13.1. *Checkland's Soft Systems Methodology*

Checkland's Soft Systems Methodology (SSM) (Checkland and Scholes 1990):

- Is a tool for gaining an understanding of a problematic situation in social situations; situations in which people are involved, in a systemic and systematic manner.
- Was developed for the express purpose of dealing with soft problems in Layer 5 of the Hitchins-Kasser-Massie Framework (HKMF) (Section 5.2).
- Is used to convert an Ill-Structured Problem into a number of Well-Structured Problems (Section 5.3.2).
- Is a seven-stage customised version of part of the generic problem-solving process. "*The function of stages 1 and 2 is to display the situation so that the range of possible, and, hopefully, relevant choices can be revealed, and that is the only function of those stages"* (Checkland 1991: page 166).
- Seems to be the most widely known version of SSM; there are others such as Avison and Fitzgerald (Avison and Fitzgerald 2003).

This section describes this author's interpretation of Checkland's SSM. The interpretation is based on perceiving SSM from the HTPs (Section 10.1) and adapting SSM in the situation described in Section 13.1.2.

13.1.1. ***The seven-stages of SSM***

The seven-stages of SSM are:

1. Recognizing the existence of a problematical or undesirable situation.
2. Expressing the real-world problematic situation.
3. Formulating root definitions of relevant systems of purposeful activity from different HTPs.
4. Building conceptual models of the systems named in the root definitions.
5. Comparing the conceptual models developed in Step 4 with the real world situations documented in Step 2.
6. Identifying feasible and desirable changes.
7. Actions to improve the problem situation.

13.1.1.1. **Stage 1: Recognizing the existence of a problematic or undesirable situation**

This stage begins when a problem owner determines that an existing situation is undesirable and needs to be changed. The problem owner is someone who has or is given the authority and appropriate resources, to initiate a project to study the situation to determine the cause or causes of undesirability and recommend appropriate actions to make a transition from the existing undesirable or problematic situation to a FCFDS. The initial parts of the study are performed by the problem solver often an analyst.

13.1.1.2. **Stage 2: Expressing the real-world problematic situation**

This is the stage that examines and documents the real-world problematic situation. The emphasis is on gaining an understanding of the real-world situation and documenting it. The original SSM documented the situation in hand-drawn Rich Pictures (Section 6.1.5) in accordance with the adage, "*a picture is worth a 1000 words*".

SSM suggested three types of analysis be carried out on organizations in which people are involved.

1. ***Analysis one:*** the role analysis identifies the roles of three of the actors in the transformation. These three roles are:
    1. The 'client' is the person or persons who caused the study to take place.
    2. The 'would be problem solver' is whoever wishes to do something about the situation in question and "*the intervention had better be defined in terms of their perceptions, knowledge and readiness to make resources' available*" in other words in the client's language.
    3. The role 'problem owner'.
2. ***Analysis two:*** is based on a model that assumes a social system to be a continually changing interaction between three elements: roles, norms and values. Each continually defines, redefines and is itself defined by the other two.
3. ***Analysis three:*** analyses the politics; "*the processes by which differing interests reach accommodation*". The analysis begins with the study of how power is expressed in the situation including authority (formal and informal), memberships of groups, committees, etc.

The analyst[1] perceives the problematic situation from a number of perspectives such as the HTPs (Section 10.1) collecting, sorting and documenting the information. Examples of such observations include:

- Perceptions from the *Big Picture* perspective include:
    - The environment.
    - The boundary of the problematic situation.
    - Adjacent systems to the problematic situation.
    - The issues that the people involved in the situation think are problematical.
- Perceptions from the *Operational* perspective include:
    - The processes or transformations taking place in the situation. Each transformation process may be considered as a black box system, the input being an entity and the output being a transformed entity.
- Perceptions from the *Functional* perspective include:
    - The internal functions inside the processes or transformations (black box) perceived from the *Operational* HTP.
- Perceptions from the *Structural* perspective include elements slow to change including:
    - The organization chart.
    - Physical elements such as buildings, locations.
    - Information used in the functions.
    - How power is expressed in the situation including authority (formal and informal), memberships of groups, committees, etc.
- Perceptions from the *Quantitative* perspective include the following three minimal criteria for evaluating a process:
    1. ***Efficacy:*** how well the process performs its intended task. This may not be the lowest cost process.

[1] Depending on the nature and scope of the problematic situation, the problem-solver may be a single analyst or a team with different disciplinary skills.

2. ***Efficiency:*** as measured by the amount of output divided by the amount of resources used.
3. ***Effectiveness:*** how well the process meets the longer term aim.

Other criteria such as Ethical and Elegance may be added depending on the situation. A minimum value for each criterion should be set at the time the project begins.

