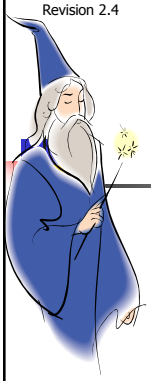
Revision 2.4



Systems Engineers – the wizards of modern society?

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Cranfield, Beds, MK43 0HH
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Topics

- What is systems engineering?
- The problem of understanding the nature of systems engineering
- Systems thinking
- Applying systems thinking to the problem
- The benefits of an education as a systems engineer
- Why systems engineers might be wizards
- Summary
- Questions and discussion

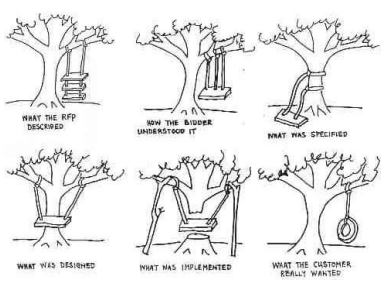
What is systems engineering?

All of them

Systems engineering 1995 - 2007

- Seems to have begun in the 1940's or 1950's
- Systems engineering will solve the complex problems we face (since 1950's)
- Disagreements
  - definitions of a "System"
  - as to the nature of systems engineering
  - on what systems engineers do
- Overlapping disciplines
- Systems of systems

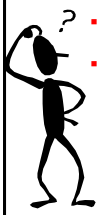
The production process



Observation & questions

- For more than 50 years, no systems engineer has come up with a definition of SE that systems engineers can agree upon.
- ***What is there about Systems Engineering that defies definition?***
- ***Why hasn't systems engineering delivered on its promise?***

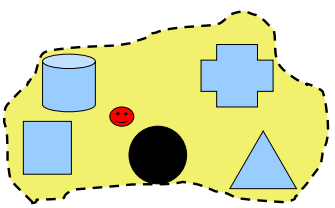
To understand a thing



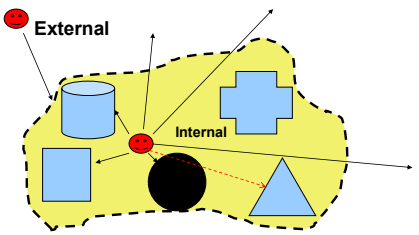
- Analysis*
  - Take apart the thing to be understood;
  - try to understand how these parts worked;
  - assemble an understanding of the parts into an understanding of the whole.
- Systems Thinking*
  - A thing to be understood is conceptualized as a part of one or more larger wholes, not as a whole to be taken apart;
  - an understanding of the larger system is sought;
  - the system to be understood is explained in terms of its *role or function* in the containing system.

* Ackoff, 1991

Representation of a system

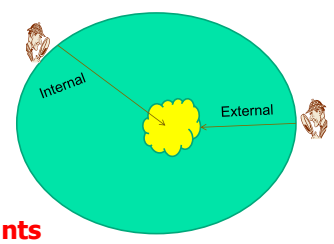


Understanding a system



Perspectives & communications

- Perspectives
  - Internal
  - External
- Cognitive filters
- Pages
- Wavelength
- **No anchor points**



Defects in systems engineering

1. Selection of independent alternative solutions
2. The V Model
3. Lack of a standard process for planning a project
4. The Waterfall model
5. Unanswered and unasked questions
6. Lack of a metric for the goodness of Requirements
7. Focus on technological solutions not solving customer's problems
8. Introducing unnecessary complexity
9. The need to focus on people as well as process

The Project Cycle

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The Project Cycle

Requirement

 14

The Project Cycle

Requirement

Design

 15

The Project Cycle

Requirement

Design

Test

 16

The Project Cycle

Requirement

Design

Test

Acceptance criteria

(property of a requirement)

 17

The Project Cycle

Requirement

Design

Test

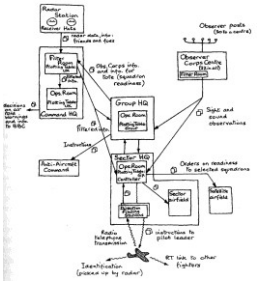
Acceptance riteria

(property of a requirement)

 18

Most successful IS of the 20th century?

