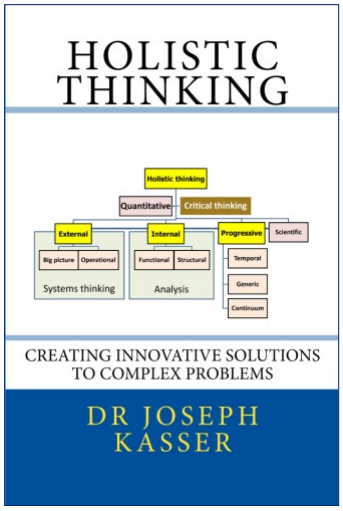
A systems thinking approach for managing complex systems
Session 5 of 6: Complexity

Version 1.2.2

Topics

- Purpose
- Thinking and systems thinking
- Systems and system of interest
- Principle of hierarchies
- Emergence and emergent properties
- Problems and solutions
- The problem formulation template
- Complexity
- Interface partitioning
- Classification and types of problems



Problem with meaning of "problem"

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:
   - ***An undesirable situation***. You might hear someone end a sentence with "… and that's the problem" when they should be saying "… and that's the undesirable situation".
   - ***The underlying cause of an undesirable situation***, usually a failure of some kind.
     - "*my watch stopped working; the **problem** was a discharged battery*".
     - the **cause** of the watch stopping working was a discharged battery;
     - the **symptom** or effect was that the watch stopped working.
3. The need to determine the necessary sequence of activities to perform the transition from an undesirable situation to a desirable situation (Schön, 1991).

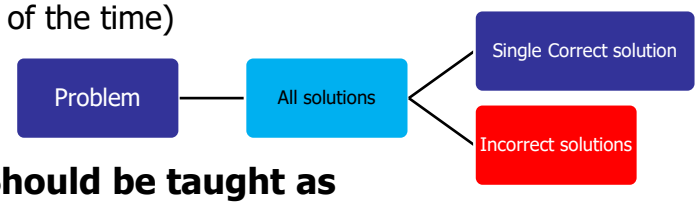
Mostly taught

- Problem
- Solve problem
- Single correct solution

- This is a special instance of a meta-situation

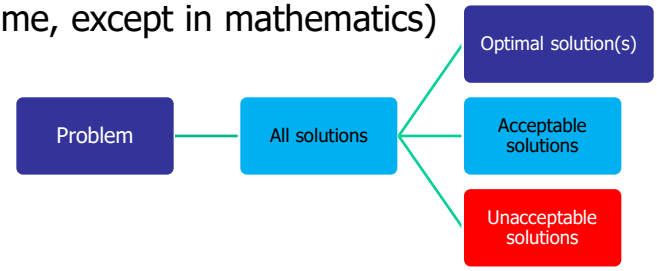
Problems and solutions

Currently taught as
(most of the time)



Should be taught as
(all of the time, except in mathematics)

Who defines the problem?

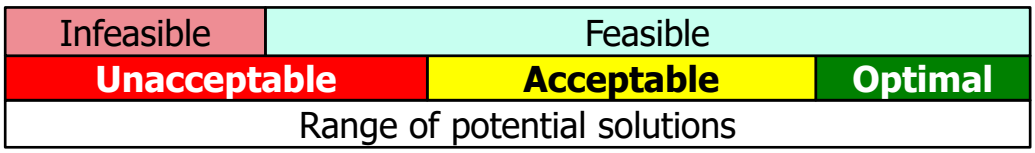


Satisfy

Satisfice

The *Continuum* of solutions

- Non-systems thinking
  - Single correct
  - Remainder are wrong (incorrect)
- Systems thinking
  - Acceptable
  - Feasible
  - Optimal
  - Unacceptable



Need for two solutions (*Temporal* HTP)

1. Fix it now (short term)
2. Prevent it from happening in the future (long term)

- Often seen in commercial products and epidemics/pandemics
  - Modification to existing versions
  - Redesign for future versions
- Seen in response to COVID-19 pandemic
  - Masks and isolation (short term)
  - Vaccine (long term)
- Requires
  - Systems thinking and beyond
  - Configuration control of versions

Acceptable solutions

- Problem
  - Hungry after presentation
- Solution
  - Eat something
- Problem
  - What to eat?
    - Chinese, Italian, Indian, Australian, American, etc.
    - Vegetarian, meat (which meat), fish (which fish), pizza, etc.
  - Where to eat?
    - Restaurant
      - Which restaurant?
    - At home
      - Take-away, delivery, cook?

