the Just-In-Time (JIT) manufacturing/delivery concept tends to overcome issues with excessive costs of inventory and tends to ensure timeliness of delivery.

11.4.2.9. The Scientific perspective

The key questions and response from this perspective is:

- ***What hypotheses could be inferred*** for conceptualizing a way in which Taiwan's SMEs could vertically integrate with minimal disruption to the working of individual SMEs? Four interdependent answers (hypotheses) were identified, namely:
    1) A consortium of SMEs can form a virtual corporation with the same structure as a large company discussed in Section 11.4.2.9.1.
    2) Systems engineering can be used to design and build the consortium discussed in Section 11.4.2.9.2.

3) Quality can be ensured by limited competition in a co-operative MATO contracting environment discussed in Section 11.4.2.9.3.
4) The SME consortium MATO structure offers greater benefits to the stakeholders than those available from large corporations discussed in Section 11.4.2.9.4.

11.4.2.9.1. A consortium of SMEs can form a virtual corporation with the same structure as a large company.

The perceptions contributing to this hypothesis include:

- The *Generic* perspective has shown that the hypothesis has been supported by the formation of consortia in the bicycle, machine tool, and fastener industries in Taiwan as discussed above in Section 11.4.2.5.

11.4.2.9.2. Systems engineering can be used to design and build the consortium

The perceptions contributing to this hypothesis include:

- The virtual large company is process-based (Hammer and Champy, 1993: page 28), uses a systems approach and can be considered as having four dimensions (product, process, people and time) (Kasser, 1995a). As such, systems engineering methodologies can be used to view, decompose and optimize the organization.

11.4.2.9.3. Ensuring the quality

Quality can be ensured by always transferring products at SME boundaries. These products must be tangible items manufactured according to a specification. Quality will be assured in the contract since, "*quality is conformance to specifications*" (Crosby, 1979). The products may be systems engineering process-products in the form of documents or electronic databases, or hardware and software components and assemblies.

11.4.2.9.4. The benefits to the stakeholders

This concept of a federation of SMEs performing systems integration appears to have many benefits to the SMEs, the government and the customers with few disadvantages. These benefits and the few disadvantages are summarized as follows:

1. Benefits to SMEs in Section 11.4.2.9.4.1.
2. Benefits to Government in Section 11.4.2.9.4.2.
3. Benefits to customers in Section 11.4.2.9.4.3.
4. The few disadvantages are summarized in Section 11.4.2.9.4.4.

11.4.2.9.4.1. *Benefits to SMEs*

Benefits to SMEs include:

- No need to change core competency to join consortium.
- Long term relationships with other members of the consortium help to develop future opportunities.
- Consortium work can be scheduled in advance so the workload is known.
- Allows for SME to work outside consortium to make use of extra capacity.
- All SME need not be local, for example suppliers can be overseas.
- The final integrator in an overseas contract can be a local (overseas) company. This concept has been used successfully in several industries in which components manufactured in one country have been shipped to another country and assembled/integrated in the second country by a "local" manufacturer.
- Good learning and political opportunity. Teaming with an established systems integration house in an overseas country will be a good way to learn the process and create opportunities for expansion of business.

11.4.2.9.4.2. *Benefits to Government*

Benefits to Government include:

- No need to give away future tax revenue to lure large (overseas) companies into the area.
- Revenues since taxes are collected from consortium (local SMEs).
- Knowledge, skills and competencies remain local.
- Funds support local (mainly) SMEs.

11.4.2.9.4.3. *Benefits to customers*

Benefits to customers include:

- Lower probability of fraud, waste and abuse and earlier visibility of deficiencies in the system development lifecycle because the Enterprise Management Company will be aware of deficiencies at the first and subsequent contractual handover point between SMEs in the value chain.
- Better quality than from single large company produced system since it is in the (internal consortium's contracts) contract and reputation of SME.

- Lower cost due to lower SME overheads.
- Increased innovation in products because SMEs are more innovative than large companies.
- Probable increase in reliability due to lack of service network which provides incentive for supplier to increase reliability.

11.4.2.9.4.4. *The few disadvantages*

The disadvantages are few, and mainly reflect the change in the manner of doing work. For example:

- System integration by a consortium of SMEs is a new concept, so it will need to provide incentives to overcome resistance to change
- The SMEs may have to share cost information with consortium partners who might be future competitors. However, this will depend on internal consortium financial agreements and will be different in a profit sharing or fixed price contractual environment.
- Formation and ramp up will take time and probably will need government help. A pilot project to use as an example in marketing the capability to all potential stakeholders will probably be needed

11.4.3. Recommendations

The recommendations from the study included:

1. Create a consortium as a pilot project to study the efficacy and effectiveness of the concept discussed in Section 11.4.3.1.
2. Use the MATO methodology to manage the consortium discussed in Section 11.4.3.2.

11.4.3.1. Create the consortium

Create the consortium or virtual corporation using perceptions of the solution consortium from:

- The *Big Picture* perspective which would be used to determine scope and range of products to be produced.
- The *Operational* perspective which would identify the value chain as a process flow ensuring a product transfer at each functional boundary (Kasser, 1997b).

In creating this consortium or designing the production system, the value chain would be created first, and then the SMEs would be mapped on to the value chain shown in Figure 11.6 (*Functional* perspective) to produce the actual organization shown in Figure 11.7 (*Structural* perspective). In this case, the steps are:

1. Identify the functions performed by the production system to produce or purchase the components, subsystems and perform system integration.
2. Except for the enterprise management function, identify several SMEs who can perform each function. Thus each SME can continue to perform its core competency.
3. Note the instances where a function cannot be allocated to an SME. This is an opportunity to create a new SME or for an existing SME to grow its competencies.
4. Create the missing functions from the existing members of the consortia or invite additional SMEs to join. Distance in itself may not a factor depending on what is being produced by each SME and how it can be shipped.

11.4.3.2. Use a MATO management methodology

Use a working methodology (Kasser, 2010) for such an organisation that:

- Is loosely based on a methodology used by a large contractor for eight calendar years in a task ordered environment at NASA GSFC (Kasser, 2007b).
- Improves on the basic methodology by adding the element of quality using the anticipatory testing paradigm (Kasser, 1995a).
- Optimizes management across the organizational boundaries.
- Enforces quality into the contractual structure.
- Emphasizes teamwork and customer involvement.
- Is tailored to the formality necessary for specific tasks of different degrees of complexity, ranging from single person tasks, to tasks requiring a large team of employees with interdisciplinary skills.
- Ensures work is performed in a cost-effective manner.
- Maps very well into managing tasks performed in geographically distributed locations by different organizations such as in this project.
- Intrinsically incorporates task management into program management.
- Reduces the cost of doing work.
- Allows the needed staffing levels and skill mix to undergo the gradual change required to perform the planned work in an optimal manner.
- Establishes baselines for the planning activity.

- Monitors task and contract performance relative to the baseline plan.
- Develops measurements of the effectiveness of performing the work.
- Incorporates control functions that effectively deal with deviations from the baseline plan in a timely manner.

In terms of the FCFDS, the Enterprise Management Company is the holding company. When the Enterprise Management Company sets up the consortium, it arranges for a pool of teaming SMEs who agree to compete for tasks on an agreed set of criteria in a MATO scenario that is transparent to the customer. The single point interface between the Enterprise Management Company and the customer remains exactly the same as in the conventional approach large corporation MATO contract. Work orders are transmitted from the customer to the Enterprise Management Company as in the conventional approach. The difference is in what happens to the work orders in the Enterprise Management Company. The Enterprise Management Company is a "task broker" planning, organizing, directing and measuring the work. In this scenario, the Enterprise Management Company has three functions, namely:

1. Breaking the work down into tasks using process architecting techniques.
2. Competing each task among the pool of qualified SMEs in the consortium.
3. Locating and qualifying additional potential consortium members. This potential inflow of new talent will tend to inhibit the consortium members from becoming complacent in their activities and keep the costs down.

Lastly, since the SMEs generally do not have deep pockets, the Enterprise Management Company should provide or arrange for bridging financing to the members of the consortium to cover the cost of doing work if so required since some of the payment from the customer will only be made after delivery of the products.

11.4.4. Summary

This Section went beyond systems thinking by providing an example of Active Brainstorming the problem of vertically integrating Small and Medium Enterprises (SME) in Taiwan in 2008, to provide a recommended FCFDS that can be adapted for vertically integrating SMEs in any part of the world. While addressing a similar issue to that in Section 11.3, this example:

- Documented some of the key questions and responses.

- Conceptualized a whole functional and purposeful solution to the problem of vertically integrating Taiwan's SMEs with minimal disruption to the working of individual SMEs.
- Developed a hypothesis for a conceptual solution.
- Provided recommendations for a pilot scheme to test the feasibility of the conceptual solution.

11.5. Determination of a set of risk-indicators to predict project failure

This Section:

- Discusses how going beyond systems thinking when performing a study on reasons for project failures produced two innovative results (Kasser and Williams, 1998), specifically:

    1) Perceptions from the *Quantitative* perspective produced an innovative alternative to PWC when ranking a large number of items as long as the scope of the ranking is limited to the most and least important items.
    2) Perceptions from the *Continuum* perspective produced a set of risk-indicators that can be used to predict the failure of a project while the project is in progress to determine if a project is going to fail and allow preventive or remedial actions to be taken in time to save the project.

- Describes research based on Case Studies written by students in the Graduate School of Management and Technology at UMUC in a postgraduate class on Independent Verification and Validation (IV&V) in 1996[10] where:

    1) Framing the problem is discussed in Section 11.5.1.
    2) The methodology is discussed in Section 11.5.2.
    3) Validating the survey results is discussed in Section 11.5.3.
    4) The presence of the risk indicators in ISO 9000 and the software Capability Maturity Model (CMM) is discussed in Section 11.5.4.
    5) The deficiencies in the study are discussed in Section 11.5.5.

[10] These students are employed in the workforce and are working towards their degree in the evening. Their employment positions range from programmers to project managers. Some also have up to 20 years of experience in their respective fields.

6) The conclusions and recommendations are discussed in Section 11.5.6.

Use the process mentioned in Section 1.1 to study the anecdote, especially if you are not familiar with the domain and pick out the pertinent points from the details.

11.5.1. Framing the problem

The problem was framed as follows:

- ***The undesirable situation:*** the feeling that useful data could be mined from the student papers and used as the bases for a published paper[ii].
- ***The FCFDS:*** a published paper.
- ***The problem:*** to find a topic and format for the students' papers that could be used as the basis for the FCFDS.
- ***The solution:*** was the FCFDS (Kasser and Williams, 1998).
- ***The methodology or problem-solving process***:
  - Identified the topic.
  - Instructed the students to write and present term papers describing their experiences in projects that had been or were in trouble. The papers adhered to the following instructions:
    - Document a Case Study. Students had to write a scenario for the paper based on personal experience.
    - Analyse the scenario.
    - Document the reasons the project succeeded or ran into trouble.
    - List and comment on the lessons learned from the analysis.
    - Identify a better way with 20/20 hindsight.
    - List a number of situational indicators that can be used to identify a project in trouble or a successful project while the project is in progress.
  - Summarized the student papers to identify common indicators.

[ii] This was in an academic environment.

- Surveyed systems and software development personnel via the Internet to determine if they agreed or disagreed with the indicators.
- Summarized and analysed the results.

11.5.2. The methodology

Consider the following aspects of the methodology of the Case Study:

1. The summary of the student papers discussed in 11.5.2.1.
2. The survey approach discussed in 11.5.2.2.
3. The survey 11.5.2.3.
4. The survey results discussed in 11.5.2.4.
5. Further analysis 11.5.2.5.
6. The sensitivity analysis on project management risk indicators discussed in 11.5.2.6.
7. The ‘other’ category discussed in 11.5.2.7.
8. The risk indicators with most disagreements discussed in 11.5.2.8.

11.5.2.1. Summary of student papers

Nineteen students produced papers that identified 34 different indicators. Each indicator identified was a symptom of a condition that led to project failure, hence the name risk-indicator. Several risk-indicators showed up in more than one student paper; “*poor requirements*” showed up in all of the papers.

11.5.2.2. The survey approach

The survey was designed to determine if the respondents agreed or disagreed with the hypothesis that each of the 34 different risk indicators was a contributor to project failure. However, we also wanted to know the relative importance or ranking of the risk indicators. Asking for a ‘yes/no’ agreement was simple but would not provide a ranking. A Lickert scale would be more subjective[12], more complicated and complex and not produce a ranking. If we were to follow the standard process and apply the traditional approach to ranking 34 items, we would have had to ask the respondents to perform a PWC on all 34 items as discussed in Section 8.7.1.7. The PWC approach was scoped by taking the time to complete the matrix shown in Table 11.1which took just over an hour. Consequently, it was felt that while the full matrix would provide lots of information, few respondents would actually take the time to perform the PWC so it was time to rethink or redefine (dissolve) the problem.