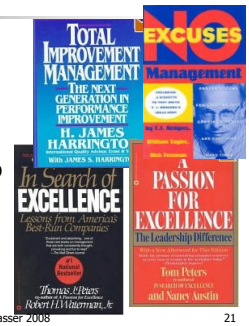
- RAF Battle of Britain Command, Control, & Communications System
  - No computers
  - Germany had better Radar Technology
  - RAF evolved and used an integrated system
  - Adequate technology
- System?
- System of Systems?
- Complex System?
- Network enabled system?



Complex or complicated?

The need to focus on people as well as process

- Literature
  - Is full of advice as to how to make projects succeed
  - Has little if anything to say about the proliferating process standards



Observation & questions

- For more than 50 years, no systems engineer has come up with a definition of SE that systems engineers can agree upon.
- ***What is there about Systems Engineering that defies definition?***
- ***Why hasn't systems engineering delivered on its promise?***

15 years research - sample (contradictory) conclusions

- 1995
  - Project management, BPR, concurrent engineering, TQM and theoretical SE all seem to be attributes of the same function; namely producing a product to (the correct) specifications by an organization within the constraints of resources, budget and schedule
  - SE is a discipline created to compensate for the lack of strategic technical knowledge and experience by middle and project managers in organizations functioning according to Taylor's "Principles of Scientific Management"
- 2002
  - SE is an alternative management paradigm
- 2007
  - To be discussed today

Insights

- It's a Wicked problem*
- Wicked problems appear in the first stage of the scientific method
- Try the scientific method – at least the next stage

* Rittel and Webber, 1973

Wicked Problems*

1. There is no definitive formulation of a wicked problem.
2. Wicked problems have no stopping rule.
3. Solutions to wicked problems are not true-or-false, but good-bad,
4. There is no immediate and no ultimate test of a wicked problem.
5. Every solution to a wicked problem is a "one-shot" operation"; because there is no opportunity to learn by trial-and-error, every attempt counts significantly.
6. Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible options that may be incorporated into the plan.
7. Every wicked problem is essentially unique.
8. Every wicked problem can be considered to be a symptom of another problem.
9. The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution.
10. The planner has no right to be wrong

* Rittel and Webber, 1973

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Hypothesis

- **A framework exists**
  - **all we have to do is find it.**

Requirements for a framework

1. The framework shall provide an understanding of why systems engineers can't agree on their roles and activities.
2. The framework shall provide an understanding of the reasons for the overlap between systems engineering and management.
3. The framework shall provide a way to cope with complexity.
4. The framework shall enable the lowering of the cost of doing work by at least an order of magnitude.

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Vertical axis - Hitchin's layers*

- **Layer 5** - Socioeconomic, the stuff of regulation and government control
- **Layer 4** - Industrial Systems Engineering or engineering of complete supply chains/circles
- **Layer 3** - Business Systems Engineering
- **Layer 2** - Project or System Layer
- **Layer 1** - Product Layer

* Hitchins, 2000

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Horizontal axis - system life cycle*

A. Identifying the need
B. Requirements analysis
C. Design of the system
D. Construction of the system
E. Testing of the system components
F. Integration and testing of the system
G. Operations, maintenance and upgrading the system (in-service)
H. Disposal of the system

* Kasser & Massie, 2001

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The HKM (2D) Framework for understanding SE

Layer of Systems Engineering \ Phase in the Life Cycle		Needs identification	Requirements	Design	Construction	Unit testing	Integration & testing	O&M, upgrading	Disposal
Socio-economic	5								
Supply Chain	4								
Business	3								
System	2								
Product	1								
		A	B	C	D	E	F	G	H