Is there only one solution?

Tools, techniques and templates

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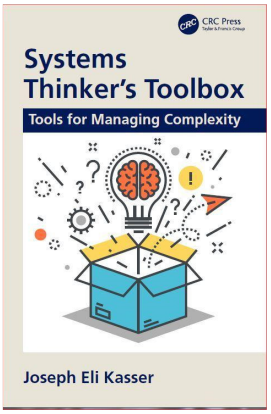

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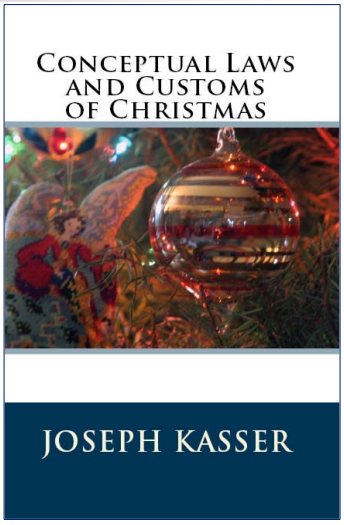
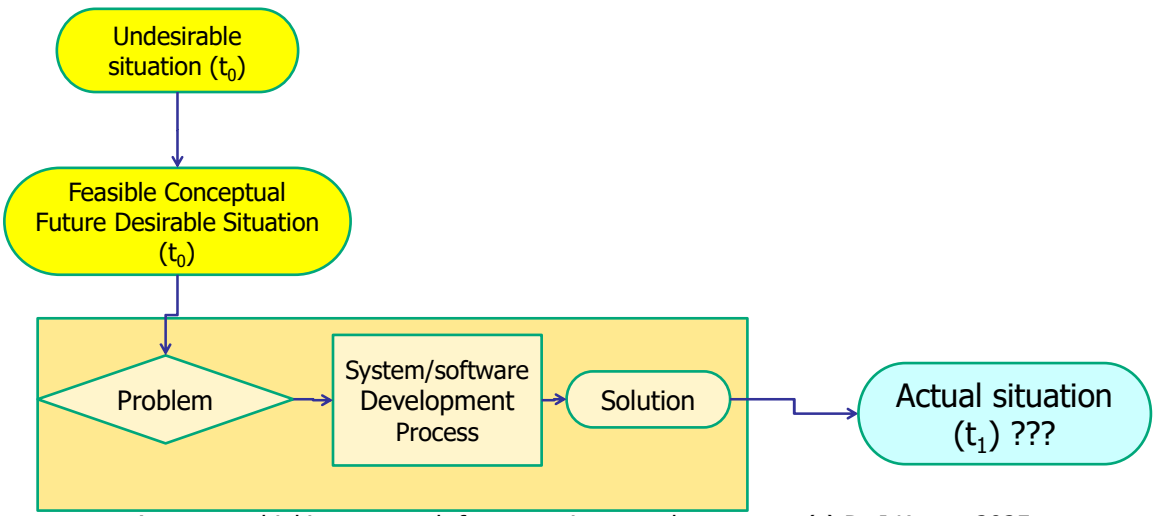


Problem Formulation Template

1. ***The undesirable situation***
   - As perceived from the HTPs (objects and relationships)
2. ***Assumptions***
   - About the situation, problem, solution, constraints etc.
3. ***The** Feasible **Conceptual** Future Desirable **Situation (FCFDS)***
   - As perceived from the HTPs
4. ***The problem***
   - **What** needs to be done to convert the FCFDS to reality in reverse order
5. ***The solution***
   - **How** the undesirable situation will be/was remedied
   - Has to be interoperable with evolving adjacent systems over the operational life of solution and adjacent systems
   - Is made of two interdependent parts
     1. The transition process (flow chart)
     2. The solution system operating in the context of the desirable situation