13.1.1.3. **Stage 3: Formulating root definitions of relevant systems**

The perceptions from the *Operational* and *Functional* HTPs are summarized in root definitions. "*A root definition expresses the core purpose of a purposeful activity system. That core purpose is always expressed as a transformation process in which some entity. The 'input' is changed, or transformed, into some new form of that same entity, the 'output'*" (Checkland and Scholes 1990: page 33). Any system generally can be conceived has being different things and performing different functions by the stakeholders many of which have no idea that a different perception exits. 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.

In the development of SSM, the names of relevant systems had to be written in such a way that they made it possible to build a model of the system named. The names became known as 'root definitions' since they express the core or essence of the perception to be modelled.

The root definition is a perception from the *Operational* HTP (Section 10.1). The simplest version of a root definition is 'a system to do something' from the perspective of a stakeholder. However, perceptions from the *Continuum* HTP indicate that different stakeholders may have different root definitions, for example a pub or bar could be (Kasser 2015: page 134):

- ***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.

Each of these systems performs a different transformation process and can be considered as a subsystem of the whole.

13.1.1.3.1. **CATWOE**

Checkland's root definitions are formulated as sentences that elaborate a transformation using six elements which are summed up in the template mnemonic CATWOE as follows:

- ***Customers:*** the victims or beneficiaries of a transformation process. These entities should be known as stakeholders since they have a stake in the process while the customers are the specific stakeholders who fund the transformation process.
- ***Actors:*** the stakeholders who perform the transformation process.
- ***Transformation process:*** the conversion of the input to an output, namely the purpose of a system.
- ***Weltanschauung:*** this world view, HTP or paradigm (Kuhn 1970) which makes the transformation process meaningful in context of the stakeholders. Perceptions from the *Continuum* HTP indicate that each stakeholder may have a different *Weltanschauung*.

- ***Owner(s):*** the stakeholder(s) who has/have the power to start up and shut down the transformation process.
- ***Environmental constraints:*** elements that exist outside the system which it takes as given.

Checkland's version of a root definition is 'a system to do something by means of something in order to achieve a goal or purpose'. Checkland provides the following example of a root definition, "*A householder-owned and manned system to paint a garden fence, by conventional-hand painting, in keeping with the overall decoration scheme of the properly, in order to enhance the visual appearance of the property*" (Checkland and Scholes 1990: page 36). The CATWOE template points to the following:

C: householder.
A: actor or person performing the transformation.
T: activity which transforms an unpainted garden fence into a painted fence.
W: amateur painting can enhance the appearance of the house.
O: householder.
E: hand painting.

"*The core of CATWOE is the pairing of transformation process T and the W, the Weltanschauung or worldview which makes it meaningful. For any relevant purposeful activity there will always be a number of different transformations by means of which it can be expressed, these deriving from different interpretations of its purpose*" (Checkland and Scholes 1990: page 35).

Perceptions from the *Generic* HTP indicate that this sentence is also an example of a Mission Statement (Section 8.9); a statement which is used as a way of communicating the purpose of an organization. Thus it seems that root definitions may be considered as Mission Statements and CATWOE can provide a template for Mission Statements. The CATWOE template seems to align with some of the HTPs (Section 10.1) as shown in Table 13.1[2]. The *Quantitative, Structural, Generic*, and *Continuum* HTPs are not implicitly invoked in SSM and the *Scientific* HTP is implied by the findings of the study using SSM.

13.1.1.4. **Stage 4: Building conceptual models of the relevant systems**

In this stage the analyst builds a set of models of each transformation process which is considered as a system. Once the set of models is complete, if there are more than nine models in accordance with Miller's Rule (Section 3.2.5), some of them should be combined into one or more complex model by appropriate grouping of functions. A useful tool for doing the grouping or aggregation task is the N^2 Chart (Section 2.10).

The model description should be in a format or language understood by all the stakeholders in the situation (Checkland and Scholes 1990) Chapter 2). Suitable tools to use include Rich Pictures (Section 6.1.5), Flowcharts (Section 2.7), PERT Charts (Section 8.10), Causal Loops (Section 6.1.1) or any process modelling language. Perceptions from the *Generic* HTP indicate that this model is also known as a "to-be" model in Business Process Reengineering (BPR).

13.1.1.5. **Stage 5: Comparing Conceptual Models with reality**

The purpose of this stage is to generate debate about possible changes which might be made within the perceived problem situation. This is the stage in which the conceptual models built

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

in Stage 4 are compared with real world expression at Stage 2. The work at this stage may lead to the reiteration of Stages 3 and 4. Perceptions from the *Generic* HTP indicate that this stage could also be known as a "gap analysis" which identifies the difference between the real world and the conceptual model. Checkland identifies the following four approaches for doing the comparison; ordered questioning, comparing history with model prediction, general overall comparison and model overlay.