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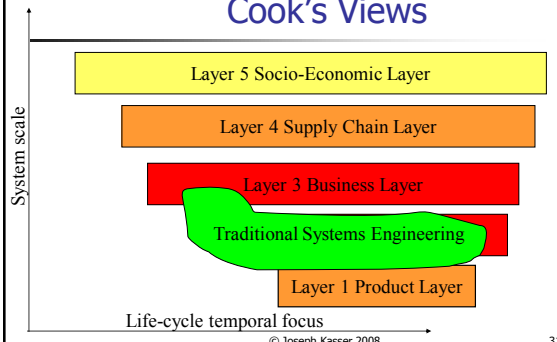
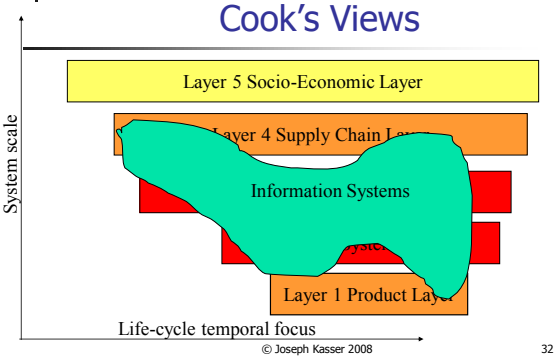
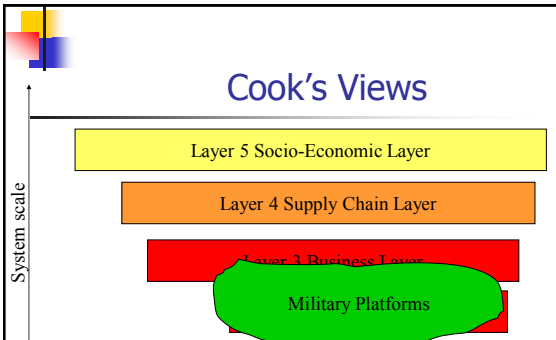
Cook's Views



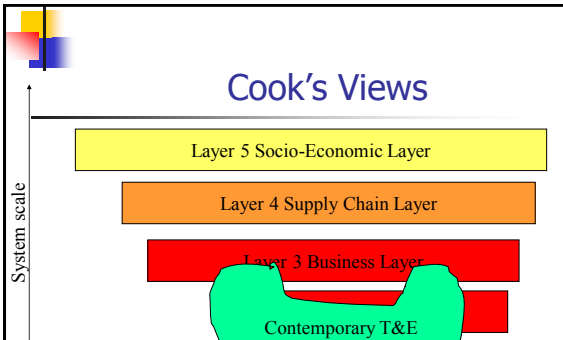
Cook's Views



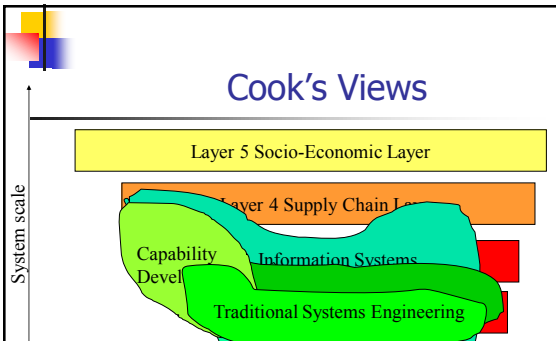
Cook's Views



Cook's Views

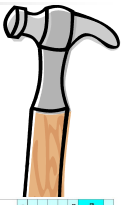


Cook's Views



Continuum STP – **Not!**

- "*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).
- "SE is solution to all problems"
  - SOS are in Area 3G
  - Column G
    - Operations Research?



Focus of Standards*

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

* Honour E.C., Valerdi R., "Advancing an Ontology for Systems Engineering to Allow Consistent Measurement", CSER 2006

Standards in the HKMF?

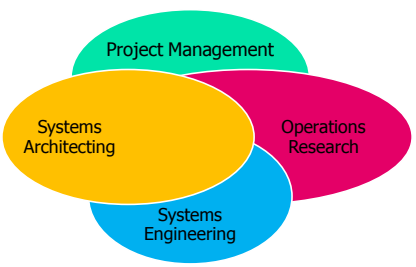
499/632

1220

15288/CMMI

Layer of Systems Engineering \ Phase in the Life Cycle		Needs identification	Requirements	Design	Construction	Unit testing	Integration & testing	O&M, upgrading	Disposal
Socio-economic	5								
Supply Chain	4								
Business	3								
System	2								
Product	1								
		A	B	C	D	E	F	G	H

What about overlaps with other disciplines?