The problem-solving process



Problem Formulation Template

1. ***The undesirable situation***
   - My watch stopped working
   - The need to make the watch work (not written as, "the need to have a device on my wrist that will tell me the correct time")
2. ***Assumptions***
   - The battery has reached the end of it's lifespan
3. ***The** Feasible **Conceptual** Future Desirable **Situation (FCFDS)***
   - My watch is working again and the time shown is *always* correct
4. ***The problem***
   1. Place watch on wrist
   2. Close up the watch
   3. Insert new battery with correct polarity
   4. Obtain a replacement battery
   5. Remove the back of the watch
   6. Find a tool that would allow me to remove the back of the watch

Working backwards from the answer

5. ***The solution***
   - **How** I replaced the battery (each step, one at a time working forwards)

Simple problem-1

1. ***The undesirable situation***
   - Need to make the boss a cup of coffee
2. ***Assumptions***
   - The ingredients are available
3. **The Feasible Conceptual Future Desirable Situation** (FCFDS)
   - The boss is drinking her coffee and is not complaining about it
4. ***The problem (what to do)***
   1. The boss is drinking her coffee and is not complaining about it
   2. Giving the coffee to the boss
   3. Stirring the mixture
   4. Adding sweetener and creamer
   5. The remaining steps to create the cup of hot coffee

Working backwards from the answer

Simple problem-2 (how)

5. *The solution* *(for percolated coffee)*

1. Putting water in percolator
2. Putting coffee beans in percolator
3. Turning on the percolator
4. Percolating the coffee
5. Pouring coffee into cup
6. Adding sweetener and creamer
7. Stirring the mixture
8. Giving the cup of coffee to the boss
9. The boss is drinking her coffee and is not complaining about it

5. *The solution* *(for instant coffee)*

1. Putting water in kettle
2. Boiling the water
3. Putting the hot water in the cup
4. Adding the coffee
5. Adding sweetener and creamer
6. Stirring the mixture
7. Giving the cup of coffee to the boss
8. The boss is drinking her coffee and is not complaining about it

Bonus – add risk management

8. Risk of running out of ingredients
9. Check amounts of coffee, sweetener and creamer
10. Reorder when necessary

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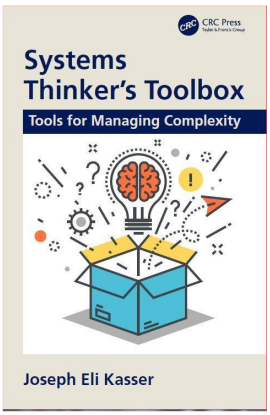

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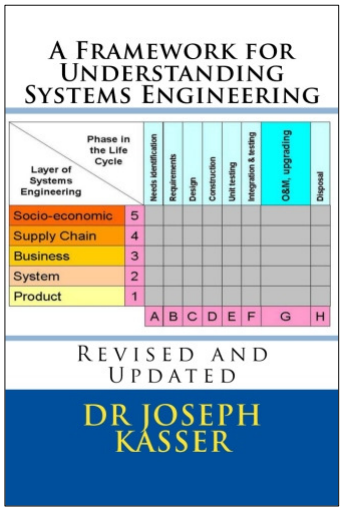

Complexity : *Big Picture*

- Complexity is all around us
- Complexity is only a concern when there is a complex problem
  - Something undesirable
- We don't understand the reason for what is being observed in some complex situations
- Different definitions of complexity and complex problems
- We tend to manage complexity by ignoring non-relevant issues
- Assumptions
  - Complexity produces complex problems

Complexity dichotomy: *Operational*

- People tackling complex problems with various degrees of success
  - Cruise ships fleets
  - Airlines
  - Oil extractions process to retailing
  - ATM for financial transactions
- Others cannot tackle complexity
  - Need new tools, techniques and templates
- Confusion between complex problems and wicked problems

