INCOSE International Symposium
Las Vegas, NV
June 30 - July 3, 2014

The NINE systems in systems engineering

Joseph Kasser
Temasek Defence Systems Institute (NUS)
Yang Yang Zhao
Norwegian Institute of System Engineering

Revision 1.0

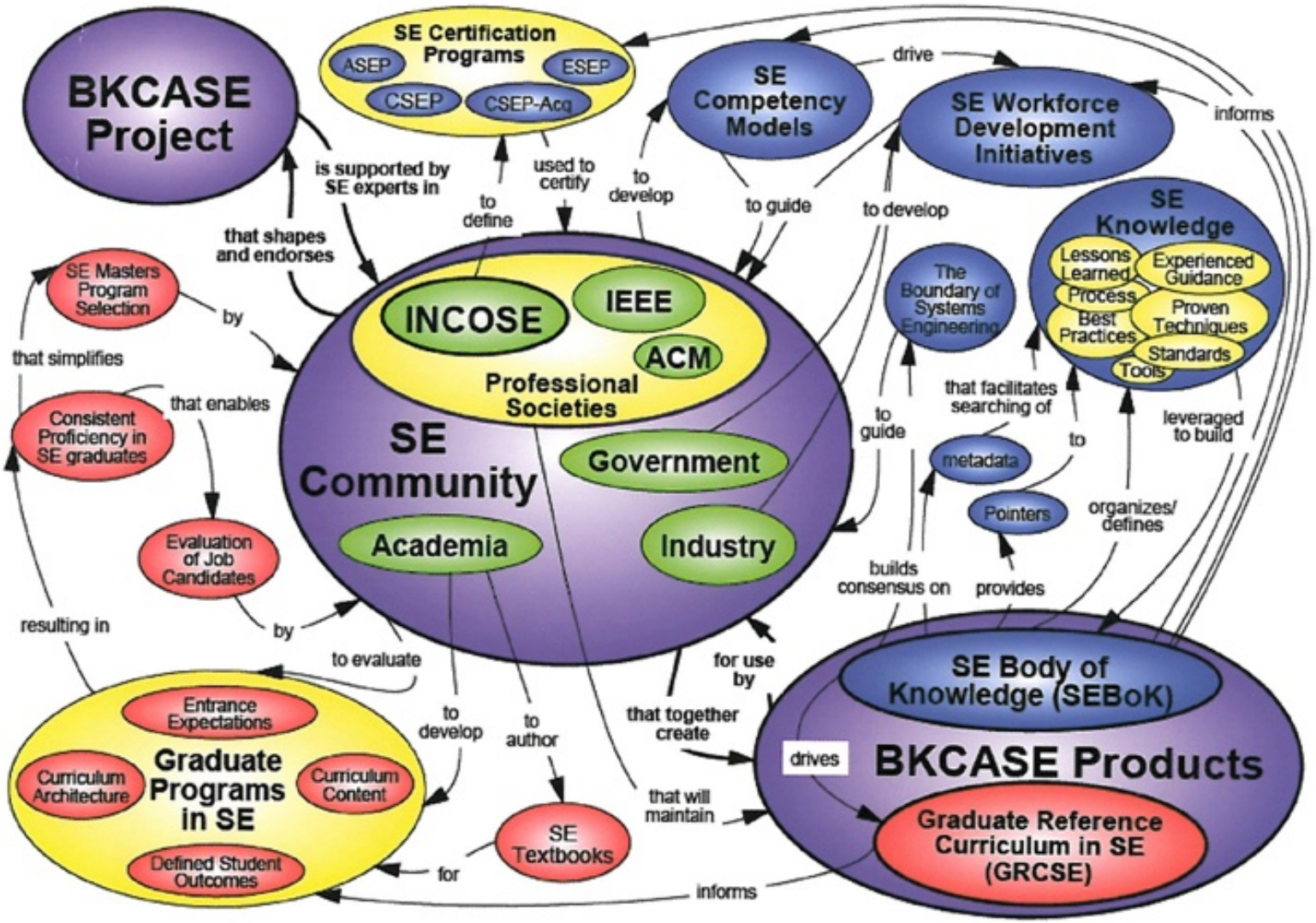
Topics

- The undesirable situation
- Previous attempts to manage complexity
- The Nine-System Model
- Examples of the Nine-System Model
- Benefits of the nine systems approach
- Questions and discussion

State of the art?

- Systems engineering has been defined as
  - "*the science of designing complex systems in their totality to ensure that the component subsystems making up the system are designed, fitted together, checked and operated in the most efficient way*" (Jenkins, 1969).
- However, in the ensuring 45 years, systems engineers seem to have been busy creating more and more complex models and processes.