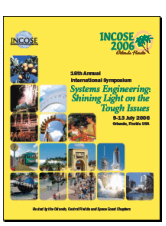
History and origin

"*Driven by cold war pressures to develop new military systems rapidly, **operations research**, **systems engineering**, and **project management** resulted from a growing recognition by scientists, engineers and managers that **technological systems had grown too complex for traditional methods of management and development**" **

* Johnson, 1997

Evolution is continuing

- The 16th International Symposium of the INCOSE
  - 8 - 14 July 2006
  - Orlando, Florida, USA
    - Risk Management
    - Software and Information Systems Engineering
    - Others



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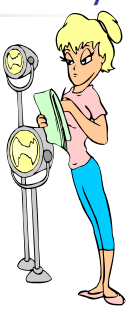
    - Software and Information Systems Engineering
    - Others
- The 2nd International Symposium on Management, Engineering and Informatics: MEI'06
  - 16 - 19 July 2006
  - Orlando, Florida, USA
    - Risk Management
    - Software and Information Systems Engineering
    - Others

Insight – draw a boundary

- **Roles** – the title or job description of a person in an organisation.
  - variations of various job titles
    - System Architect, System Engineer, and Project Manager.
- **Functions** – activities performed by a role in an organisation.



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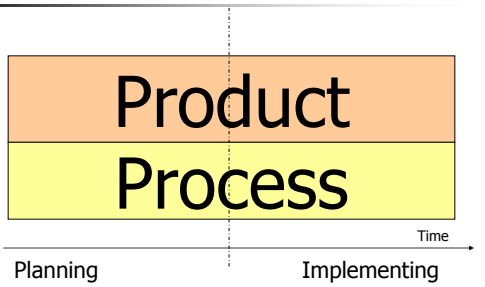
Mapping roles and functions (inside Layer 2)



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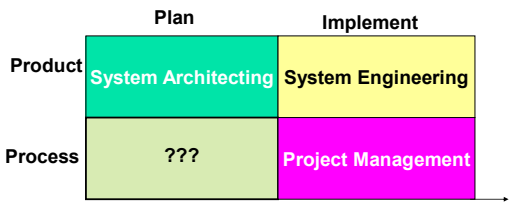
Mapping organisational functions in technical projects



Functions are/are not done, but no universally defined role

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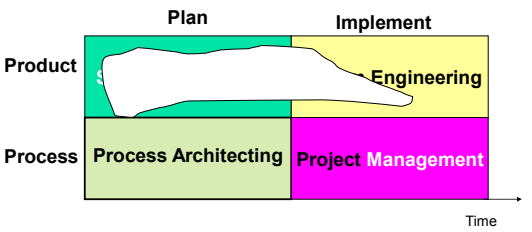
Roles and functions in organisations



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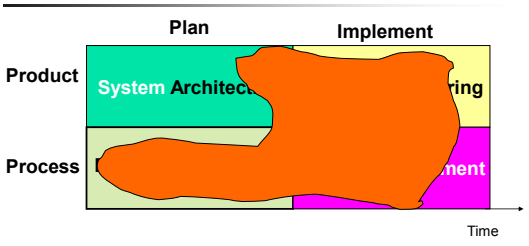
Roles and functions in organisations



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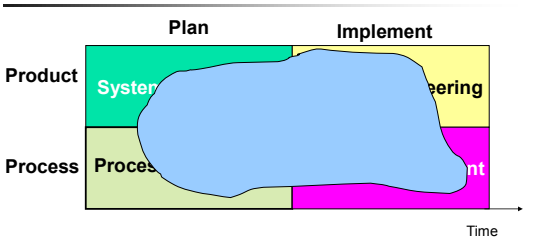
Roles and functions in organisations



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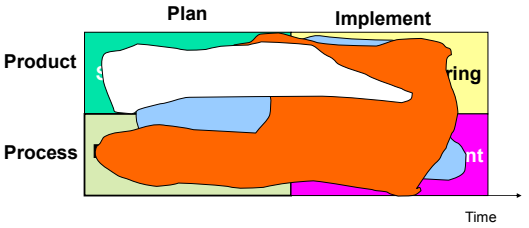
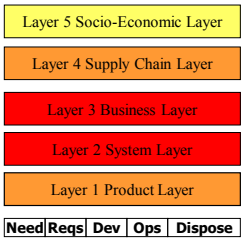
Roles and functions in organisations