Complexity : *Structural*

1. Layers of complexity (the HKM^{2}F)
   - Man-made systems
2. Definitions of complexity contain
   - "Large" number of elements
     - Large is undefined
   - Interactions between elements
   - Unpredictable outcomes
   - Difficult to understand

The Hitchins-Kasser-Massie-Mabelo Framework - (HKM²F)

Complexity: Layer of complexity		A	B	C	D	E	F	G	H
Global (Planetary)	7								
Regional	6								
Socio-economic	5								
Supply chain	4								
Business	3								
System (single)	2								
Product	1								
Component	0								

Lifecycle States

A – Customer needs identification | **B** – System requirements | **C** – Subsystem design | **D** – Subsystem construction | **E** – Subsystem testing

F - Systems Integration and test | **G** - Operations and maintenance | **H** – System disposal

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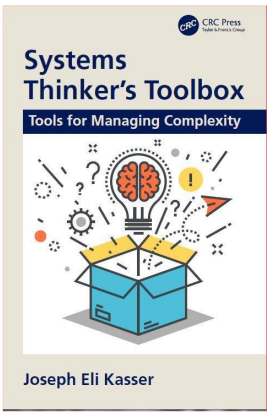

Complexity: *Generic*

- Lack of understanding what is going on also happens in scientific research
  - First situation in scientific method
- Definitions (various)
  - **Complexity** is in the eye of the beholder
    - Jackson, M. C. and Keys, P., "*Towards a System of Systems Methodologies*", Journal of the Operations Research Society, Vol. 35 (1984), no. 6, pages 473-486
  - A **complex** system is an assembly of interacting members that is difficult to understand as a whole
    - Allison, J. T., "Complex System Optimization: A Review of Analytical Target Cascading, Collaborative Optimization, and Other Formulations," The University of Michigan, 2004, page 2

Complexity: *Continuum*

1. A dichotomy (Operational)
   1. It's a major problem
   2. What's the problem?
2. Confusion between complex problems and wicked problems (Operational)
3. Complexity can be split into
   1. Objective complexity
      - Based on connections and interactions
   2. Subjective complexity
      - Based on difficulty of understanding
4. Different problems may contain different mixes of subjective and objective complexity

Complexity: *Quantitative*

- Objective complexity
  - No specific numbers attached to
    - Large number of elements
    - Large number of interactions
  - General lack of weighting of contribution of element to complexity
    - All assumed to be equal
- Subjective complexity
  - Levels of difficulty of problem
  - Domain knowledge

Complexity: *Scientific*

- *Operational*
  - Complexity is in the eye of the beholder
    - Jackson, M. C. and Keys, P (1984)
- *Functional*
  1. Complexity is actually sensed by the eye of the beholder
  2. Beholder thinks about the complexity
  3. Complexity is in the mind of the beholder
- *Quantitative*
  - Limitation on number of manageable elements in mind is 7 ± 2 (Miller's rule)
- *Scientific* (out of the box) conclusion
  - Value of 'large' is "more than 7 ± 2" (applying Miller's rule)

Generic HTTP: Hypothesis test

- (Where) is that number being used to manage complexity successfully?
  - Management span of control
  - Civilian and military organization structures (>=10)
- How?
  - Using the Principle of Hierarchies
    - E.g., "*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, Mark K., and E. Rechtin. 2000. *The Art of Systems Architecting*. 2nd ed: CRC Press.