[12] The whole survey was subjective anyhow.

The initial concept was to ask the survey respondents to rank all of the risk-indicators in order of priority. Yet was that the real need? Perceptions from the *Quantitative* perspective produced the following key questions:

1. "*Do we need to know the ranking of **all** of the risk-indicators or are we only interested in the most and least important*?" the answer was, "*just the most and least important*".
2. "*How many most and least important items*?" the answer invoked Miller's rule of 7±2 (Miller, 1956) resulting in the need to only identify the top and bottom seven items in the rankings.

11.5.2.3. The survey

A survey questionnaire was constructed and sent to systems and software development personnel via the Internet. The survey asked respondents to:

1. State if they agreed or disagreed that the student provided risk-indicators were causes of project failure[13].
2. List the top seven risk-indicators they thought were causes of project failures.
3. List the seven risk-indicators they thought contributed the least to project failures.
4. Write in an additional cause of project failure that was not on the list if they could think of one.

One hundred and forty-eight responses were received. The initial findings are summarized in Table 11.2. While all 19 of the students agreed that poor requirements were a risk-indicator that could be used to predict project failure, not every survey respondent agreed or disagreed with every risk-indicator. In Table 11.2:

- ***The first column*** contains an identification number (ID) identifying the risk-indicator.
- ***The second column*** lists the name of the risk-indicator.
- ***The third column*** lists the number of students that identified the risk-indicator. The maximum number is 19 because 19 students provided information for the study.
- ***The fourth column*** contains the percentage of agreement.
- ***The fifth column*** contains the percentage of disagreement.

[13] The author recognized that there were other causes of (risks) project failure and added an 'other' category to the survey questionnaire for 'write-in' risks

Table 11.1 PWC matrix for ranking risk-indicators

Risk-indicator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	1's	0's	Total	Rank
Poor requirements	X	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	31	0	31	2
Failure to use experienced people		X	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	33
Failure to use Independent Verification and Validation (IV&V)			X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34
Lack of process and Standards				X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	1	0	1	5	1	6	29
Lack of, or, poor plans					X	0	0	1	1	1	0	0	1	1	1	0	0	1	1	1	0	0	0	0	0	0	1	1	0	1	0	1	0	1	14	3	17	16
Failure to validate original specification and requirements						X	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	27	4	31	2
Lack of Configuration Management							X	1	1	1	0	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	22	4	26	7
Low morale								X	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	5	3	8	26
Management does not understand System Development Lifecycle									X	1	0	0	0	0	1	0	0	1	0	1	1	1	0	0	1	1	1	1	0	1	1	1	0	1	14	3	17	16
Management that does not understand technical issues										X	0	0	0	0	1	0	0	1	0	0	0	0	1	0	1	0	1	1	0	0	1	1	0	1	9	3	12	22
No single person accountable/responsible for project											X	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	22	8	30	4
Client and development staff fail to attend scheduled meetings												X	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	4	7	11	24
Coding from high level requirements without design													X	0	0	0	0	1	0	0	1	0	0	0	0	0	1	1	0	1	1	1	0	1	8	7	15	19
Documentation is not produced														X	1	0	1	1	0	1	1	0	0	0	0	0	1	1	0	1	1	1	0	1	11	9	20	13
Failure to collect performance and process metrics and report them to management															X	0	0	1	0	1	1	0	0	0	0	0	1	1	0	0	0	1	0	1	7	6	13	21
Failure to communicate with the customer																X	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	17	13	30	4
Failure to consider existing relationships when replacing systems																	X	1	0	1	1	1	1	0	0	1	1	1	0	0	1	1	0	1	11	10	21	12
Failure to reuse code																		X	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	3	3	6	29
Failure to stress test the software																			X	1	1	1	1	1	1	1	1	1	0	0	0	1	0	1	11	12	23	9
Failure to use problem language																				X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	7	27
High staff turnover																					X	0	0	0	0	0	1	1	0	0	0	1	0	1	4	8	12	22
Key activities are discontinued																						X	0	1	1	1	1	1	0	1	1	1	0	1	9	13	22	10
Lack of Requirements Traceability Matrix																							X	0	1	1	1	1	0	1	1	1	0	1	8	14	22	10
Lack of clearly defined organizational (responsibility and accountability) structure																								X	1	1	1	1	0	1	1	1	0	1	8	16	24	8
Lack of management support																									X	0	1	1	0	0	1	1	0	1	5	13	18	15
Lack of priorities																										X	1	0	0	0	0	0	0	0	1	14	15	19
Lack of understanding that demo software is only good for demos																											X	0	0	0	0	0	0	0	0	4	4	32
Management expects a CASE Tool to be a silver bullet																												X	0	0	0	0	0	0	0	6	6	29
Political considerations outweigh technical factors																													X	1	1	1	1	1	5	28	33	1
Resources are not allocated well																														X	1	1	0	1	3	16	19	14
The Quality Assurance Team is not responsible for the quality of the software																															X	1	0	1	2	14	16	18
There are too many people working on the project																																X	0	1	1	8	9	25
Unrealistic deadlines - hence schedule slips																																	X	1	1	27	28	6
Hostility between developer and IV&V																																		X	0	7	7	27
0's	0	0	0	1	3	4	4	3	3	3	8	7	7	9	6	13	10	3	12	7	8	13	14	16	13	14	4	6	28	16	14	8	27	7				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34				

Table 11.2 Initial survey findings

Risk ID	Risk-Indicators	Students	Survey agree %	Survey disagree%	Rank
1	Poor requirements	19	97	3	1
2	Failure to use experienced people	7	79	1	13
3	Failure to use IV&V[1]	6	38	62	31
4	Lack of process and standards	5	84	16	11
5	Lack of, or, poor plans	4	95	5	2
6	Failure to validate original specification and requirements	3	91	9	3
7	Lack of Configuration Management	3	66	34	19
8	Low morale	2	51	49	24
9	Management does not understand the SDLC	2	59	41	22
10	Management that does not understand technical issues	2	56	44	23
11	No single person accountable/responsible for project	2	69	31	18
12	Client and development staff fail to attend scheduled meetings	1	42	58	28
13	Coding from high level requirements without design	1	75	25	14
14	Documentation is not produced	1	63	38	21
15	Failure to collect performance & process metrics and report them to management	1	48	52	25
16	Failure to communicate with the customer	1	88	12	5
17	Failure to consider existing relationships when replacing systems	1	85	15	10
18	Failure to reuse code	1	27	73	34
19	Failure to stress test the software	1	75	25	15
20	Failure to use problem language	1	34	66	30
21	High staff turnover	1	71	29	16
22	Key activities are discontinued	1	74	26	17
23	Lack of Requirements Traceability Matrix	1	67	33	19

[1] The papers were written for a class on IV&V, hence the emphasis on IV&V. However, if the descriptions of tasks that IV&V should have performed (in the papers) are examined, the word 'IV&V' could easily be replaced with the word 'systems engineering', and the papers would be equally valid.

Risk ID	Risk-Indicators	Students	Survey agree %	Survey disagree%	Rank
24	Lack of clearly defined organizational (responsibility and accountability) structure	1	82	18	11
25	Lack of management support	1	87	13	6
26	Lack of priorities	1	85	15	8
27	Lack of understanding that demo software is only good for demos	1	47	53	26
28	Management expects a CASE Tool to be a silver bullet	1	45	55	27
29	Political considerations outweigh technical factors	1	86	14	9
30	Resources are not allocated well	1	92	8	4
31	The Quality Assurance Team is not responsible for the quality of the software	1	40	60	29
32	There are too many people working on the project	1	36	64	32
33	Unrealistic deadlines - hence schedule slips	1	86	14	7
34	Hostility between developer and IV&V	1	33	67	33

- ***The sixth column*** is the ranking of the risk-indicator by the number of agreements in the survey results where a 1 represents a high agreement that the risk-indicator is a contribution to project failure.

11.5.2.4. Survey results

The survey results were surprising especially for risk number 31. Total Quality Management (TQM) holds that the Quality Assurance Department is not responsible for the quality of the software; everybody shares that responsibility. Thus, while it was expected that most respondents would agree with this risk-indicator, only 40% of the respondents agreed and 60% disagreed. It was also anticipated that most respondents would agree with the other risk-indicators, yet the overall degree of agreement was:

- 0.7% (one respondent) agreed with all 34 risk-indicators.
- 8.1% agreed with at least 30 risk-indicators.
- 51% agreed with at least 20 risk-indicators.
- 93% agreed with at least 10 risk-indicators.

As for the degree of disagreement:

Table 11.3 Top seven causes of project failures

Risk	Risk-indicator	Responses
1	Poor requirements	134
5	Lack of, or, poor plans	125
6	Failure to validate original specification and requirements	113
30	Resources are not allocated well	109
16	Failure to communicate with the customer	106
25	Lack of management support	98
33	Unrealistic deadlines - hence schedule slips	97

- 0.7% (one respondent) disagreed with 25 risk-indicators.
- 4.7% disagreed with at least 20 risk-indicators.
- 52% disagreed with at least 10 risk-indicators.
- 88% disagreed with at least one risk-indicator.

11.5.2.5. Further analysis

The top seven (high priority) risk-indicators were identified using the following approaches:

1. The Tally discussed in 11.5.2.5.1.
2. The Priorities discussed in 11.5.2.5.2
3. The Top seven discussed in 11.5.2.5.3.

11.5.2.5.1. The Tally

An 'agree' was allocated a value of +1, a 'disagree' a value of -1. The answers to each survey statement were then tallied. The raw results are shown in Table 11.2. The seven risk-indicators that received the highest positive values (most agreement) as causes of project failure are shown in Table 11.3.

11.5.2.5.2. The Priorities

The survey asked respondents to rank the top seven risk-indicators in order of priority. The weighted results are shown in Table 11.4 (top priority first):

11.5.2.5.3. The Top seven

Since the actual position may be subjective, the number of times a risk-indicator showed up in any position in the top seven priority list was also counted. The results for the top seven showing items are as shown in

Table 11.4 Priority causes of project failure

Risk	Risk-indicator	Weight
1	Poor requirements	864
16	Failure to communicate with the customer	683
5	Lack of, or, poor plans	574
4	Lack of process and standards	361
25	Lack of management support	350
6	Failure to validate original specification and requirements	329
29	Political considerations outweigh technical factors	304

Table 11.5. The results show a high degree of consensus on these risk-indicators as causes of project failures.

11.5.2.6. Sensitivity analysis on project management risk indicators

The sample size for respondents without management experience was 99. The raw tallies for the risk-indicators associated with project management shown in Table 11.6 were examined to see if there was a difference between non-managers and managers with various years of experience. No differences of more than 10% were noted.

11.5.2.7. The 'other' category

The 'other' category was added to perform risk management and avoid Simpson's paradox (Section 4.3.2.6.12). Several respondents added one or two additional risk-indicators in the 'other' category of the questionnaire. These were:

1. Failure to control change.
2. Rapid rate of change of technology.
3. Low bidding.
4. Poor management.
5. Lack of a technical leader.

Table 11.5 Top seven causes

Risk	Risk-indicator	Count
1	Poor requirements	99
16	Failure to communicate with the customer	86
5	Lack of, or, poor plans	77
4	Lack of process and standards	51
25	Lack of management support	51
29	Political considerations outweigh technical factors	45
6	Failure to validate original specification and requirements	44

Table 11.6 Project management related risk-indicators

Risk	Risk-indicator
5	Lack of, or, poor plans
8	Low morale
15	Failure to collect performance & process metrics and report them to management
25	Lack of management support
27	Lack of understanding that demo software is only good for demos
29	Political considerations outweigh technical factors
32	There are too many people working on the project
33	Unrealistic deadlines - hence schedule slips

Thus, the small student sample size of 19 seems to have identified most of the important risk-indicators. However, applying some critical thinking, the question remains as to what these items would have scored had they had been in a list of 39 risk-indicators. This is why the survey results needed validating by comparison with an independent similar study.

11.5.2.8. The Risk-indicators with most disagreements

Part of the analysis of the survey results was to determine which risk-indicators received the most disagreement as well as the least agreement as causes of project failure (*Continuum* perspective). This was to validate the results by ensuring that the same risk-indicator did not show up in the top seven agreements as well as in the top seven disagreements and was done by determining the:

- Most disagreements by the recipients.
- Least agreements by the recipients.