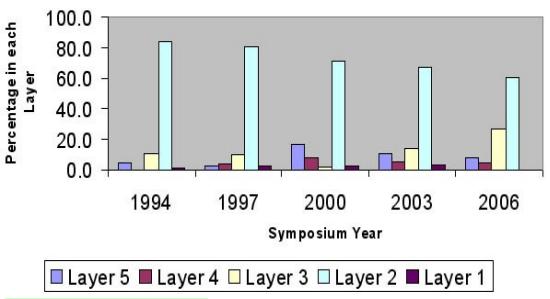


Reasons why SE's can't agree on roles, activities and definition

1. They work in different parts of the Framework
2. They do more than systems engineering
3. They do different things in different organisations



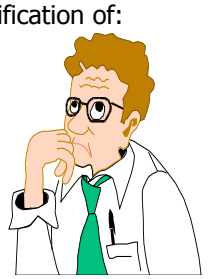
INCOSE's changing area of focus*



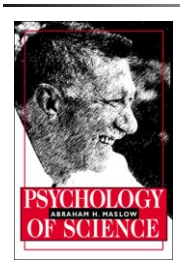
*Preliminary findings, Tran and Kasser, 2007

The third dimension of the HKM Framework?

- Candidates based on classification of:
  - Complexity
  - Domain
  - Types of systems
  - Risks
  - Problem solving
  - Other ways ?

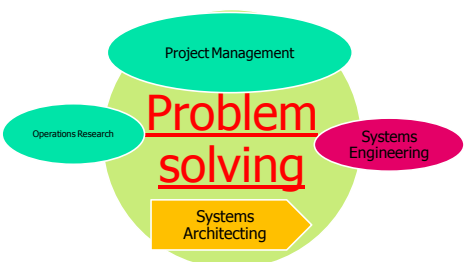


Lessons learnt from Behavioral Psychology



- Murrays' list of needs
  - 1938
  - Narrowed down to 27
  - To long to be useful
- Maslow's hierarchy
  - 1954 -1970
  - Grouped and showed linkages
  - Short list of 5
- Alderfer
  - 1972
  - Proposed reducing Maslow's list to 3

What do overlaps have in common?

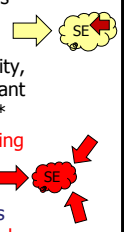


Problem solving/risk mitigation

- Shenhar and Bonen, 1997
  - Three levels of system scope
    - ~Hitchins' lower three layers
  - Four levels of technological uncertainty (risk)
    - **Type a** — Low-Technology Projects.
    - **Type b** — Medium-Technology Projects.
    - **Type c** — High-Technology Projects.
    - **Type d** — Super-High-Technology Projects

Systems engineering?

- An engineering discipline whose responsibility is creating and executing an interdisciplinary process to ensure that the customer and stakeholder's needs are satisfied in a high quality, trustworthy, cost efficient and schedule compliant manner throughout a system's entire life cycle*
- The application of systems thinking in the making systems happen function?
- A speciality discipline developing and providing the making systems happen function [in Layers 1-3] with the methodologies, processes and tools to solve problems?



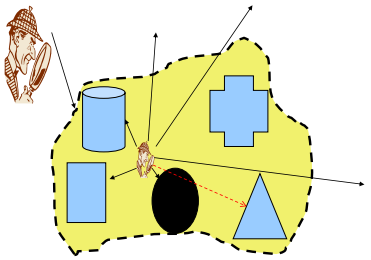
* INCOSE Fellows

Selection of problem solving methodologies

- Individual methodologies apply to one or more specific areas of the framework
- What works in one area may not work in another area
- There is no current universal methodology that works in every area
- Need to learn what methodology to use for which type of problem in which area

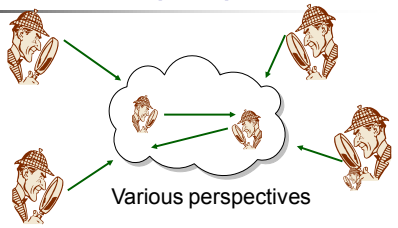
Systems thinking perspectives

- Temporal
- Functional
- Generic
- Big picture
- Structural
- Operational
- Continuum
- Quantitative
- Scientific



Journalist's perspective

- Who?
- What?
- Where?
- When?
- Why?
- How?