Subjective complexity (Level of difficulty*)

1. ***Easy***
   - Can be solved in a short time with very little thought
2. ***Medium***
   - Can be solved after some thought
   - May take a few more steps to solve than an easy problem
   - Can probably be solved without too much difficulty, perhaps after some practice
3. ***Ugly***
   - Will take a while to solve
   - Involves a lot of thought and many steps
   - May require the use of several different concepts
4. ***Hard***
   - Usually involve dealing with one or more unknowns
   - Involves a lot of thought and some research
   - May also **require iteration through the problem-solving process** as learning takes place

* Based on Ford, W., Learning and teaching math, 2010, http://mathmaine.wordpress.com/2010/01/09/problems-fall-into-four-categories/, accessed on 29 March 2024

More subjective levels of difficulty*

5. **Unsolvable**
   - Cannot be solved based on the knowledge 'we know we know' today with available resources
6. **Impossible**
   - Can never be solved based on the knowledge 'we know we know' today (we think)

- Not much use in engineering, but research is continuously moving problems in these levels down into lower levels by increasing the knowledge 'we know we know'

* Proposed by Bruce Lerner in online Oasis Café meeting on 29 March 2024, adjusted 12 April with help from Ricardo Reis and Pascal Boholu Mabelo

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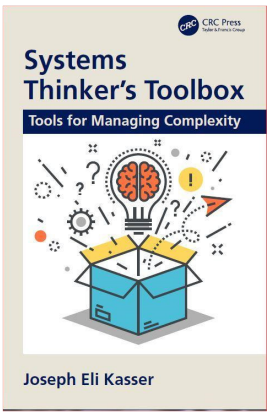


Separating subjective and objective

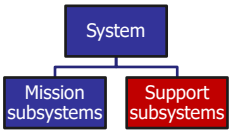
1. Manage subjective complexity
   - By gaining an understanding of the situation (reducing subjective complexity)
2. Manage objective complexity
   - Apply Meir and Rechtin 2000
   - Start by using the principle of hierarchies (reducing objective complexity) to build a mental model of the situation
     - set the architecture/structure to 5-10 system/subsystems
     - at each level in the hierarchy
3. Iteratively if necessary

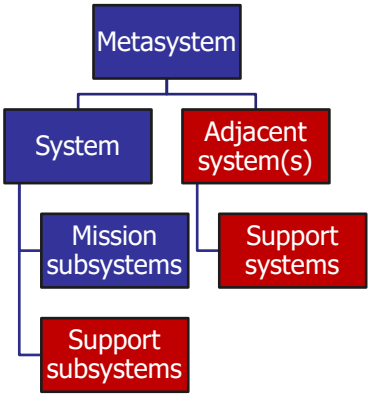
Reducing objective complexity at any level in the hierarchy

1. Abstract out non-pertinent aspects of the situation
   - Minimizes artificial objective complexity
2. Keep number of subsystems at any level to less than 7±2
   - Miller's rule for comprehension (Miller 1976)
   - Use principle of hierarchies
3. Optimize the interfaces
   1. Minimize coupling between subsystems
      - Weaken interactions
   2. Maximize cohesion of subsystems
4. Configure subsystems for the maximum degree of homeostasis
   - Self regulation

System partitioning

1. Mission subsystems
   - Subsystems that perform the mission
2. Support subsystems
   - Subsystems that support the mission subsystems
     1. Inside system
     2. Inside adjacent systems





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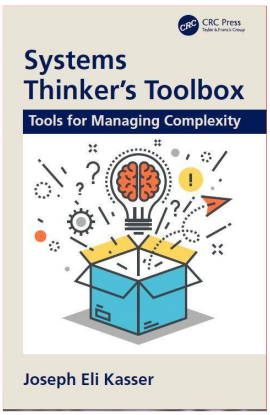

Exercise 5 Mission and support systems

1. Identify INCOSE's mission (or purpose)
2. Identify some of the mission and support subsystems of INCOSE
3. Identify at least 10 entities in the mission and support subsystems of INCOSE
   - Mainly from the *Operational*, *Functional* and *Structural* HTPs
4. Aggregate them into subsystems using the principle of hierarchies
5. Prepare presentation containing
   1. Reformulate the problem according to the Problem Formulation Template
   2. Compliance matrix
   3. Lessons learned
   4. Three views of the subsystems (each view maybe split into several graphics)
   5. A copy of this slide and the version number of the lesson
6. Save file as yourlastname-firstname-5.pptx (e.g., mouse-michael-5.pptx)
7. Email file to Beyondsystemsthinking@yahoo.com