1. ***Ordered questioning:*** an approach which can be used when the real world situation is very different from the conceptual model. The system models are used to open up debate about change. The model is used as a source of questions to ask of the existing situation. The questions are written down and answered systematically. The answers to the questions can provide illumination of the perceived problem. Perceptions from the *Generic* HTP indicate that Active Brainstorming (Section 7.1) which can be used irrespective of the relationship between the real-world and the conceptual model encompasses Ordered Questioning.
2. ***Comparing history with model prediction:*** a comparison method which reconstructs a sequence of events in the past and compares what had happened with what should have happened if the relevant conceptual model has actually been implemented. In this way, the meaning of the models can be exhibited and satisfactory of comparison can be reached. Checkland also warned that this method of comparison should be used carefully because it could reveal the inadequacies of the actual procedure and people might interpret the results as offensive recrimination concerning their past performance.
3. ***General overall comparison:*** identifies the features of the conceptual models that are especially different from the real-world and the reasons for the differences. This comparison is also generally discussed in terms of the "What's" (*Operational* HTP) and "How's" (*Functional* HTP). Stages 3 and 4 produced systems models which themselves derive from the careful naming, in root definitions, of human activity systems which are relevant to the problem situation and to its improvement.
4. ***Model Overlay:*** overlays the conceptual model based on the chosen root definition with the second model of the real-world. The second model should have has as near as possible the same form as the conceptual model, i.e.; it is based on the same template. The direct overlay of one model on the other reveals the gap.

13.1.1.6. Stages 6 and 7: Action to improve the existing situation

Stage 6 is the stage in which feasible and desirable changes are identified and discussed. Once consensus is reached, Stage 7 is the realization stage in which the changes are implemented. Checkland recognised three kinds of changes:

1. ***Changes in structure:*** changes made to those parts of reality which do not change during normal operations.
2. ***Changes in procedure:*** changes to the dynamic elements.
3. ***Changes in attitude:*** changes to the behaviour appropriate to various roles, as well as changes in the readiness to rate certain kinds of behaviour as 'good' or 'bad' relative to others.

Changes in structure and procedure are easy to specify and relatively easy to implement. At least, these can be done by the people who have authority or influence. Attitude on the other hand is relatively difficult to change because one must first understand why people have that attitude and what must be done to motivate them to change their attitude.

13.1.2. *The Command, Control, Communications, and Intelligence (C3I) group morale Case Study*

The discussion on SSM has been abstract, so this section provides an example of how SSM can be used (Kasser 2013b). This section tells the anecdote of how SSM was adapted and combined with the systems approach to problem-solving to investigate an organisational problem in a government organisation. The case study has been set in the context of a fictional organization in a fictitious country. In early 2000, the Defence Systems and Technology Department (DSTD) within the government of Engaporia[3] performed a variety of research tasks that were 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[4] for the intervention investigation in the form of the systems engineering problem-solving approach to tackling a problem shown in Figure 11.3. This Section just covers:

- ***Task 2:*** understand the situation and define the root cause (problem) discussed in Section 13.1.2.1.
- ***Task 6:*** perform trade-off to find the optimum solution discussed in Section 13.1.2.2.
- ***Task 7:*** formulate strategies and plans to implement the preferred option discussed in Section 13.1.2.3.

13.1.2.1. **Task 2: define the problem**

This task began with a review of the relevant documentation[5]. 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.

[3] A fictitious third world country, ex British Colony used to provide a context for Case Studies in my classes in systems engineering.

[4] This section focuses on the activities and products elements of the task. Cost, schedule and other resource information are omitted.

[5] This is not an unusual first step.

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 - 225). The CATWOE elements in this instance were:

- ***Customers:*** The C3I group had two distinct groups of customers, namely:
    1. ***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[6].
    2. ***Internal customers*** in the form of DSTD management and other groups within DSTD.
- ***Actors:*** the members of the C3I group, the Research Leader and the Big Chief.
- ***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 13.1. The group's goal was the improvement of the effectiveness of the