Table 11.7 Risk indicators with most disagreements

Risk	Risk-indicator	Responses
18	Failure to reuse code	88
3	Failure to use IV&V	80
32	There are too many people working on the project	75
12	Client and development staff fail to attend scheduled meetings	74
34	Hostility between developer and IV&V	70
31	The Quality Assurance Team is not responsible for the quality of the software	68
15	Failure to collect performance & process metrics and report them to management	67

Table 11.8 Risk indicators with least agreements

Risk	Risk-indicator	Responses
20	Failure to use problem language	30
18	Failure to reuse code	32
34	Hostility between developer and IV&V	34
32	There are too many people working on the project	43
31	The Quality Assurance Team is not responsible for the quality of the software	45
3	Failure to use IV&V	49
28	Management expects a CASE Tool to be a silver bullet	53
12	Client and development staff fail to attend scheduled meetings	54
27	Lack of understanding that demo software is only good for demos	55

The risk-indicators receiving the most disagreements are shown in Table 11.7.

11.5.2.9. The Risk-Indicators receiving least agreement

The risk-indicators receiving the least agreement as causes of project failure are shown in Table 11.8.

The seven risk-indicators receiving the least agreement as causes of project failure showing up in Table 11.7 and Table 11.8 were:

1. ***Failure to reuse code:*** a major advantage of the object-oriented approach is said to be the ability to lower costs by reusing code. Yet 73% of those surveyed did not agree with this risk-indicator.
2. ***Hostility between developer and IV&V:*** this risk-indicator shows a team problem and results in less than optimal costs due to the lack of cooperation.
3. ***There are too many people working on the project:*** this risk-indicator is based on the mythical man-month (Brooks, 1982) which describes the problems associated with assigning additional people to projects.
4. ***Failure to use problem language:*** the use of problem language was promoted as one of the major advantages by Ward and Mellor published ten years before the survey (Ward and Mellor, 1985). Yet, only 34% of the respondents agreed that it was a risk-indicator. Several did not know what the term meant.

Table 11.9 Comparison of results with Chaos study

Risk	This study	Chaos Study
1	Poor requirements	Incomplete requirements
16	Failure to communicate with the customer	Lack of user involvement
30	Resources are not allocated well	Lack of resources
--	No equivalent	Unrealistic expectations
25	Lack of management support	Lack of executive management support
--	No equivalent	Changing requirements and specifications
5	Lack of, or, poor plans	Lack of planning

5. ***The Quality Assurance Team is not responsible for the quality of the software:*** as discussed above, this was the only risk-indicator that should have shown agreement not disagreement.
6. ***Client and development staff fail to attend scheduled meetings***: this is a symptom of poor communication between the client and the developer. In addition, while there are other communication techniques available, if meetings are scheduled, and not attended, negative messages are sent to the project personnel.
7. ***Failure to collect performance & process metrics and report them to management:*** if measurements are not made and acted upon, how does management know what is going on and can the process be improved? Yet **52% of the respondents** disagreed that this was a risk-indicator!

11.5.3. Validating the survey results

The approach used to validate the survey results was to use the Chaos study as a reference (CHAOS, 1995). The study had recently (at that time) identified a number of major contributors to project failure. Five risk-indicators in this study that were chosen as the most important causes for project failure also appear on the Chaos list of major reasons for project failure. The correlation between the findings of this study and the Chaos study is shown in Table 11.9. While '*resources are not allocated well*' did not show up in the top seven lists of this study, it was fourth in the Tally. '*Changing requirements and specifications*' which showed up in the Chaos study as a contributor to project failure was not identified by the students[2] but was written in to the survey results as an 'other' by a few of the

[2] See Simpson's paradox in Section 4.3.2.6.12.

respondents[3]. Thus, this study supports the findings of the Chaos study (more or less).

11.5.4. Presence of risk-indicators in ISO 9001 and the software-CMM

The elements of Section 4 of the International Standards Organization (ISO) 9001 Standard and the five levels of the Software-Capability Maturity Model (CMM) (CMM, 1995) were examined and interpreted to determine if the top seven student risk-indicators were addressed in the ISO Standard and in the Software-CMM. The ISO 9001 Standard defines the minimum requirements for a Quality system, while the Software-CMM tends to address the issues of continuous process improvement more explicitly than does the ISO 9001 Standard. The findings are shown in Table 11.10 where the 'x' represents the presence of the risk-indicator. The same two major risk-indicators could not be mapped into either the elements of Section 4 of the ISO Standard, or the Software-CMM, namely:

- 29: Political considerations outweigh technical factors.
- 33: Unrealistic deadlines - hence schedule slips.

Thus, conformance to either or both Quality standards does not ensure mitigating these risk-indicators which is not surprising since ISO 9001 and the CMM focus on the process.

However, just changing the metrics paradigm may not be the complete solution. Cobb's Paradox (VOYAGES, 1996) states, *'We know why projects fail, we know how to prevent their failure, so why do they still fail?'* Now a paradox is a symptom of a flaw in the underlying paradigm. Perhaps Juran and Deming provided the remedy. Juran, as quoted by Harrington stated that management causes 80 to 85% of all organizational problems (Harrington, 1995), page 198). Deming stated that 94% of the problems belong to the system (i.e., were the responsibility of management) (Deming, 1993). In this survey, both managers and non-managers tended to disagree with the following two management risk-indicators:

- 09: Management does not understand the SDLC
- 10: Management that does not understand technical issues

The survey results support the statements by Deming and Juran which are ignored by the profession. It is difficult to understand how Information Technology managers can make good informed decisions if they don't understand the implications of their decisions.

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[3] Which brings us back to the question posed in Section 11.5.2.7

11.5.5. Deficiencies in the study

The following deficiencies are present in the study:

- The sample size is small.
- The level of expertise of the respondents is unknown.

11.5.6. Conclusions and recommendations

Except for *poor requirements*, none of the risk-indicators identified by this study are technical. Thus, the findings support:

- Resources spent mitigating technical risks are wasted unless the major risks discussed in this section are also mitigated. Thus, it is critical to develop and use good metrics for them.
- The need for continual training to provide managers with the skills to become capable of effective management of technical projects.

The use of the risk-indicators to predict the failure of projects during the SDLC in time to prevent the failure by carrying out an audit to determine the presence of the top seven risk indicators. These audits could even be associated with the major milestone reviews.

Table 11.10 Comparison with ISO 9001 and CMM

Risk	Section 4.x of ISO 9001																				Software-CMM				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	1	2	3	4	5
1	o	o	x	x	x	x	o	x	o	o	o	o	x	o	o	o	o	o	o	o	o	x	x	o	o
4	o	x	o	o	x	o	o	x	x	x	o	o	o	o	o	x	x	o	x	x	o	x	x	x	o
5	o	x	o	o	x	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	x	x	o	o
6	o	o	x	x	o	x	o	x	o	x	x	o	o	o	x	o	x	o	x	o	o	x	x	o	o
16	o	o	x	o	x	o	o	o	o	o	o	o	o	x	o	x	o	o	o	o	o	x	x	o	o
25	x	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	x	o	o
29	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
30	x	o	o	o	o	o	o	o	x	o	x	o	o	x	o	o	x	x	x	o	o	o	o	x	o
33	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o

11.6. Dealing with the ALSEP CVW failure

This is an anecdote about how different HTPs contributed to remedying an undesirable situation in an ALSEP central station in 1970.

Use the process mentioned in Section 1.1 to study the anecdote, especially if you are not familiar with the domain and pick out the pertinent points from the details.

11.6.1. Framing the problem

The problem was framed as follows:

- ***The undesirable situation:*** Once upon a time in 1970, an undesirable situation was noted when one of the ALSEP systems was being tested during the development phase of its SDP. Each time a command was uplinked to the ALSEP, the Command Verification Word (CVW) received on the downlink was wrong (symptom).
- ***The FCFDS:*** receiving 100% correct CVW responses.
- ***The problem:*** to identify the cause of the undesirable situation so that it could be remedied by repairing or replacing.
- ***The solution:*** was the FCFDS.

11.6.2. The situational analysis

Perceive the undesirable situation from the perspectives perimeter.

- ***Big Picture:*** the system consists of the control station, and the uplink receiver, command decoder, telemetry encoder and downlink transmitter in the ALSEP Central Station.
- ***Operational:*** the command and control link worked in the following manner. The control station would uplink an 8-bit command to the ALSEP. Upon receipt of the command, the ALSEP would downlink a CVW that was identical the uplinked command. The control station would then compare the CVW with the uplinked command, and if they were identical, the control station would then uplink the instruction to execute the command. This handshaking protocol was used to ensure that the correct command would be executed. Each time a command was uplinked to the ALSEP, the CVW received on the downlink was wrong (symptom). An analysis of several commands and corresponding CVWs identified an error pattern showed that the last two bits (bits 7 and 8) were always identical to the previous bit (bit 6) (analysis of symptoms). For example, if bit 6 was a 0, bits 7 and 8 were also 0's and if bit 6 was a 1, bits 7 and 8 were also 1's.

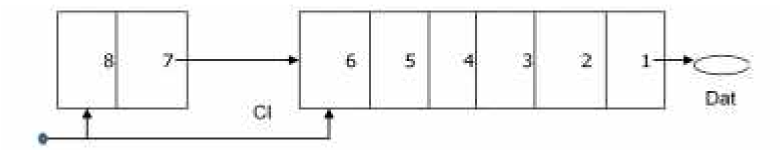

Figure 11.8 CVW Structure in Integrated circuit

- ***Functional:*** the CVW logic functions were performed in the ALSEP Central Station Command Decoder.
- ***Structural:*** the control system hardware in the ALSEP Central Station Command Decoder was made up of digital Transistor-Transistor-Logic (TTL) Integrated Circuits (IC)[4].
- ***Scientific:*** the hypothesis for the cause of the wrong CVW was based on the perception from the *Structural* perspective that if the TTL shift register that stored the CVW in the ALSEP Central Station Command Decoder was made up of two ICs as shown in Figure 11.8 and the second one stored the last two bits (bits 7 and 8), the symptoms noted could be caused by a hardware failure of the second IC. The hypothesis was based on the domain knowledge of how the functions were allocated to the physical components (*Structural* perspective). The schematic was checked and the circuit diagram showed two TTL ICs in series as shown in Figure 11.8.

The hypothesis was tested by designing a test to transmit several commands containing a representative set of bit patterns and predicting the corresponding actual incorrect CVW's. The test was carried out and the results conformed to expectations supporting the hypothesis. The offending IC was replaced and the operation of the ALSEP Central Station Command Decoder was restored to nominal. The undesirable situation had been converted to a desirable situation.

11.7. Summary and comments on the applications of holistic thinking

This chapter provided macro and micro examples of going beyond systems thinking by perceiving several issues/systems from the perspectives perimeter for different purposes, the insights obtained and the resulting innovative solutions. In each situation, holistic thinking helped pose the key questions, but the domain knowledge also known as subject matter expertise was the key to the feasibility of the insight that produced the innovative solutions. For example in:

[4] This situation took place in 1970, well before the age of the microcomputer.

1. ***The NASA GSFC Pacor Panic Attack*** discussed in Section 11.1: domain knowledge about the characteristics of low earth orbits prompted the key question from the *Temporal* perspective about the expected lifetime of the current satellites. Similarly domain knowledge that there were probably used computers in the marketplace prompted the second key question to confirm the hypothesis that used minicomputers were available.
2. ***An alternative teaming approach for Small and SDBs in certain types of government contracts*** discussed in Section 11.2: the key element in the innovative approach to obtaining useful information from small sample sizes came from knowledge of statistics, not systems thinking. However, perceptions from the *Continuum*, *Generic* and *Quantitative* perspectives provided the insights and impetus to rearrange the structures of the teams.
3. ***Redrawing the contractor sub-contractor boundaries in certain types of Defence contracts*** discussed in Section 11.3: it was the domain knowledge from research into the lack of teaming that enabled perceptions from the perspectives perimeter to be applied to the problems facing government contracting and the Small and SDBs to produce the hypothesis for changing the contract boundaries (*Scientific* perspective).
4. ***Addressing the problem of vertically integrating Taiwan's small and medium sized enterprises*** discussed in Section 11.4: the key insight came from beyond systems thinking using perceptions from the *Generic* perspective to conceptualise a virtual enterprise architecture using a MATO management methodology.
5. ***The determination of a set of risk-indicators to predict project failure*** discussed in Section 11.5: the key element in the study was the perception from the *Continuum* perspective that the risk-indicators could be used proactively as predictors of probable project failure (project management domain). The key to obtaining a reasonable amount of survey responses and useable data about the most important risk-indicators came from an understanding of human nature (the survey respondent domain) and perceptions from the *Quantitative* perspective, namely we just needed the top seven risk-indicators, and not an entire ranking. The study also provided an example of the need to formulate the right question. In this case the right question dealt with identifying the needed number of risk-indicators to be prioritized
6. ***Dealing with the ALSEP CVW failure*** discussed in Section 11.6: the key insight in this example came from the combination

of perceptions from the *Functional* and *Structural* perspectives. The domain knowledge about the allocation of shift register memory functions to hardware ICs was the key to solving the problem of the faulty CVWs.