Building artificial complexity



IS 2009 submission (not in proceedings)

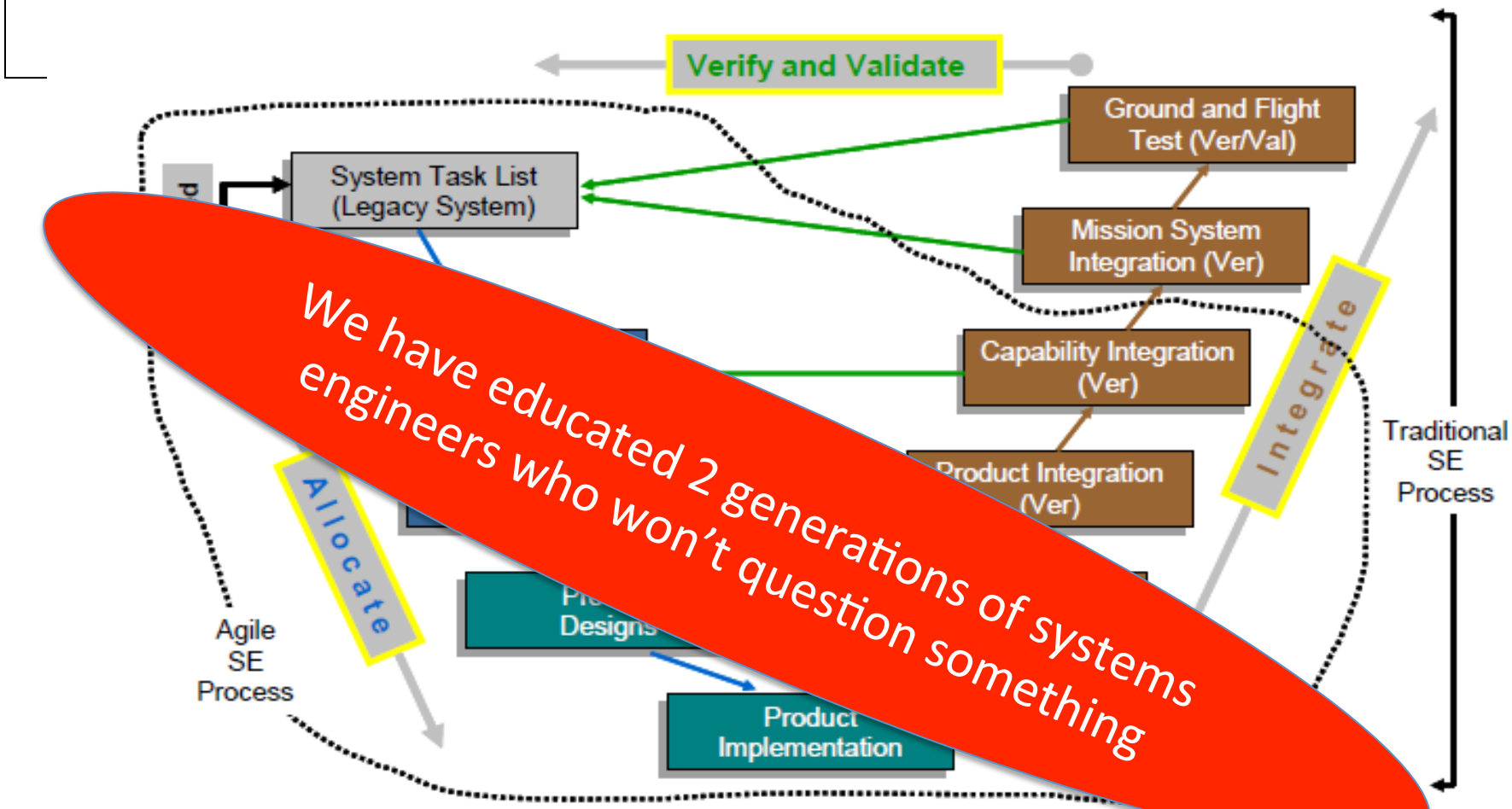
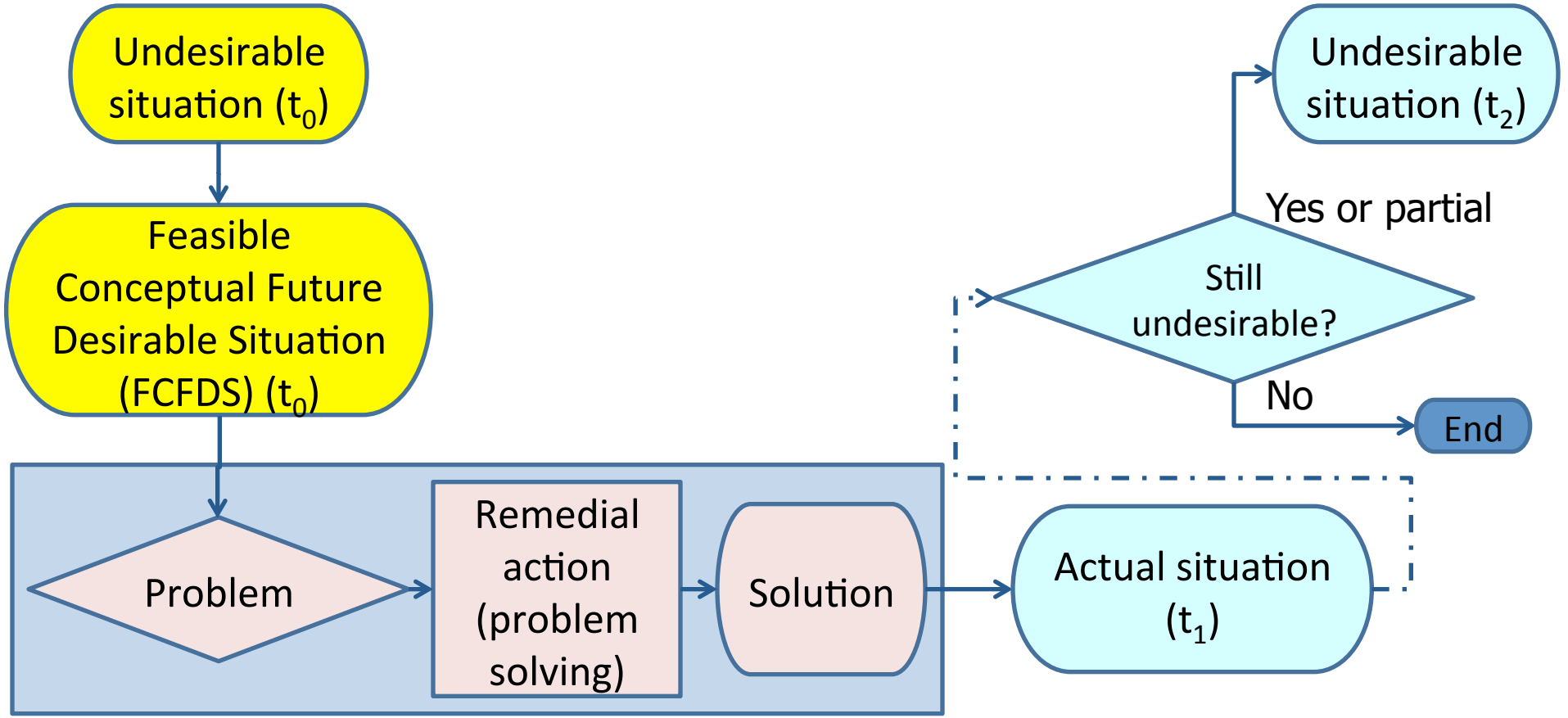