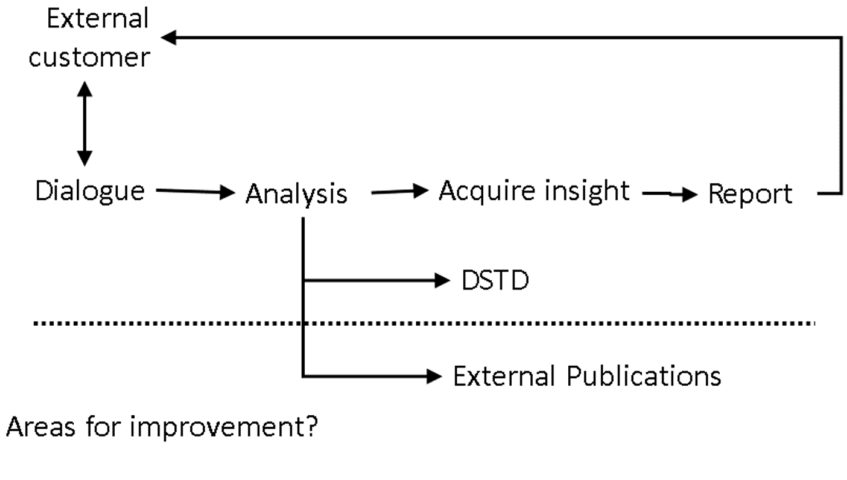


Figure 13.1 The transformation process

EDF by performing organizational analysis tasks on elements of the EDF and then providing timely reports and recommendations to those elements (customers). The

[6] Within two weeks or less

analysis sub-process was further broken out as shown in Figure 13.2. 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 conceptual reference model and acquired insight as a 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[7].

- ***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

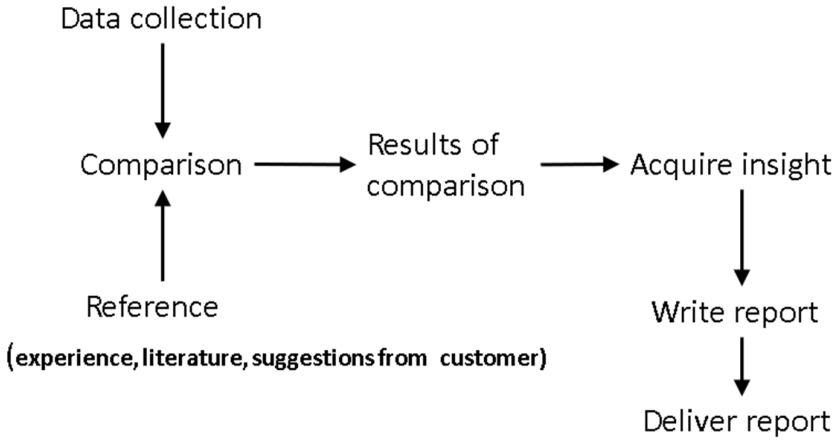


Figure 13.2 The analysis process

Weltanschauung.

- ***Ownership:*** resided in the DSTD.
- ***Environmental constraints:*** external and internal as follows:
  - ***External:*** military activities were changing; there was a so-called "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.

13.1.2.1.1. **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 *Weltanschauung*s exacerbated by a communications breakdown between the Big Chief, the Research Leader and the members of the C3I group.

13.1.2.1.2. **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

[7] This study performed the same task on the C3I group as the C3I group performed on their customers.

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 on the list was telephoned.

13.1.2.1.3. **The C3I group's *Weltanschauung***

After thanking the person for taking the time for the interview (Section 8.13) and explaining the sampling algorithm[8], each interview began with the following five open-ended questions:

1. What do you like doing?[9]
2. What do you not like doing?
3. What does the group do?[10]
4. What does the person feels group should be doing but isn't?[11]
5. What does the person feel the Big Chief wants the group to be doing?[12]

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.

13.1.2.1.4. **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.

13.1.2.1.5. **What the individual dislikes[13]**

- Uncertainty of the future.
- Work overload.
- Changing directions.
- Political agendas.
- Nugatory work.

---

[8] The interview began with common courtesy, and explained the sampling algorithm to avoid upsetting members of the C3I group.

[9] 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.

[10] 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.

[11] This question was posed to obtain ideas for improving the work and obtain buy-in to the results of the intervention.

[12] This question was posed to determine/confirm if there was a communications gap within the hierarchy of the DSTD.

[13] Responses to these questions confirmed the presence of a communications gap between the members of the group and the Research Leader.

- Rushing through the process.
- Interfacing with customer[14].
- 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.

13.1.2.1.6. **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.
- 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.

13.1.2.1.7. **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.

13.1.2.1.8. **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.

[14] This was from an individual whose job required meeting with customers!

- "*No idea, I only hear things second and third hand*"[15].

13.1.2.1.9. **Research Leader's *Weltanschauung***

The open-ended starter questions and findings are listed below.

13.1.2.1.9.1. **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.

13.1.2.1.9.2. **What should the C3I group be doing?**

- 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.

13.1.2.1.9.3. **How well are they doing it?**

- Strengths:
  - Work together well as teams.
  - Glowing reports from satisfied external customers.
- Weaknesses:
  - The way in which the job is done.
- Is Management satisfied?
  - Yes and no.