Section 6.4 contained three additional examples:

1. ***The LuZ SEGS-1 project:*** the insight for the distributed control structure in the LuZ SEGS-1 command and control system discussed in Section 6.4.1 came from applying domain knowledge of Telemetry Tracking and Control (TT&C) in aerospace to the problem of command and control of a terrestrial network. The *Generic* perspective domain knowledge applied was from the domain of TT&C not aerospace or computer networks. Applying solutions from similar situations in other domains to the problem you are facing in your domain is one way to achieve an 'out of the box' solution.
2. ***Designing a UAV:*** holistic thinking could provide the generic functions and properties that the UAV would inherit as discussed in Section 6.4.2. The domain knowledge relating to the UAV and the specific missions it would be performing in the specific environment would be a critical element in designing the correct UAV for the problem.
3. ***The RAFBADS:*** it was easy to identify the need to change the system to incorporate the rescue of pilots downed in the English Channel, add electricity generators in case of power failures and relocate the HQs away from the airfields after experience had shown the need to do so as discussed in Section 6.4.3. The benefits of going beyond systems thinking are identifying those needs ahead of time and designing the system so those needs never arise in operation. Active Brainstorming can raise the questions, but it takes domain knowledge to provide the right answers.

Chapter 10 presented three examples of applying holistic thinking:

1. ***The C3I problem:*** went beyond systems thinking even though it used SSM (Checkland and Scholes, 1990). The key perception was the communications problems due to the differences in Weltanschauung between the actors in the anecdote.
2. ***The MCSSRP:*** which went beyond systems thinking by tailoring the Systems Engineering Process (SEP) in the Requirements State to produce an outstanding SRR.
3. ***Developing an optimal postgraduate classroom teaching and learning environment***: which used holistic thinking to provide an example of how easy it is to make the wrong deci-

sions if there is insufficient information or lack of domain expertise in the project team even when you are using systems thinking.

In summary, the key to success is both going beyond systems thinking in perceiving the situation from the perspective perimeter and the domain knowledge also known as subject matter expertise either present in the team or acquired when researching the answers to the questions posed in the Active Brainstorming sessions.

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12. Creating your own innovative solutions to complex problems

Creating innovative solutions to complex problems means that you have to perceive things differently and then go beyond systems thinking and think creatively about what you have seen. This book was written to help you achieve that goal. This Chapter:

1. Provides suggestions for how you can go about creating your own innovative solutions to complex problems.
2. Summarizes practical ways to use the tools and methodologies presented in this book.
3. Discusses innovation.
4. Begins with a summary of the previous chapters of the book in Section 12.1 to refresh your memory.
5. Discusses generating ideas in Section 12.2.
6. Discusses the four steps of creativity in Section 12.3.
7. Discusses maximising creativity in Section 12.4.
8. Discusses habits that hinder creating and adopting new ideas in Section 12.5.
9. Discusses perceiving similarities where others do not and its consequences to you in Section 12.5.6 with some examples.
10. Discusses perceiving differences to dissolve paradoxes and create the impossible in Section 12.7.
11. Discussed examining complex descriptions of situations in Section 12.8.
12. Discusses pretending you are living a Case Study in Section 12.9.
13. Discusses two examples of combining parts into a new innovative application in Section 12.10.
14. Discusses perceiving things differently in 12.11.
15. Summarises the Chapter in Section 12.12.
16. Closes with a last word in Section 12.13.

12.1. A summary of the previous chapters of the book

This Section summarises the previous chapters to refresh your memory.

12.1.1. Part I

The first part of the book provided the tools used to create innovative solutions to complex problems.

Chapter 1:

1. Explained how to read and use the book in Section 1.1.
2. Explained why the book was written in Section 1.2.
3. Explained the gap filled by the book in Section 1.3.
4. Explained why the systems approach is important in Section 1.4.
5. Introduced the contents of the book in Section 1.5.
6. Provided a list of acronyms used in the book in Section 1.6.
7. Provided a glossary of the meanings of some specific words used in the book in Section 1.7 since their meaning in the literature depends on the author.

Chapter 2:

1. Introduced you to thinking and introduced some of the tools you can use to assist your creative thinking.
2. Started with an introduction to some types of thinking in Section 2.1.
3. Introduced types of thinking in Section 2.2 and discussed top down and bottom up thinking in Section 2.3.
4. Discussed judgment and creativity in Section 2.4.
5. Introduced a concept map as the basic tool for thinking in Section 2.5.
6. Described just a few of the tools that can help you to think starting with tools for generating ideas in Section 2.6 and a few tools to assist with thinking in Section 2.7.
7. Ended with Table 2.3, a quick reference table to help you select the appropriate tool for the thinking task

Chapter 3:

1. Discussed ways to communicate ideas because there is little point in generating ideas if you are not going to do anything with them.
2. Began with a discussion on formal written communications in Section 3.1 namely documents and introduced a process for creating a document starting with an abstract and continued with developing and using annotated outlines.
3. Discussed formal verbal communications and presentations in Section 3.2.
4. Alerted you to some barriers to successful communications in Section 3.3.

5. Followed up with some ways to overcome those barriers in Section 3.4.
6. Discussed IP and ways to avoid plagiarism in Section 3.5.

Chapter 4:

1. Addressed multiple perspectives.
2. Began with a description of analysis as an internal perspective and systems thinking as an external perspective in Section 4.1.
3. Introduced the perspective perimeter to provide anchor points for discussions from a wider set of viewpoints that go beyond analysis and systems thinking in Section 4.2.
4. Introduced nine Holistic Thinking Perspectives (HTP) as anchor points on the perspectives perimeter and more in Section 4.3.
5. Comparing the HTPs with some other versions of systems thinking in Section 4.4.

Chapter 5:

1. Introduced and provided an overview of critical thinking.
2. Perceived critical thinking from the perspectives perimeter in Section 5.1 and:

    1) Showed how the perspectives perimeter can be used to examine critical thinking.
    2) Used perceptions from the Functional perspective to separate out the rules for thinking from the evaluation of ideas.

3. Discussed creating and analysing arguments in Section 5.2.
4. Introduced a number of ways of evaluating critical thinking in Section 5.3.

12.1.2. Part II

The second part of the book covered the problem-solving aspect of creating innovative solutions to complex problems.

Chapter 6:

1. Summarised holistic thinking as the combination of the use of the HTPs and critical thinking (the evaluation of ideas).
2. Began with an introduction to how to use the HTPs to store information about Case Studies and real world situations in Section 6.1.
3. Introduced Active Brainstorming in Section 6.2 as a way to increase the number of ideas generated by brainstorming using the

HTPs coupled with the Kipling questions "who, what, where, when, why and how" (Kipling, 1912).

4. Introduced three problem-solving Idea Storage Templates (IST) in Section 6.3 for storing the ideas produced in the Active Brainstorming session.
5. Contained three examples of using the HTPs and ISTs in Section 6.4.
6. Provided suggestions for using the perspectives perimeter in creating innovative solutions to provide a context for the examples in Section 6.5 and those that follow in the remainder of the book

Chapter 7:

1. Discussed the nature of systems because:
    1) Undesirable situations, desirable situations, problems and solutions tend to manifest themselves in systems.
    2) The process to change from an undesirable situation to a desirable situation incorporates the problem-solving process which often includes or overlays the System Development Process (SDP).
    3) The process is itself a system.
2. Began with a list of definitions of a system in Section 7.1.
3. Perceived the nature of systems from the different HTPs in Section 7.2.
4. Introduced yet another definition of a system in Section 7.3.
5. Discussed basic system behaviour in Section 7.4
6. Discussed the properties of systems in Section 7.5.
7. Introduced a standard functional template for a system from which it should be possible to develop a set of reference functions for any class of system in Section 7.6.
8. Discussed complex systems in Section 7.7.
9. Summarised ways of reducing complexity in Section 7.8 including examples of how to optimise systems based on the interactions at the interfaces of the subsystems.

In some of the examples discussed above the subsystem boundaries were traditional, in others they were non-traditional. The tank development can be mapped into the holistic approach but the development wasn't holistic and the results were less than optimal. The objective was achieved but the price in loss of lives and materiel was higher than it could and should have been. The holistic approach to designing a system is a slightly different approach from that currently employed. It is a structured hierarchical approach to design and analysis. The functional allocation of the CONOPS is mapped into two major subsystems and an interface (subsystem) between them. The interfaces between the functional subsystems are then optimized.

Domain knowledge in the problem, solution and implementation domains is a critical element in the holistic approach to optimizing complex systems. The systems engineer uses the domain knowledge to visualize a conceptual two subsystems and optimized interface implementation of the CONOPS.

Chapter 8:

1. Discussed decision-making because decision-making is at the heart of problem-solving. Decision-making is the part of the problem-solving process, where the candidate solutions, options or choices are evaluated against predetermined selection criteria and a decision is made to select one or more of the options. The decision may be easy or difficult, simple or complicated. Some decisions can be made instantaneously; some decisions may require weeks or even years of study to gather the relevant information necessary to make the decision. Some people have problems making decisions; others make decisions instantaneously or intuitively.
2. Began by discussing qualitative and quantitative decision-making, in Section 8.1.
3. Introduced a number of decision-making tools in Section 8.2.
4. Discussed decision traps that produce bad decisions in Section 8.3.
5. Discussed decision outcomes including how to avoid unanticipated consequences in Section 8.4.
6. Discussed sources of unanticipated consequences in Section 8.5.
7. Discussed risk and opportunity in decision-making in Section 8.6.
8. Discussed the four key elements in making decisions with several anecdotal examples in Section 8.7.
9. Summarised Decision Trees and Multi-attribute Variable Analysis (MVA) in Section 8.8

Chapter 9:

1. Discussed problems and solutions, the assumptions behind problem-solving, and ways to remedy problems and introduced a holistic approach to managing problems and solutions.
2. Began with the properties a of good problem statement in Section 9.1.

3. Discussed the problem posed by the different meanings of the word 'problem' in Section 9.2.
4. Discussed the initial reaction to a problem in Section 9.3.
5. Discussed the traditional problem-solving process in Section 9.4.
6. Provided some examples of the systems engineering approach in Section 9.5.
7. Examined the relationship between problems and solutions in Section 9.6.
8. Discussed the holistic extended problem-solving process in Section in Section 9.7.
9. Discussed the difference between problems and symptoms in Section 9.8.
10. Discussed the assumptions underlying formal problem-solving in Section 9.9.
11. Discussed the components of problems in Section 9.10.
12. Discussed a problem formulation template used in this book in Section 9.11.
13. Classified problems in four ways in Section 9.12.
14. Defined the problem classification matrix discussed in Section 9.13.
15. Described ways of remedying problems in Section 9.14.
16. Compared varieties of the problem-solving process in Section 9.15.
17. Discussed the System Lifecycle (SLC) as an example of a complex problem solving process in Section 9.16.
18. Discussed the real world including two examples of how people adapt it when problem solving often in unexpected ways in Section 9.17.
19. Discussed remedies for complex problems based on the structure of the problem rather than the complexity of the problem in Section 9.18.
20. Discussed the complex problem solving process perceived as being made up of multiple series-parallel iterations of the non-complex problem-solving process in Section 9.19.
21. Discussed the dynamic complex situational loop in Section 9.20.

12.1.3. Part III

The third part of the book:

- Provided examples of innovative solutions to complex problems.
- Showed how the progressive perspectives went beyond systems thinking and contributed to the innovative solutions.

- Concludes by suggesting things you can do to start to become an innovator.

Chapter 10 provided the following examples of the adaptation of the holistic thinking approach to problem-solving mentioned in Section 9.15:

1. ***The C3I group morale issue*** discussed in Section 10.1: an application of how SSM was applied in the context of the systems engineering problem-solving approach to identify an organizational problem in a government organisation and recommend an appropriate solution. The last part of the Case Study showed that SSM is a useful tool for gaining an understanding of certain aspects of situations but needs to be used within the context of holistic thinking.
2. ***The Multi-Satellite Operations Control Center (MSOCC) data switch replacement project*** discussed in Section 10.2: documented the way a soft systems approach was used to go beyond systems thinking and achieve a consensus on the system requirements in a situation with multiple stakeholders holding a plurality of views. The anecdote also described two sets of trade-off studies; the first for the solution system and second for the transition approach to upgrade the facility.
3. ***Developing an optimal classroom teaching and learning environment*** discussed in Section 10.3: provided an example of how easy it is to make the wrong decisions if there is insufficient information or lack of domain expertise in the project team.
4. ***Creating and guide a successful student software engineering project class when the instructor is halfway around the world*** discussed in Section 10.4: used the evolutionary build-a-little-test-a-little process coupled with optimising the interfaces between the subsystems to provide a great deal of flexibility and a successful agile adaptation to the changing circumstances.
5. ***The apartment dwellers' amateur radio antenna system*** discussed in Section 10.5: an example of how adapting the problem-solving process is but the first step in creating the best FCFDS. The anecdote started with a non-holistic thinking approach which satisficed the undesirable situation, the anecdote then perceived the situation from the perspectives perimeter and showed how holistic thinking produced a better solution.