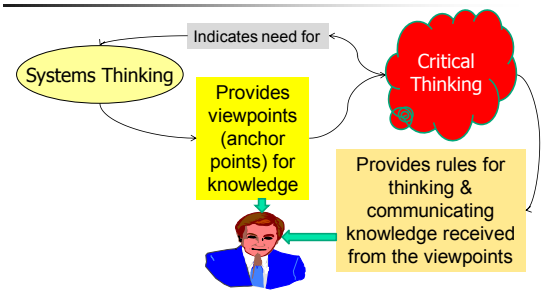
STP traceability Matrix

	1	2	3	4	5	6
STP	**Who?**	**What?**	**Where?**	**When?**	**Why?**	**How?**
Operational						
Functional						
Big Picture						
Structural						
Generic						
Continuum						
Temporal						
Quantitative						
Scientific						

Active Brainstorming

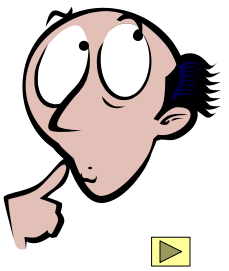
There may not be an immediate answer to every question

Systems thinking & critical thinking



Critical thinking

- Five steps or levels*
  - 4 Strategic re-visioner
  - 3 Pragmatic performer
  - 2 Perpetual analyzer
  - 1 Biased jumper
  - 0 Confused fact finder



* © Susan K Wolcott 2003

0 - Confused fact-finder

- 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" answer even to open-ended problems

1 - Biased Jumper

- 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

2 - Perpetual analyzer

- Does not reach or adequately defend a solution
- Exhibits strong analysis skill, but appears to "wishy-washy"
- Write papers that are too long and seem to ramble
- Doesn't want to stop analysing
  - "I can look at it this way, and I can look at it that way..."
  - Wait! What about ?"

3 – Pragmatic performer

- Objectively considers alternatives before reaching conclusions
- Focuses on pragmatic solutions
- 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

4 – Strategic Re-Visioner

- Seels continuous improvement/lifelong learning
- More likely than others to think "out of the box"
- Anticipates change
- Works toward construction knowledge over time

Systems Engineer (minimum) Competency matrix

	Junior	Intermediate	Advanced
Systems engineering	Theoretical knowledge of SE + Knowledge of 1 domain	+ Able to apply SE under supervision	+ Understand nature of SE
Ability to identify and solve correct problem	Perpetual analyzer	Pragmatic performer	Strategic re-visioner
Interpersonal skills	Communications	+ personal	+ leadership

Benefits of SE education

- Understanding of systems, information technology and what it takes to produce them
- Understand and apply systems thinking
- Ability to recognise area in HKM framework
- Ability to identify type of problem
- Ability to identify appropriate text-book methodologies
- Ability to tailor methodology(s) for the problem
- Ability to proceed to solve problem

Why systems engineers might be wizards

1. SE achieve unprecedented results successfully and nobody notices
   - if they are successful
2. Layers 1-3 focus on technology
3. Technology and magic grant wishes

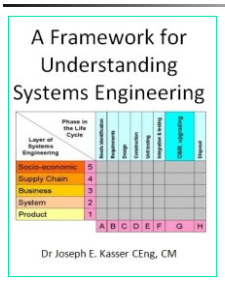
Any sufficiently advanced technology is indistinguishable from magic*

* Clarke A C, 1961

Summary

- What is systems engineering?
- The problem of understanding the nature of systems engineering
- Systems thinking
- Applying systems thinking to the problem
- The benefits of an education as a systems engineer
- Why systems engineers might be wizards

Questions? - discussion



- What's a Wicked Problem?
- Please repeat those Streams of Systems Thinking?
- What are the six questions to ask?
- What is the generic answer to all questions?
- Where did you get the clip art?