13.1.2.1.9.4. **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[16].
- Reduction of budget will have an effect.

13.1.2.1.10. **Big Chief's *Weltanschauung***

The Big Chief was asked to:

- Comment on group.
- Define "research".

---

[15] A definite communications gap

[16] The Research Leader seems to be applying Management by Exception (Section 8.7). However, the C3I group perceived it in a negative manner. There is a communication issue here.

- Provide metrics for successful "research".

The answers to the questions are summarized below.

13.1.2.1.10.1. **Comments on group**

- Group performed a useful role.
- 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.

13.1.2.1.10.2. **Definition of "research"**

- Was not publish - publish – publish.
- Was:
  - Document in a manner consistent with Scientific Method (Section 11.1.10.5.1).
  - Use the Scientific Method in their work.

13.1.2.1.10.3. **Metrics for successful "research"**

- Needed to be convinced on authority of conclusions[17].
- Needed to quote from the literature to reinforce conclusions and justify methodology[18].

13.1.2.1.11. **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.
3. The group needed to consider the enterprise architectural framework in which the customer organization operated both in the present and future (*Temporal* HTP).
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.

[17] By citing references to the literature that support the conclusions
[18] An application of Critical Thinking

13.1.2.2. **Task 6: select the preferred option**

After considering several solutions[19], the investigator 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 13.1 into the CONOPS (for what they should be doing) shown in Figure 13.3. 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.

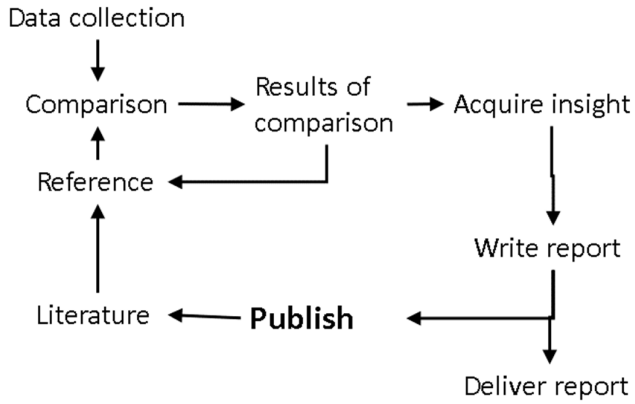


Figure 13.3 C3I group conceptual functional reference model

13.1.2.3. **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[20], a description of the study methodology, the recommendations and an Action Plan.

13.1.2.3.1. **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:

1. DSTD Management to remove the fear of "research" and uncertainty about future.
2. For the C3I group to:
    1. Take continuing education courses[21] on how to do "research", Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) Architecture Frameworks and SSM as applied to Information Systems.
    2. Develop personal career plans.
    3. Modify their methodology by adding architecture issues to customer dialogue and considering medium and long term impacts.

[19] Not described in this chapter since this chapter focuses on describing an application of SSM.

[20] Presented first and then amplified later in the presentation.

[21] The intervention was performed by academics from Hypothetical University.

4. Develop conceptual models based on the literature for appropriate customer organizations which would speed task completion[22], provide an objective basis for work and allow structured analysis of impact of technology to units and force structure.
5. Reorganize to match current and expanded functions to personal skills/likes dislikes.
6. Team within the group for publication in Journals and at the annual Engaporean Systems Engineering Conference the following year.
7. Acquire mentors within DSTD on research methods, C4ISR Architecture Frameworks, and systems methodologies.

3. Carry out the Action Plan.

13.1.2.3.2. **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[23].
2. Members of the C3I group to attend courses starting within two months.
3. Members of the C3I group to acquire mentors within DSTD within three months.
4. Create a target for acceptance for publication of at least three manuscripts within 12 months[24].

13.1.2.4. **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[25]. 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[26].

13.1.3. ***Comments***

The *Big Picture*, *Operational* and *Functional* HTPs line up with CATWOE as shown in Table 13.1. In addition:

- The *Structural* HTP 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.

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[22] By the use of pattern matching (*Generic* perspective)

[23] Each recommendation was quantified to be specific requirements.

[24] 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. Publication was also useless because publications dates depended on the specific publication.

[25] 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.

[26] As examples they could follow.

Table 13.1 Apparent relationship between SSM's CATWOE and the HTPs

CATWOE	Holistic Thinking Perspective (HTP)
Client/customer	*Big picture*
Actor	*Operational*
Transformation	*Functional* and *Quantitative*
Weltanschauung	*Big Picture*
Owner	*Big Picture*
Environment	*Big Picture*

- The 'to be' or reference model came from prior experience, namely going beyond systems thinking and using perceptions from the *Generic* and *Temporal* HTPs.
- The *Temporal* HTP 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 also find out the reason for the failure of the previous intervention.
- The conclusion from the analysis of the initial observations produced the hypothesis (*Scientific* HTP) that the situation was the result of a failure in the hierarchical communications path 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* HTP 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.