Each Case Study and anecdote provides examples of aspects of finding innovative solutions to complex problems such as where things went correctly and where and how things can and did go wrong. The common denominator in each of the examples is that rather than follow the book, in each Case

Study/anecdote the methodology was adapted, or should have been adapted, to fit the situation

Chapter 11 provided macro and micro examples of going beyond systems thinking by perceiving several issues/systems from the perspectives perimeter for different purposes, the insights obtained and the resulting innovative solutions. In each situation, holistic thinking helped pose the key questions, but the domain knowledge also known as subject matter expertise was the key to the feasibility of the insight that produced the innovative solutions. For example in:

1. ***The NASA GSFC Pacor Panic Attack*** discussed in Section 11.1: domain knowledge about the characteristics of low earth orbits prompted the key question from the *Temporal* perspective about the expected lifetime of the current satellites. Similarly domain knowledge that there were probably used computers in the marketplace prompted the second key question to confirm the hypothesis that used minicomputers were available.
2. ***An alternative teaming approach for Small and SDBs in certain types of government contracts*** discussed in Section 11.2: the key element in the innovative approach to obtaining useful information from small sample sizes came from knowledge of statistics, not systems thinking. However, perceptions from the *Continuum*, *Generic* and *Quantitative* perspectives provided the insights and impetus to rearrange the structures of the teams.
3. ***Redrawing the contractor sub-contractor boundaries in certain types of Defence contracts*** discussed in Section 11.3: it was the domain knowledge from research into the lack of teaming that enabled perceptions from the perspectives perimeter to be applied to the problems facing government contracting and the Small and SDBs to produce the hypothesis for changing the contract boundaries (*Scientific* perspective).
4. ***Addressing the problem of vertically integrating Taiwan's small and medium sized enterprises*** discussed in Section 11.4: the key insight came from beyond systems thinking using perceptions from the *Generic* perspective to conceptualise a virtual enterprise architecture using a MATO management methodology.
5. ***The determination of a set of risk-indicators to predict project failure*** discussed in Section 11.5: the key element in the study was the perception from the *Continuum* perspective that the risk-indicators could be used proactively as predictors of probable project failure (project management domain). The key to ob-

taining a reasonable amount of survey responses and useable data about the most important risk-indicators came from an understanding of human nature (the survey respondent domain) and perceptions from the *Quantitative* perspective, namely we just needed the top seven risk-indicators, and not an entire ranking. The study also provided an example of the need to formulate the right question. In this case the right question dealt with identifying the needed number of risk-indicators to be prioritized

6. ***Dealing with the ALSEP CVW failure:*** discussed in Section 11.6: the key insight in this example came from the combination of perceptions from the *Functional* and *Structural* perspectives. The domain knowledge about the allocation of shift register memory functions to hardware ICs was the key to solving the problem of the faulty CVWs.

12.2. Generating ideas - creativity

Generating ideas is known as being creative in the literature and there are a number of opinions on the topics. The word 'creativity' has several meanings as shown by the following dictionary.com[1] definitions.

- The state or quality of being creative.
- The ability to transcend traditional ideas, rules, patterns, relationships, or the like, and to create meaningful new ideas, forms, methods, interpretations, etc.; originality, progressiveness, or imagination.
- The process by which one utilizes creative ability.

The second definition is the one that is pertinent to creating innovative solutions to complex problems. So consider creativity.

12.3. The four steps of creativity

Creativity is a problem-solving process where the goal is to produce an idea for something that will remedy undesirable situations and problems. Ways the creative process can start include:

- A need that needs to be satisfied. The traditional undesirable situation that kicks off the problem-solving process.
- A product or parts and that need an application. For example, given a portable tape cassette player, the creative idea to match it with lightweight high fidelity headphones and use them as a

[1] Accessed on August 15, 2012

portable single person music player produced the Sony Walkman.

The literature portrays creativity as having the following four steps:

1. Preparation discussed in Section 12.3.1.
2. Incubation discussed in Section 12.3.2.
3. Illumination discussed in Section 12.3.3.
4. Implementation discussed in Section 12.3.4.

12.3.1. Preparation

The preparation step is where you:

- Make the perceptions and collect other information. The information can be arranged around the perspective perimeter as discussed in Section 6.1.
- Process (think about) the collected information and observations. You might evaluate the ideas or decide you need to collect more information.
- If you are going to hold an ideation meeting, then the preparations for the meetings are done in this step.

12.3.2. Incubation

Incubation is a period of time where the thinker takes a conscious rest and allows the subconscious to deal with the issue. This is where you let your subconscious do the thinking. The incubation time can vary from seconds when in an ideation meeting to days or even years. This is why you should always provide an agenda for a meeting ahead of time. It will give the participants time to incubate ideas ahead of the meeting.

12.3.3. Illumination

This step is the 'aha!' moment when the light bulb in the mind illuminates and the idea comes forward. At this point of time, the idea is an unproven hypothesis or a guess that needs to be evaluated.

12.3.4. Implementation

This step is the actual conversion of the idea to reality, or the realisation of the idea. This step can be as simple as doing it, or can be so complex and complicated that it will take years such as sending a man to the moon and bringing him back for the first time. The implementation process should start with an evaluation of the correctness and the feasibility of the idea as well as its implementation.

The four steps are iterative because the incubation state might uncover the need for further information so one would have to go back to the preparation state and obtain the information. Alternatively, the idea might not be feasible, or problems may arise during the implementation step.

12.4. Maximizing creativity

Creativity can be maximised in various ways, most of which are inexpensive. These ways, discussed below, include:

- Preparing yourself discussed in Section 12.4.1.
- Maximising creativity in meetings discussed in Section 12.4.2.
- Identifying and validating assumptions discussed in Section 12.4.3.
- Establishing an idea-generating environment discussed in Section 12.4.4.
- Writing the ideas down on paper or in a personal journal discussed in Section 12.4.5.
- Taking a break discussed in Section 12.4.6.

12.4.1. Preparing yourself

Ways to prepare yourself as discussed below, include:

1. Evaluating yourself discussed in Section 12.4.1.1.
2. Practicing using traditional thinking tools discussed in Section 12.4.1.2.
3. Developing your curiosity discussed in Section 12.4.1.3.
4. Thinking out of the box discussed in Section 12.4.1.4.
5. Practicing using the perspectives perimeter discussed in Section 12.4.1.5.
6. Practicing Active Brainstorming discussed in Section 12.4.1.6.
7. Developing the seven habits of positive critical thinking discussed in Section 12.4.1.7.
8. Living overseas for a while discussed in Section 12.4.1.8.
9. Shifting your perspective discussed in Section 12.4.1.9.
10. Becoming a radio amateur discussed in Section 12.4.1.10.
11. Learning a foreign language discussed in Section 12.4.1.11.

12.4.1.1. Evaluating yourself

Innovative solutions are the result of perceiving things differently to produce ideas and then developing those ideas into solutions. Do you have it in you to be innovative? How can you evaluate your holistic thinking ability? Section 5.3 discusses ways to evaluate critical thinking. William Perry evaluated critical thinkers based on ability to see multiple solutions (Perry, 1981)) in a learning environment in nine levels. Susan K.

Wolcott defined five levels of critical thinking integrating other aspects of critical thinking into a single number (Wolcott and Gray, 2003), Paul and Elder (Paul and Elder, 2006) and Peter A. Facione and Noreen C. Facione (Facione, et al., 2000) similarly defined four slightly different levels. Review the section and think about where you would position yourself in the various scales. This becomes your baseline. Now spend some time developing your holistic thinking abilities as described in the following sections, then in a month or so, re-evaluate yourself and find out if you have changed.

12.4.1.2. Practicing using traditional thinking tools

Practice using the traditional tools for creativity which can be grouped into:

- ***Tools for prompting ideas*** such as those discussed in Section 2.6 as well as:
    - Active Brainstorming as discussed in Section 6.1.3.
    - TRIZ, briefly mentioned in Section 4.3.2.5.
    - Diverse thinking using the *Continuum* perspective.
    - Changing the perspective often in the form of diverse thinking, but a change to any of the other perspectives should produce ideas.
- Tools for processing ideas.
- ***Tools for storing ideas*** such as notebooks, databases and the ISTs discussed in Section 6.3.2.
- ***Tools for generating and communicating ideas*** such as those discussed in Section 2.7.

Practice using the tools, not just by using the tools for the sake of using the tool, but to try and do something useful with them. Try them in the context of the suggestions in the remainder of this section. From time to time try using different tools to think about the same issue and see which tools are better for which types of thinking.

12.4.1.3. Developing your curiosity

Learn to develop or improve your curiosity. Look around you. When you see something, ask yourself some questions about it including:

- What is its purpose?
- Why is it doing whatever it is doing in the way it is doing it?
- How does it work?
- How could it be improved?

Figure 12.1 A staircase

Try using the Active Brainstorming starter questions in Section 6.2.2. If you don't know the answers look them up on the Internet or in an encyclopaedia. For example, perceive the staircase shown in Figure 12.1 from the perspectives perimeter:

- ***The Big Picture perspective:*** the staircase is located between an apartment development (at the top) and two supermarkets, bus stops and shopping centres.
- ***The Operational perspective:*** people walk up and down the staircase. If you used your imagination properly, a CONOPS for the use of the staircase would include:
  - People climbing the staircase after shopping carrying bags or pulling shopping carts.
  - Families with small children pushing child strollers.
  - Travellers carrying small suitcases.
- ***The Functional perspective:*** people have to carry everything up and down the staircase in their hands. This means that for example:
  - Senior citizens may have problems carrying large amounts of groceries, so have to go shopping more times than younger people.
  - Families have to carry the child strollers and often the children as well when the children are tired.

Figure 12.2 Shopper on staircase

  - Travellers have to carry their suitcases.

- ***The Scientific perspective:*** there should be a ramp at the side of the stairs wide enough for a small carry-on sized suitcase, child stroller or the grocery cart shown in Figure 12.2 to facilitate travelling up and down the staircase[2]. This is an idea to improve the current situation or to be used when designing such staircases in the future.

12.4.1.4. Out-of-the-box thinking

Out-of-the-box thinking means transferring ideas seen in another box to your box. This means you need to be exposed to ideas in other boxes so you can consider them for your situation. So where do you find those ideas? Try:

[2] A really good design would have catching areas every 10 Meters or so to allow the person to take a short rest without having to struggle to hold the wheeled item in place.

- Reading history, biographies and other non-fiction books to learn from other people's experiences and to learn about things in fields in which you may or may not become interested. As an electrical engineer, I thought that the postgraduate courses in sociology and psychology I had to take for my Master's degree were a complete waste of time. However, a few years later when I became a manager, I finally realised how useful the courses had been.
- Reading science fiction to open your mind to other perspectives specially the *Temporal, Generic* and *Continuum* perspectives.
- Reading detective fiction to will help you with deduction and inference.
- Reading books or web pages on various topics you know nothing about.
- Looking around you and using the *Continuum* perspective to ask yourself "what if this or that is reversed?" Gary Larson's The Far Side® cartoons (Larson, 1984) are wonderful examples of perceiving situations differently using the *Continuum* perspective.
- Looking for similarities using the *Generic* perspective.
- Looking for differences using the *Continuum* perspective.
- Looking at cartoons in the newspaper and analysing the humour for change in perspective, ambiguity and irony.
- Collecting things and learning about the things you collect such as postage stamps, coins, antiques, etc. I don't mean collecting things specially produced as collectables.
- Browsing in the library. Open any book that catches your eye and skim it.
- Surfing the Internet. Put a phrase into your favourite search engine and follow up the links it returns. If you can't think of any words, try a few words from a song, a book title, and some words from an advertisement or poster. You will enjoy a fascinating journey learning about all sorts of things. Remember to apply critical thinking to evaluate what you see on those Web sites.
- Looking around you and identifying things that could be improved. The staircase example was discussed in Section 12.4.1.3. Look at the photograph in Figure 12.3 for a second example. Notice the water on the uphill side of the path after a recent rain shower. Conclusion/hypothesis the drainage channel is on the wrong side of the footpath. And it took more than four days to repair by cracking and digging up freshly laid concrete.

Figure 12.3 Poor drainage

These activities will expand your horizons and you will pick up all sorts of knowledge that will someday help you perceive connections that other people cannot. Store the knowledge in your long term or extended memory (Figure 2.1) for access when it will be needed in the future.

Don't forget to apply critical thinking to evaluate the ideas when you retrieve them from memory to determine their suitability for the situation. Do the evaluation after retrieval, because an idea that is not suitable in one situation may be suitable in another.

12.4.1.5. Practicing using the perspectives perimeter

Two examples of using the perspectives perimeter were provided in:

- Section 12.4.1.3 which discussed a way to improve a staircase.
- Section 12.4.1.4 which discussed a drainage situation.

If you keep your senses active and your ears and eyes open, you will perceive lots of similar examples.

12.4.1.6. Practicing Active Brainstorming

Applying Active Brainstorming just takes practice. Copy Table 6.2 on to a business or name card and use it as a reminder. You can do it on your own or in teams. Try it on the situation shown in Figure 12.4. Notice the cigarette packages and stubbed out cigarettes. Use your imagination. For example, start by asking about the type of person who smokes or smoked at the bench. The answers might include: lovers having a clandestine

Figure 12.4 Smoker's bench with many possible stories

meeting, thieves planning a bank robbery or waiting for the getaway vehicle, or just smokers from the office building having a quick smoke. Keep at it and you could develop the plot for a short anecdote or even a novel.

12.4.1.7. Developing the seven habits of positive critical thinking

Facione describes the following seven habits of positive critical thinking (Facione, 2011: page 30) which you it would not hurt you to develop:

1. ***Truth-seeking:*** developing intellectual integrity and a desire to develop the best knowledge in any situation by asking probing questions and following reasoning and evidence wherever they may lead even if it means revising your cherished beliefs. It might also get you into trouble as mentioned in Section 10.3.4.
2. ***Open-mindedness:*** being tolerant of divergent opinions and sensitive to the possibility that you may be biased or even wrong.
3. ***Analytical:*** being alert to potential problems trying to foresee short- and long-term consequences of events, decisions and other actions; in other words, performing risk management on the fly. For example, when you hold a cup containing a cold drink in your hand, you place your fingers around the cup. Where do you place your little finger? In parallel with the other fingers or under the cup? If you place it under the cup then you are performing risk management for the undesirable situation in which your fin-

gers loosen slightly and the cup drops to the floor. I was sensitized to this situation when I dropped a bottle of Johnny Walker Blue Label whisky in an airport duty free shop. I had gripped the bottle tightly enough to hold the cellophane wrap but not tightly enough to hold the bottle. Luckily I got my foot under it and cushioned the fall. The sales attendants were very polite when they removed the bottle.

4. ***Systematic:*** taking an organised approach to identifying and remedying problems.
5. ***Reasoning with confidence:*** trusting in your own skills. However, trusting on the skills that you think you have but in reality do not have is a habit that hinders critical thinking as discussed in Section 12.5.6.
6. ***Inquisitiveness:*** striving to be well-informed, wanting to know how things work, and developing your curiosity. Take things apart and put them back together.
7. ***Judiciousness:*** approaching situations and problems with the sense that some are ill-structured, others may have more than one solution; recognising that many issues may not be black and white and that at times, judgements (decisions) must be made under conditions of uncertainty.

Notice the overlap with the *Generic* and *Continuum* perspectives.

12.4.1.8. Living overseas for a while

Studies have shown that living overseas for a while will help you become more innovative (Maddux and Galinsky, 2009). This may be because different countries have different cultures and do things differently[3]. Consequently, when you perceive and compare the similarities and differences between the overseas culture and your own, you develop your skills of perception from the *Generic* and *Continuum* perspectives. This may be a long-term effect because the studies did not show any correlation between travelling abroad for short trips and innovation.

12.4.1.9. Shifting your perspective

In a given situation try to shift your perspective and perceive things differently. For example, many years ago I went to the theatre with a group of friends to see a show (Section 3.2.8). I hadn't realized that it was a musical with very little plot; something that I am not interested in. Resigning myself to a boring three hours I started to notice how the colour and intensity of lights changed and how the different actors gesticulated. I spent the rest of the show studying their use of lighting techniques and

[3] Inference of a hypothesis that needs investigation

acting gestures and had an interesting and educational experience. You can always learn something from a situation even if it is what not to do next time.

12.4.1.10. Becoming a radio amateur

Join Fred's fraternity and become a radio amateur and build and operate your own equipment (software and hardware). You will have ample opportunity to scrounge for parts, create innovative uses of electronic and computer hardware and software. It is a rewarding way of finding out what works and what does not. Radio amateurs can be classified into two groups, communicators and technical. The communicators use amateur radio to talk over radio frequencies. A few of the technical radio amateurs apply holistic thinking and systems engineering principles and made many important contributions to the state-of-the-art in telecommunications and their professional domains[4]. For example, they:

- Discovered and pioneered the long-distance communications potential of short waves in the early years of the 20th century.
- Pioneered many of the techniques now used for the VHF/UHF personal communications services.
- Constructed and communicated via the world's first multiple access communications satellite (OSCAR 3) in 1965.
- Pioneered the Emergency Locator Transmitter System now used to locate downed aircraft via AMSAT-OSCAR 6 in the mid 1970's.
- Often provide communications capabilities for the public services immediately following a natural disaster or other event which wipes out commercial communications into or out of the disaster zone.
- Developed systems that range from simple to complex.
- Set up permanent and temporary amateur radio stations in:
    - Terrestrial fixed and mobile land, sea and air locations.
    - Outer space (Kasser, 1986; 1978) in amateur built spacecraft (Kasser and King, 1981), the Soviet Mir Space Station (Kasser and Krondatko, 1990) and on the International Space Station.

These days amateur radio is a hobby that covers a broad range of activities. It even has its own annual international conferences and technical symposia. Amateur radio technical symposia contain presentations of the same quality as professional events. For example, the Wireless Institute

[4] Several have even won the Nobel Prize.

of Australia held a one-day seminar in Adelaide on October 2, 2004. Topics incorporating systems engineering techniques discussed by the speakers included, communicating by bouncing radio signals off the moon (McArthur, 2004) and communications using VHF radio signals reflected off meteorite ionization trails in the ionosphere (Moncur, 2004).

If you plan for a career in engineering, systems engineering, and information technology, the opportunities to exercise your brain and the practical knowledge you will acquire as a radio amateur are priceless.

12.4.1.11. Learning a foreign language

Words are symbols for ideas and not the ideas themselves. Different languages combine those symbols in different ways and there can be subtle differences in the ideas expressed by the words and the ways ideas are expressed. Sometimes concepts that are communicated in one language do not have corresponding words in another language which makes communicating those concepts extremely difficult. Learning a foreign language exposes you to these concepts and can also make you privy to concepts other people who don't understand that language cannot experience. For example:

- In the Star Wars movies (Lucas, 1977), while Yoda might have been using English words, he was using the grammar and style of a language like German where the verb comes at the end of the word.
- In the movie Blazing Saddles (Brooks, 1974), the Indians, now called Native Americans, were speaking Yiddish. Moreover, the subtitles did not translate the words they were speaking.
- Similarly, in the move Top Secret! (Zucker, et al., 1984), the bad guys were also speaking Yiddish, and the subtitles did not translate what they were saying.

You do not need more than a basic knowledge and a limited vocabulary to begin to understand the concept that different languages express similar and different concepts which will help you both communicate with speakers of those languages and understand the concept of subtle differences in the meanings of words. You'll learn to begin to recognize what the other person is trying to communicate even if the words they are using are incorrect. Active listening (Section 3.4.3) is a very useful communications tool in this situation.

12.4.2. Maximizing creativity in meetings

You can maximise creativity in meetings by:

1. Recognizing the four steps and taking advantage of them discussed in Section 12.4.2.1.
2. Focusing on the right HTP for the issue discussed in Section 12.4.2.2.

12.4.2.1. Recognizing the four steps and taking advantage of them

Many brainstorming sessions don't pose the question until the meeting begins. Since the four steps of creativity contain that incubation step, allow for that time by posing the question prior to the meeting in the invitation to the meeting. Preparing and circulating a meeting agenda serves the same purpose for other types of meetings. Reading the meeting agenda ahead of time allows the participants to think about the issues and incubate ideas ahead of time as well as during the meeting.

12.4.2.2. Focusing on the right HTP for the meeting

Section 5.3.5 discussed evaluating critical thinking based on the different characteristics of problem solvers and solution finders, namely:

- ***Problem formulators:*** score high in ability to find differences among objects which seem to be similar, namely they are focusing on the *Continuum* perspective.
- ***Problem solvers:*** score high in ability to find similarities among objects which seem to be different, namely they are focusing on the *Generic* perspective.

So, in addition to *Operational*, *Functional* and *Structural* perspectives, if the meeting is to:

- ***Define the problem:*** concentrate[5] on perceptions from the *Generic* and *Continuum* perspectives.
- ***Remedy the problem:*** concentrate on perceptions from the *Generic* and *Continuum* perspectives. Out-of-the-box solutions tend to come from these perspectives as demonstrated in the examples in this book.
- ***Determine exactly what makes the situation undesirable:*** concentrate on perceptions from both the *Generic* and *Continuum* perspectives.

12.4.3. Identifying and validating assumptions

Almost everything we do is based on underlying assumptions which are often implied and rarely articulated. Try determining the assumptions underlying proverbs as practice for determining assumptions. For exam-

[5] Concentrate, but do not exclude, the other perspectives.

ple, consider the assumptions underlying the ancient Chinese proverb, "*Give a man a fish; feed him for a day. Teach a man to fish; feed him for a lifetime*". The assumptions include:

- The man can be taught.
- The man is willing to be taught.
- The supply of fish will last a lifetime.
- The man likes to eat fish.
- The man is willing to eat nothing but fish.
- Eating fish will provide 100% of the man's nutritional needs.

Can you think of any other assumptions in the proverb? For example what about the assumptions regarding the tools used in fishing?

12.4.4. Establishing an idea generating environment

While creativity is not limited to specific times and places, it is worthwhile setting up an environment that facilitates your thinking process. You ought to know how you work best and what tools can help you think, so set up an environment accordingly. For example, I like to use:

- ***A whiteboard*** like the one in shown in Figure 2.29 to develop concept maps when thinking about issues.
- ***A large size monitor*** for my personal computer which enables me to have two full size windows open at the same time. I can research information on the Internet via the web browser while working on a document.
- ***Sticky notes*** on a wall or whiteboard to capture and associate idea***s.***
- ***Music*** from time to time so I have a set up a stereo in my home office and can also play music on the computer.

You need to establish your own.

12.4.5. Writing the ideas down on paper or in a personal journal

Keep a journal and carry a notebook in paper or electronic format to capture the often-fleeting ideas that can appear at any time. When noting ideas, add the date the idea surfaced to the note. If the idea has potential to become an innovation, you may need to be able to prove the date on which you had the idea. So, find someone to witness the journal entry or copy the journal entry, insert the copy into an envelope and mail it to yourself. Do not open the envelope when you receive it, file it away in a safe place unopened. The postmark will provide proof that the idea existed on that date. If you use a softcopy, copy the file to write-only memory such as a Compact Disk every month or so to help you to establish that the idea existed at that date. Don't forget to review the ideas from time to time otherwise the notebook will become a write only memory.

12.4.6. Taking a break

If you are facing a problem and can't think of a solution try taking a break and focusing your thoughts on something else, or even relaxing. Allow time for the ideas pertaining to the solution to incubate. I've often used this approach when writing computer software. Unsolved problems at the time of leaving work on Friday afternoons tended to be solved or resolved on Monday morning with little conscious thought on the matter over the weekend.

12.5. Habits that hinder creating and adopting new ideas

Applying perceptions from the *Continuum* perspective, there are a number of habits or cognitive filters that, in general[6], hinder creating and adopting new ideas so you should avoid or at least minimise them. One set of habits that hinder thinking is (Ruggiero, 2012: pages 54 to 61):

1. Mine is better discussed in Section 12.5.1.
2. Face saving discussed in Section 12.5.2.
3. Resistance to change discussed in Section 12.5.3.
4. Conformity discussed in Section 12.5.4.
5. Stereotyping discussed in Section 12.5.5.
6. Self-deception discussed in Section 12.5.6.

12.5.1. Mine is better

'Mine is better' manifests itself in cultures, nations, organisations and individuals who exhibit a sense of superiority over outsiders. One example can be found in their jokes. The (US) Americans tell Polish jokes, the English tell Irish jokes and the Australians tell New Zealand jokes. Perceiving the jokes from the *Generic* perspective, the jokes are identical while the ethnicity of the actors is different. The Jews couldn't find anyone lower in the ethnic hierarchy so they invented an imaginary town called Chelm and told jokes about the inhabitants of Chelm. Jewish jokes also involve irony as well as ambiguity and some degree of holistic thinking. For example:

> It took a few weeks for the Rabbi of Chelm to finally notice that his congregants had stopped listening to his Saturday morning sermons. Their minds seemed to be elsewhere during the sermons. So after the service, at the post-service breakfast,

[6] The words "in general", generally refer to the *Generic* perspective.