13.1.3.1. **Lessons Learned**

The Lessons Learned (Section 9.3) 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 problematic 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* HTP). 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.

13.2. *Concept of Operations*

A Concept of Operations Document (CONOPS) is:

- A tool for facilitating communication among the various stakeholders in a project.
- A descriptive document; its contents include descriptions of:
  - The problematic or undesirable current system or situation.
  - The justification and nature of the changes.
  - The FCFDS.
  - A summary of the impacts of the new system and its development.

There are several versions of the CONOPS in the literature including IEEE Standard 1320-1998.

13.2.1. *IEEE Standard 1320-1998*

The IEEE Guide for Information Technology - System Definition - Concept of Operations (ConOps) Document is a document template containing an Annotated Outline (Section 14.1) for the contents of a CONOPS (IEEE Std 1362 1998). The relevant sections which cover the product and process are:

```
3.0 Current system or situation.
3.1 Background, objectives, and scope.
3.2 Operational policies and constraints.
3.3 Description of the current system or situation.
3.4 Modes of operation for the current system or situation.
3.5 User classes and other involved personnel.
3.6 Support environment.
4. Justification for and nature of changes.
4.1 Justification of changes.
4.2 Description of desired changes.
4.3 Priorities among changes.
4.4 Changes considered but not included.
5. Concepts for the proposed system.
5.1 Background, objectives, and scope.
5.2 Operational policies and constraints.
5.3 Description of the proposed system.
5.4 Modes of operation.
5.5 User classes and other involved personnel.
5.6 Support environment.
6. Operational scenarios.
7. Summary of impacts.
7.1 Operational impacts.
7.2 Organizational impacts.
7.3 Impacts during development.
8. Analysis of the proposed system.
8.1 Summary of improvements.
8.2 Disadvantages and limitations.
8.3 Alternatives and trade-offs considered.
```

13.2.2. *Creating a CONOPS*

The procedure to create a CONOPS is as follows:

1. Locate previously published CONOPS or a Standard such as the IEEE template (Section 13.2.1) to use as a Template (Chapter 14).
2. Modify the template table of contents to fit your situation.
3. Create the Annotated Outline (Section 14.1) to show the contents of each Section.
4. List the scenarios the CONOPS will cover in both the product and process domain as appropriate.

5. Fill in the Annotated Outline as appropriate to the situation.
6. For each scenario, Visualise the scenario (Section 7.11) from:
    1. The *Operational*, *Functional* and *Structural* HTPs, identifying inputs, outputs and resources used or needed.
    2. The *Generic* and *Continuum* HTPs to identify similar scenarios in other situations, differences between the scenario and similar scenarios in other situations, and the effect of things failing or not being available when needed.
    3. The *Temporal* HTP to understand how the need arose, and to identify any lessons that need to be learned (Section 9.3).
7. Follow the process for creating a document (Section 11.4) to complete the document.

13.3. *A methodology for tackling complexity*

Observations of the way people manage complexity have identified a dichotomy; managing complexity seems to be a major problem for some people and a way of life for others who just get on with managing it. The dichotomy can be explained by postulating that are two paradigms.

1. The non-systems paradigm in which managing complexity is a major problem.
2. The systems paradigm in which it is a way of life (Hitchins 1998).

Further observations of the systems paradigm for managing complexity, is that it is mostly used without people realising they are using systems thinking to manage complexity. For example, complex systems that are being managed include fleets of cruise ships, financial and banking networks, oil rigs, airlines, transportation systems and hospitals. Accordingly, before presenting the framework, the non-systems approach to tackling complexity needs to be discussed so that the different paradigm represented by this framework will be understood.

13.3.1. ***The non- systems approach***

The non-systems approach seems to have difficulty tackling complexity for several reasons including:

1. Not distinguishing between subjective and objective complexity discussed in Section 13.3.1.1.
2. Creating artificial complexity (Section 13.3.1.1) due to poor system decomposition and partitioning.
3. The systems optimization paradox discussed in Section 13.3.1.2.
4. The boundary of the system is not fixed for all purposes discussed in Section 13.3.2.3.