> he asked several of the notables in the community to tell him what they had been thinking about during the sermon. Each of them apologised for not listening and told him that they had been, and still were, worrying about something. Making further enquiries he discovered that the whole community was worrying, often about the same things. He brought this to the attention of the board of directors, and they admitted they were also worriers but had not realised that it was a community-wide problem; truly an undesirable situation. So they brainstormed the problem of what to do about the worrying. After a refreshment break they evaluated the ideas and decided that the best idea was to increase the duties of Moishe, the synagogue caretaker. Moishe would be given the additional duty of worrying on behalf of the community and his salary would be increased to compensate him for the extra wear and tear on his nerves caused by the worries[7]. This action would free the congregants from worry and improve their quality of life.
>
> The president made a motion to the effect that the community worrying be delegated to Moishe with appropriate compensation. After some discussion they achieved a consensus that $100 a week was a more than generous salary increment. It was a small sum for the entire community to bear and at the same time a significant raise for Moishe. The president then called the question and asked for a show of hands. At that instant, one of the board members who had been silent throughout the discussion asked, "if Moishe is going to get a raise of $100 a week, what will he have to worry about?[8]"

As far as thinking is concerned, the 'mine is better' habit destroys objectivity and the willingness to hear new ideas. It often manifests itself as the 'Not Invented Here' (NIH) syndrome. It seems to be a symptom of the lack of use of the *Generic* and *Continuum* perspectives coupled with an unwillingness to allow an objective evaluation of your ideas.

---

[7] The idea for the joke came from the *Generic* perspective perception of the similarity between the high priest placing the sins of the community on the scapegoat on the Day of Atonement in Biblical times, and the concept of placing the worries of the community on Moishe's shoulders. The difference being that Moishe would be compensated for his duties, while the scapegoat was led out into the wilderness taking the sins with it.

[8] How about 'how long will his good fortune last', for a start?

You can try to overcome this hindering habit by pretending that the idea is not yours and evaluate it objectively. If you have a problem pretending the idea is not yours, then pretend you have an even better idea while evaluating the first idea. Who knows you might even think of one during the idea evaluation process.

12.5.2. Face saving

Face saving or 'it wasn't my fault' which while acknowledging that an error of some kind occurred does not accept responsibility for the error. This failure to admit mistakes is an example of the misuse of the *Continuum* perspective to shift the blame to someone else. Face saving can lead to:

- ***Rationalizing:*** which creates evidence for beliefs rather than using evidence to create beliefs.
- ***Compounding the error and undesirable consequences:*** for example, identifying the wrong underlying cause for the error and remedying the wrong problem while the true cause remains untreated.

While it is generally easy to see this habit in someone else, pride and arrogance are effective cognitive filters that inhibit you seeing this habit in yourself. You can try to overcome this hindering habit by pretending that the idea is not yours and evaluate it objectively in the manner discussed in Section 12.5.1.

12.5.3. Resistance to change

Resistance to change manifests itself as a tendency to reject new ideas and innovations. It is nothing new. For example:

- The stakeholders in the products the new idea or innovation is replacing have resisted almost every innovation in history. For example, 500 years ago Machiavelli wrote, "*And it ought to be remembered that there is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things. Because the innovator has for enemies all those who have done well under the old conditions, and lukewarm defenders in those who may do well under the new*" (Machiavelli, 1515).
- Kuhn wrote regarding change that paradigm shifts do not occur without a great deal of resistance since it is nigh impossible for people to unlearn something they know is correct (Kuhn, 1970).
- Tradition is often used as an excuse for not changing something.

Sometimes change is resisted due to laziness, and sometimes due to fear of the unknown. You can overcome this hindering habit by showing people how the new idea will benefit them[9]. For example, it may:

- Reduce the amount of work they will have to do once the idea is implemented which will give them increased leisure or extra time to accomplish other tasks.
- Increase their income.

In other words, find out what is undesirable about the current situation or what problem people are having, then show them how the change will help them (Crosby, 1981: page 92). You can and should apply this idea to yourself.

While no two companies' business situations are identical (Hammer and Champy, 1993: page 159), there are methodologies that can be employed to perform the paradigm shift in an effective manner. **The change does not have to be, and should not be, chaotic.** Do not radically change everything in the organization at the same time. **The change must be gradual and made with care.** Start with a vision of the desired result and work backwards along the transition path via identifiable milestones to the present. For example, the sequence for implementing a transition from the current paradigm to the 'customer-driven process organization' paradigm is as follows:

1. Communicate the need to change.
2. Identify the current processes performed by the organization and determine the value chain.
3. Baseline the current state of the organization.
4. Create the draft vision statement of the changed organisation.
5. Create the transition plan.
6. Design the Reward and Recognition System (RRS) to support the changed organisation.
7. Pilot one process transition to the new paradigm.
8. Implement the RRS.
9. Baseline the change.
10. Evaluate the experience
11. Update the transition plan
12. Start the transition cycle for the next process.

Think of the normal distribution curve in statistics as a fence. Most people are sitting on the fence; your job is to encourage them to slide down the fence on your (the improved) side. You will encounter three types of people when implementing the change. They are those:

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[9] Especially if you want them to adopt your innovative idea

- ***For the change:*** who will make it happen if given the chance, whatever it takes. They tend to be the people involved with the process who can see the defects and want to initiate improvements. Implement the first change with these people. They will make it work. If you reward them visibly, you will set up the next batch of people to implement the next change.
- ***Who are undecided:*** they are sitting on the fence waiting to see which way the wind is blowing. The goal is to move them to your side of the fence so they support you.
- ***Against the change:*** they have no motivation to effect the change. The goal is to make them amenable to the change by first moving them to the undecided camp.

If there is a real hard core of resistance on the other side of the fence, don't confront it early in the change process; bypass it for as long as you can, it may fade away on its own.

12.5.4. Conformity

This hindering habit is conforming to the normal behaviour without thinking if it is still the best way to do something. This hindering habit is basically the lack of thinking. This type of behaviour is often used to justify behaviour such as 'going by the book' or 'following the process'; the basis for the cartoon shown in Figure 12.5. You can overcome this hindering habit by using the thinking tools described in this book to determine if, when and why you think a change is necessary and how to overcome resistance to that change. However, be alerted that domain knowledge is critical to ensuring that your idea for a change is feasible and valid and you are not doing the equivalent of building a factory to put the smoke back into broken electronic equipment to restore them to a working condition (Section 5.1.3.2).

12.5.5. Stereotyping

Stereotyping is generalizing extremes. Stereotyping allows us to associate positive or negative attributes without having to think about the instance. Stereotypes are an extreme form of inheritance of attributes from a generic class, taking the form of a cognitive filter based on assumptions that 'all X are Y' and the premise that your specific instance of X is Y. For example:

- All politicians are corrupt, so Mr Smith, a politician, is corrupt.
- Blondes are dumb, so Wendy, who is blond, is dumb.

Figure 12.5 Reaction to innovative idea

- "*Mad dogs and Englishmen go out in the midday sun*" (Coward, 1931). So, Joe who is English and lives in Singapore always goes out for a lunchtime stroll on sunny days.

You can overcome this hindering habit by trying not to stereotype or by recognising that you are using stereotypes as baselines and then thinking about how the instance you are ideating differs from the stereotypes.

12.5.6. Self-deception

Self-deception is not being able to face up to your own shortcomings and making excuses. Self-deception tends to be:

- A failure to accept responsibility for an error, namely "it wasn't my fault" and shifting the blame to someone else as discussed in Section 12.5.2. You can try to overcome this hindering habit as discussed in 12.5.2.
- An unwillingness to face up to or fear of confirming bad news. For example, if you think you have a serious illness you put off going to the doctor to get a diagnosis. After all what you don't

know can't hurt you, right? Wrong. What you don't know can and often does hurt you. The type of hurt lies on a continuum ranging from minor, such a failing an examination because you did not memorize the knowledge, to major, such as dying from cancer because you did not go to the doctor in time to catch the cancer in its early treatable stage. You can try to overcome this hindering habit by facing your fears and acting to take control of events in a proactive manner.

- A willingness to talk in an authoritative manner about a subject that you have little knowledge rather than to admit that you don't know very much about the subject. You can try to overcome this hindering habit by remembering the following aphorism, "*if you keep your mouth shut, people will only think that you are stupid*" (Kasser, 1960). Before you open your mouth to say something or start to write something. Think about it. If you open your mouth people will …[10].
- A willingness to consider unsubstantiated opinions as facts and then act accordingly. This is Wolcott's biased jumper level of critical thinking ability mentioned in Section 5.3.1.2. You can try to overcome this hindering habit by improving your critical thinking skills.

12.6. Perceiving similarities when others do not

Holistic thinkers create innovative solutions to complex problems: they can perceive things that are not there; and I don't mean hallucinations. They can perceive similarities and differences when others don't and can apply ideas from that other situation (out-of-the-box thinking) (Section 5.3.5).

You need to develop the ability to use the *Generic* perspective perceive similarities when others do not. This will provide you with innovative ideas which will need to be evaluated. Moreover, you must realise that you may not be qualified to evaluate the ideas because you lack the relevant domain knowledge. For example consider the:

1. Similarities and overlaps between problem-solving and decision-making discussed in Section 12.6.1.
2. Similarities between the human brain and a personal computer[11] discussed in Section 12.6.2.

[10] Realize that you indeed are stupid or ignorant

[11] This example was chosen because this is a book about holistic thinking.

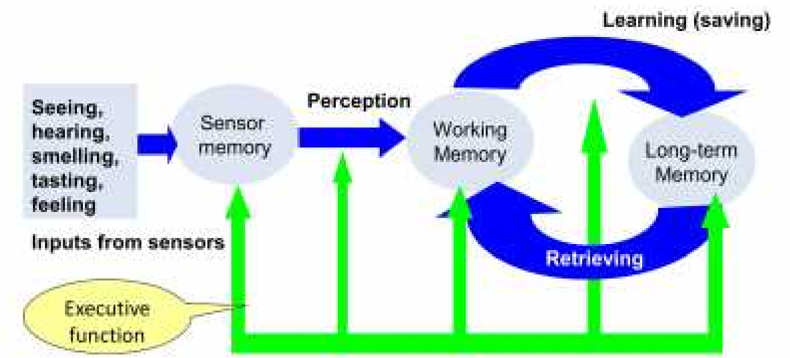

Figure 12.6 The cognitive psychology model of the human brain

12.6.1. Similarities and overlaps between problem-solving and decision-making

This is a simple example. The failure to perceive different aggregations of the same activities in different contexts and domains has created slightly different descriptions of the same processes. For example:

- The variations of the problem-solving processes discussed in Section 9.15.
- The overlap between decision-making and problem-solving.
- The four steps of creativity (Section 12.3) are tightly coupled with, not separate from, problem-solving.

12.6.2. Similarities between the human brain and a personal computer

This is a more complex example of perceiving the similarities from the *Functional* perspective. The human brain does not seem to be configured for perceiving anything from different perspectives at the same time. Moreover, according to Anderson we can only pay attention to one cognitively demanding task at a time (Anderson, 1995). This gap may be fillable by perceiving the similarity between the ways that the single processor personal computer and the brain could multi-task from the *Functional* perspective.

12.6.2.1. The basic digital computer multi-tasking concept

The most widely used cognitive psychology information processing model of the brain based on the work of (Atkinson and Shiffrin, 1968) cited by (Lutz and Huitt, 2003) shown in Figure 12.6 likens the human mind to an information processing computer. Both the human mind and the computer ingest information, process it to change its form, store it, retrieve it, and generate responses to inputs (Woolfolk, 1998).

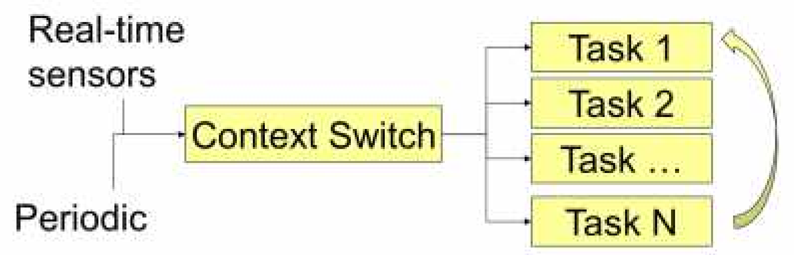

Figure 12.7 Digital computer multi-tasking architecture

The basic digital computer multi-tasking concept is broadly shown in Figure 12.7. The several tasks or applications loaded in memory are represented by Tasks 1, 2, to N. Each task contains a program that processes information or 'thinks' about something and accesses and stores data in memory. The Context Switch is the program that performs the task switching function by transferring the attention of the Central Processing Unit (CPU) in the computer from one task to the next when it receives an interrupt signal.