13.3.1.1. **Not distinguishing between subjective and objective complexity**

The non-systems approach does not distinguish between subjective and objective complexity. This is probably because the English language, rich as it is, does not have any words that uniquely define and distinguish the concepts of ‘subjective complexity’ and ‘objective complexity’ other than the word “difficult” which means subjective complexity. The commonly used words ‘complex’ and ‘complicated’ have been used for both concepts interchangeably because dictionary definitions of their meanings contain both a subjective and objective meaning. However, once a distinction is made (*Continuum* HTP):

- Subjective complexity
    - Can be defined as, “*people don’t understand it and can’t get their heads round it*” (Sillitto 2009), namely difficulty.

  - Appears to have a different value for different observes, for example, "*A system is commonly thought of as "complex" if it is made up of a large number of parts interacting in a nonsimple [sic] way. The linguistic usage, implying as it does that complexity is an attribute of the system itself, obscures the fact that complexity is a relation between an observer and the thing observed, i.e., that the same system can be seen as of greater or lesser complexity by different observers or even by a single observer before and according to comments, after he comes to "understand" it*" (Conant 1972).
  - Can be measured using the levels of difficulty that range from 'easy' to 'hard' (Section 5.3.1).
- Objective complexity:
  - Can be defined as, "*the problem situation or the solution has an intrinsic and measurable degree of complexity*" (Sillitto 2009) .
  - Has various definitions in the literature which makes measurement difficult; these definitions include:
    - "*A complex system usually consists of a large number of members, elements or agents, which interact with one another and with the environment*[27]" (ElMaraghy et al. 2012).
    - "*Colwell (Colwell 2005) defined thirty-two complexity types in twelve different disciplines and domains such as projects, structural, technical, computational, functional, and operational complexity*" (ElMaraghy et al. 2012).
    - "T*he measure of uncertainty in achieving the functional requirements (FRs) of a system within their specified design range*." (Suh 2005)[28].
    - Tomiyama et al. introduced two different types of complexity: (i) complexity by design and (ii) the intrinsic complexity of multidisciplinary, from the viewpoint of knowledge structure (Tomiyama et al. 2007).
- Artificial complexity:
  - An artefact of objective complexity defined as, "*a complex situation in which the non-pertinent aspects have not been abstracted out*" (Kasser 2007).

The non-systems approach often does not differentiate between complexity and the structure of the problem because it includes the structure of the problem inside the definition of complexity, e.g. complex problems are equated to Wicked Problems (Section 5.3.2.3) (APSC 2012). By concluding the structure of the problem inside the definition, the problem often becomes insurmountable (Section 5.3.2). This is because they are no solutions to Ill-Structured Problems. Ill-Structured Problems have to be converted to Well-Structured Problems before the undesirable situation can be transformed into a desirable situation (Simon 1973). The Problem Classification Framework (Section 5.3) abstracts objective complexity out of issue and considers subjective complexity and the structure of the problem.

13.3.1.2. **The systems optimization paradox**

The systems optimisation paradox has been stated over the years in various ways including the following examples:

[27] According to this definition the only difference between a system and a complex system is in the interpretation of the meaning of the word 'large'.

[28] Suh also stated the need to abstract out things that were not pertinent to the issues at hand.

- "*The principle of suboptimization [sic] 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:.
- "*Conventional systems engineering wisdom has it that if subsystems are optimized, then the system cannot be optimum*" (Wymore 1997)

Accordingly, according to the principle of suboptimisation a system can never be optimised, hence the paradox. The principle of suboptimisation is ignored in the systems approach to system optimisation because although Wymore articulated the paradox, he then used a mathematical approach to show that conventional wisdom was mistaken and how it was possible for systems engineering to ensure that optimum design of the subsystems can result in optimum design of the system. System optimization at one level is always a subsystem optimization of the meta-system. If any system is a subsystem of the containing or meta-system, then where does the optimization take place? The answer in the systems thinking paradigm is that system optimization at any level optimizes the interactions between the subsystems of that system level within the constraints imposed by the systems engineer of the meta-system. For example:

- Consider an allied naval convoy crossing the North Atlantic Ocean in 1942. The convoy is a system[29]. Each ship in the convoy can be considered as both a subsystem of the convoy, or as a system[30]. There was a CONOPS (Section 13.2) for the convoy[31]. There were separate CONOPS for the naval escort ships and the merchant ships describing the actions and interactions of these subsystems of the convoy in various scenarios. The system was optimised to minimise the interactions between the individual ships.
- Consider the complex problem of docking two spacecraft (Kasser and Palmer 2005). Once the spacecraft are close, the problem is simplified by minimizing artificial complexity (Section 13.3.1.1) and creating a closed system view to only consider the:

  1. Relative positions of the spacecraft.
  2. Relative velocity of the spacecraft.
  3. Relative alignment in X, Y and Z orientation of the spacecraft.

  The optimisation problem is then set up in the context of a closed system view to produce a relative docking velocity close to zero with the docking collars on both spacecraft properly aligned.

13.3.2. *The systems approach*

The systems approach used by those who can deal with complexity seems to be based on a different paradigm and absolves the problems faced by the non-system approach in the manner of a new paradigm (Kuhn 1970). The framework includes a number of interdisciplinary methodologies as summarised in the following sections:

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[29] Some people might call it a System of Systems or a complex system.

[30] Alternatively, the naval ships could be one subsystem and the merchant marine ships a second subsystem of the convoy. Each ship is then a subsystem within the naval or civilian subsystem of the convoy. If there are ships from the navies of more than one allied country in the convoy, then the ships of each country could constitute a subsystem within the naval subsystem. The choice of subsystem partitioning depends on the issues being considered.

[31] The documents may not have been called CONOPS but would have contained much of the information in today's CONOPS.

1. Distinguishing between subjective and objective complexity as discussed in Section 13.3.1.1.
2. Reducing artificial complexity by abstracting out the non-pertinent aspects of objective complexity as discussed in Section 13.3.2.1.
3. Partitioning the system as discussed in Section 13.3.2.2.
4. Redrawing the boundary of the system to suit the purpose discussed in Section 13.3.2.3.
5. Attempting to dissolve the problem as discussed in Section 13.3.2.4.
6. Using the Problem Formulation Template (Section 14.3) to think through the problem and solution before taking any action.

13.3.2.1. **Abstracting out the non-pertinent aspects of objective complexity**

The systems thinker abstracts out the non-pertinent aspects of the complexity by applying the following:

1. Minimizing artificial objective complexity by abstracting out non-pertinent aspects of the situation complexity (Section 5.3.2).
2. Applying the 'Don't Care' situation (Section 3.2.2) to abstract out other non-pertinent aspects of the situation.

13.3.2.2. **Partitioning the system**

The choice of partitioning is a major factor in the efficacy of any system description (Aslaksen and Belcher 1992). Thus optimal subsystem boundaries must be designed for simplicity, namely:

- To abstract (hide) non-relevant information.
- To bound subsystems into self-regulating or self-sufficient entities with maximal internal cohesion of subsystems and minimal coupling between them.
- That the maximum number of subsystems at any level of decomposition should generally be no more than 7 (±2) to comply with Miller's Rule (Section 3.2.5).

Maier and Rechtin 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: page 6). However, as they point out:

- Poor aggregation and partitioning during development can increase complexity (i.e. artificial complexity) (Section 13.3.1.1).
- The concept that a complex system can be decomposed into a single set of smaller and simpler units omits an inherent characteristic of complexity, the interrelationships among the components (i.e. real-world complexity).

However, Simon set forth strong arguments for believing that hierarchic structure is the rule rather than the exception in physical, biological, social, symbolic, and many other types of systems. Accordingly, when trying to understand or create complex system, start by assuming that that it has a hierarchic structure and is decomposable into subsystems within which the interaction of variables is relatively intense (maximize cohesion) and between which the interaction is relatively weak (minimize coupling), for if that is the case attention can be turned to the detailed workings of each subsystem (Simon 1962).

13.3.2.3. **Redrawing the boundary of the system to suit the purpose**

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 (Kasser 2013a). The purpose is not in the system, it is in the mind of the person drawing the

boundary that creates the system because people draw boundaries (Churchman 1979: page 91). Accordingly, the boundary of the system need not be fixed for all purposes or from all perspectives. Thus, observe the situation from a number of viewpoints or perspectives on the Perspectives Perimeter (Chapter 10) instead of the complex and complicated single views discussed in Section 13.3.1.1. 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 artificial complexity (Section 13.3.1.1). 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:
    1. Wave theory (Huygens 1690) to explain some aspects of electro-magnetic radiation.
    2. Particle theory (Newton 1675) to explain other aspects[32].

13.3.2.4. **Attempting to dissolve the problem**

Recognize that when faced with extremely complex problems, the best way to deal with them is to understand that the complexity may indicate that there is a defect in the current paradigm[33] and there is a need to look for an alternative paradigm (Kasser 1995) while trying to develop the solution in the current paradigm.

13.4. *Mathematical tools*

Mathematical tools:

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

33 But not necessary the nature of the defect.

- Are used in the front-end of systems engineering in column A of the HKMF (Section 5.2) to analyse systems and situations.
- Used by systems engineers include: (Alexander and Bailey 1962, Wilson 1965, Chestnut 1965, Goode and Machol 1959)
    - Probability.
    - Single thread – system logic.
    - Queuing theory.
    - Game theory.
    - Linear programming.
    - Group dynamics.
    - Simulation and modelling.
    - Information theory.

13.5. *References*

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