12.6.2.2. Interrupts and interrupt processing

The interrupt signal may be generated periodically at fixed periods of time by a hardware signal, by a sensor in response to an event or even within the task when the program recognises the need to terminate the task. This transfer of attention or task switching requires ways to save and restore the state of each task when the switching occurs as discussed below.

12.6.2.2.1. Periodic interrupts

When a periodic interrupt is received the Context Switch responds in the following manner.

1. The state of the current task is saved.
2. The state of the next task in the sequence is retrieved.
3. The new task becomes the current task.
4. The next task is identified. If the current task is the last task, then the next task is the first task.
5. The current task is enabled to continue from where it left off in the previous task sequence cycle.

In most digital computer multi-tasking operating systems based on a periodic interrupt, the number of tasks can be large, and since the time allocated to each task is a fraction of the time available for all the tasks (including the time to save and restore the state of the task between task switches), the more tasks loaded into memory, the slower any one task seems to take[12].

12.6.2.2.2. Real-time interrupts

When a real time interrupt is received the Context Switch responds in a slightly different manner as follows.

1. The state of the current task is saved.
2. The state of the task associated with the specific real time interrupt is retrieved.
3. The new task becomes the current task.
4. The next task is identified. If the current task is the last task, then the next task is the first task.
5. The current task is enabled to continue from where it left off in the previous task sequence cycle.

12.6.2.2.3. Self-terminating tasks

When a task self terminates, the sequence of activities performed is the same as for a periodic interrupt.

12.6.2.3. Foreground and background tasks

One arrangement of tasks in a digital computer is to divide tasks between foreground and background tasks. Background tasks are those that are routine autonomic housekeeping activities such as those that monitor the state of the system, diagnostics, etc. Foreground tasks are the user's applications controlled by the operating system and depend on the context in which the system is deployed.

12.6.2.4. Holistic thinking as human multi-tasking

"*We can only pay attention to one demanding task at a time*" (Anderson, 1995). In computer terms the human information processing system, while capable of multi-tasking, can only handle one foreground or conscious task at any particular time. In holistic thinking the mind moves round the perspectives perimeter (Section 4.2) perceiving the system or situation from each of the HTPs one perspective at a time. The approach is holistic when considered over a period of time or a number of cycles around the perspectives perimeter. The switching between perspectives may be sequential or may be driven by association of ideas where an idea from one perspective triggers a switch to a different perspective out of sequence in the manner of a self-terminating task. One focused way of switching perspectives is Active Brainstorming discussed in Section 6.2.

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[12] This is why reducing the number of open windows on a Personal Computer can seem to speed up the computer.

The time spent in each perspective will depend on the person's attention span. While the digital computer spends a fraction of a second in each task, the attention span of the human brain (time spent on a task) seems to vary. Sometimes tasks are completed before switching to the next task; these are cases where the person is focused on that task to the exclusion of others, and at other times switching takes place before a task is completed.

12.6.2.5. Multi-tasking in the brain

Multi-tasking covers autonomic and cognitive activities. Autonomic activities can be considered as the background tasks, while cognitive activities can be considered as foreground tasks. Cognitive activities include accessing, processing and storing information. The most widely used cognitive psychology information processing model of the brain based on the work of (Atkinson and Shiffrin, 1968) cited by (Lutz and Huitt, 2003) likens the human mind to an information processing computer. Both ingest information, process it to change its form, store it, retrieve it, and generate responses to inputs (Woolfolk, 1998). In this multi-tasking model, the inputs from the external sensors also feed the executive as interrupts. Internal sensors for pain also feed interrupts. Some people seem to be able to set the threshold of their pain sensors (to ignore the input) at higher levels than others. From the *Generic* perspective, some people also seem to be able to focus on a single task and set the threshold of other interrupts at higher levels which allow them to ignore the sensor inputs up to a point. Some people can set the threshold so high that they do not respond to any external stimulus and may have to be physically shaken in order to attract their attention to a different task.

In a computer the number of tasks can be large. In the human brain, perhaps Miller's rule of seven plus or minus one (Miller, 1956) limits the number of perspectives on the perspectives perimeter that can be used during holistic thinking.

12.6.2.6. Inferences from the Scientific perspective

This Section lists a number of hypotheses or conclusions inferred from the perceptions. These conclusions must be evaluated using critical thinking by those with the applicable domain knowledge to make sure that they are not statements equivalent to "electronics only works while the smoke is inside the box" discussed in Section 5.1.3.2.

1. People who can multi-task have short attention spans, and/or low thresholds on their interrupt circuits. Hence women who claim they can multi-task while men cannot are really saying that women have shorter attention spans than men.

2. Consider left brain and right brain activities as being performed by independent parallel processors. Each side of the brain can perform separate tasks and sometimes both sides of the brain process data from the same inputs. When the left brain and right brain and processes produce complimentary results they reinforce each other. However, issues arise when the processes produce contradictory results due to a failure in one side of the brain. This insight might explain some of the observations in Daniel Goleman's book on emotional intelligence (Goleman, 1995).
3. Interrupt circuit switching thresholds range along a continuum from boredom (low threshold) to being very interested in something (high threshold).
4. Faulty high interrupt thresholds may account for abnormal intellectual abilities which result in people being locked into one cognitive task to the exclusion of others.

For now, I'll leave the evaluation of these hypotheses to those who have detailed knowledge of the domain[13].

12.7. Perceiving differences to dissolve paradoxes and create the impossible

A paradox or impossibility is often based on implied assumptions. Use perceptions from the *Continuum* perspective to find (1) a paradox, or (2) something that is impossible and then assume it is possible, or (3) something that is not technically possible at present, and then try to dissolve the paradox or try to figure out what needs to be invented or discovered to make the impossible possible. For example:

- ***Bumblebees can't fly but do so:*** this paradox[14] is only valid if the bumblebee is perceived as a fixed-wing aircraft. At the time the paradox was developed, the only type of aircraft known was fixed-wing. The paradox was dissolved in the 1990's when the mathematics for analysing variable-wing aircraft was developed. When perceived from the variable-wing perspective, the mathematics explained the flight of the bumblebee.
- ***What came first, the chicken or the egg?*** Perceiving the question from the *Continuum* perspective, the answer depends on the context in which the question is being posed, namely:

[13] This is an example of knowing what you don't know and acting accordingly: a vital characteristic of a holistic thinker

[14] In its time, this paradox was recognized an instance where science was unable to explain an observation.

  - According to the theory of evolution (Darwin, 1859), the egg came first because the chicken evolved from the creature that laid the egg.
  - According to creationism, the chicken came first because it was created and then laid the egg.
  - In the context of a meal, it depends on what was on the menu for the previous course.
  - Which egg are we talking about, the one the chicken laid, or the one it hatched from? If we are talking about the former then the chicken came first, if we are talking about the latter, then the egg came first.
- ***Faster than light travel***. Science states that this is impossible. Assume it is possible and there are spacecraft out there flying faster than light (assume in, or visible in, normal space and not in hyperspace of some kind). Now think about how they would appear when observed from the Earth. Test the hypothesis by correlating your hypothesis with known astronomical phenomena. If you find a correlation, your hypothesis might be supported, although there may be other current explanations of the phenomena. So try to figure out which part of Einstein's theory of relativity (Einstein, 1916) needs to be changed. Remember from the *Temporal* perspective, today's theory is but a stepping stone in the staircase of history (Section 4.3.2.7) so there is a good probability that there will eventually be a modified version or even a replacement theory.
- ***The blaster weapon in science fiction***. The *Operational* perspective is well known from the many uses of blasters in films such as Star Wars (Lucas, 1977). One example of how the blaster works internally (*Functional* perspective) is to generate a small quantity of Ball lightning [in a chamber[15]] and then accelerate the ball through the weapon's barrel to a high speed in the direction of the target. I've stated how it functions; now all you have to do is figure out how to construct a prototype (the *Structural* perspective)?

Perceptions from the *Temporal* perspective indicate that if one person can imagine it, someone else will eventually figure out a way to make it happen.

[15] Note the use of solution language in the [square brackets] to help convey the concept.

12.8. Examining complex descriptions of situations

If you feel that you are facing a complex situation, recognise that excessive complexity is a symptom of a defect in the paradigm where the perspective needed to remedy the defect is unknown. This is where you use the Scientific Method version of the problem-solving process discussed in Section 9.12.2.1 to examine the situation and formulate and test a hypothesis for a simpler paradigm. Try using the techniques discussed in Section 7.8 to reduce the complexity.

12.9. Pretend you are living a Case Study

Case Studies describe history; something that happened in the past. In some instances, when learning from Case Studies you take up the role of a person in the case and examine the situation before making a decision. From the *Temporal* perspective, you may be able to think of yourself as living a Case Study. Except in your situation you won't know if you made the right decision until you experience the outcomes from the decision. And that may take weeks, months or even years.

Try to document the situation using the approaches discussed in Section 6.1. Then use Active Brainstorming (Section 6.2) and the ISTs (Section 6.3.2) as appropriate for your situation.

12.10. Combining parts into a new application.

Imagine how combining a few parts could create a new product or software application or think of a new product and how it could be realized from existing parts. For example, consider:

- A remote controlled dental drill.
- An undetectable security camera.

12.10.1. A remote controlled dental drill

Have you ever sat in a dentist's chair having a tooth filled and wondered if there was a better way than having the dentist's fingers in your mouth? How about a small device that could be clamped onto the tooth? The device would contain a laser drill head and a camera. The dentist would operate the drill by remote control using the camera to see the drilling progress. This device would be a new product developed by combining two existing items.

12.10.2. An undetectable security camera

Combine the camera sensor from a web camera with a USB memory stick and some additional software into a device that wakes up once a second and examines the area covered by the camera. Charge the battery and place the device in an area you wish to monitor. If there is no change from the previously stored picture, the device goes back to sleep. If there is a change, the device stores the changed picture tagging it with date and time. While not providing a real-time alarm function, the device will show who intruded into the area and when; information that can be used as appropriate. The device is undetectable because it is not connected to any wires nor does it radiate a radio signal. On the down side, it has to be periodically checked and recharged manually.

12.11. Perceiving things differently

Innovation often comes from performing a mental gap analysis between what is perceived and a conceptual mental model of what could be. This is where innovators perceive things differently to other people. Sometimes they will find an undesirable situation that other people may not realise exists. For example, consider:

- ***Restroom[16] doors open the wrong way***. The doors generally open inwards into the restroom which means that you have to touch the door handle to open the door to leave the restroom. If everybody washes their hands before opening the door, everything should be healthy. However, that is an assumption and not everybody does wash their hands. People who do not wash their hands before opening the door may deposit harmful bacteria on the door handle so that even if you do wash your hands, you will pick up someone else's leavings when you touch the same door handle. Restroom doors should open outwards or slide out of the way, preferably without the need to be touched in the same manner that many public buildings have automatic sliding entrance doors.
- ***Lecture theatre and classroom clocks***. The clocks should be placed where the lecturer can see them while facing the students, rather than being placed behind the lecturer where the students can see the clocks. This placing will facilitate the lecturer pacing the lecture and finishing on time.

Holistic thinkers who perceive things differently and prevent these types of undesirable situations from occurring are generally not appreciated because nobody knows what undesirable situations were prevented since they never happened. However, it is this skill to perceive things differently that leads to the out-of-the-box solution. The skill may come

[16] Also known as toilets or washrooms

from having knowledge and experience that others do not. That is why you need to prepare yourself as described in Section 12.4.1.

12.12. Summary

This Chapter:

1. Provided suggestions for how you can go about creating your own innovative solutions to complex problems.
2. Discussed innovation.
3. Summarized practical ways to use the tools and methodologies presented in this book.
4. Began with a summary of the previous chapters of the book in Section 12.1.
5. Discussed generating ideas in Section 12.2.
6. Discussed the four steps of creativity in Section 12.3.
7. Discussed maximising creativity in Section 12.4.
8. Discussed habits that hinder creating and adopting new ideas in Section 12.5.
9. Discussed perceiving similarities where others do not and its consequences to you in Section 12.5.6 with some examples.
10. Discussed perceiving differences to dissolve paradoxes and create the impossible in Section 12.7.
11. Discussed examining complex descriptions of situations in Section 12.8.
12. Discussed pretending you are living a Case Study in Section 12.9.
13. Discussed two examples of combining parts into a new innovative application in Section 12.10.
14. Discussed perceiving things differently in 12.11.
15. Summarised the Chapter in Section 12.12.
16. Closes with a last word in Section 12.13.

12.13. Last word

What is the difference between an optimist, a pessimist and a holistic thinker? To an:

- ***Optimist:*** the glass is half full.
- ***Pessimist:*** the glass is half empty.
- ***Holistic thinker:*** the glass is obviously the wrong size.

Which are you, and which do you strive to becomes, assuming you want to change. Well you did read this far in the book, so it is probably a valid assumption.

--oo--

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