Figure 5. Modified Vee Model for Streamlined Acquisition Programs

Holistic systems approach to managing problems and solutions

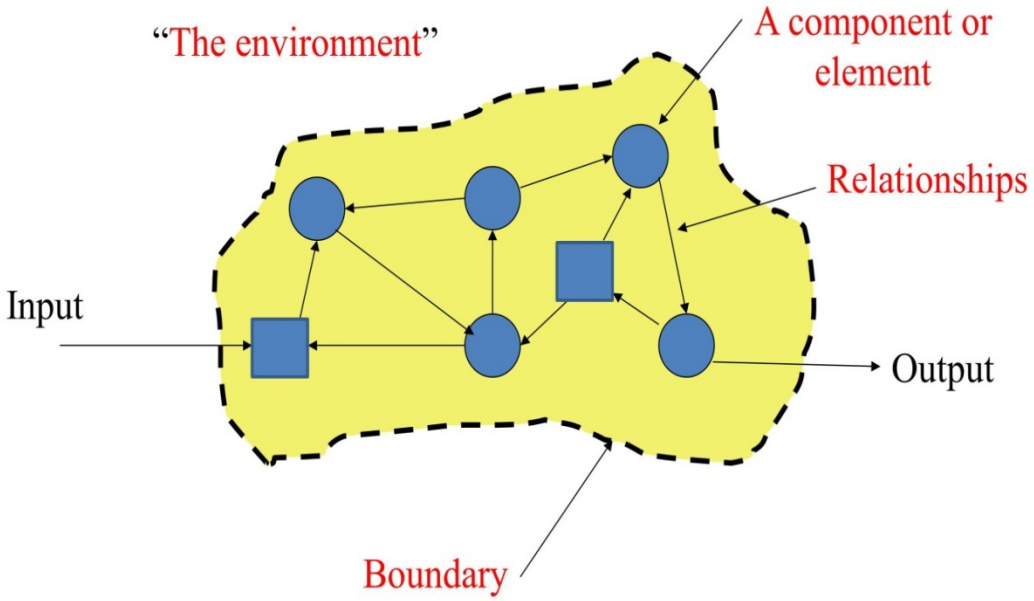


Managing complexity

- ***The undesirable situation***
  - The failure of systems engineering to manage the complexity of the systems development environment
- ***The FCFDS***
  - Systems engineering managing the complexity of the systems development environment
- ***The solution***
  1. A theory of how to manage complexity
  2. A set of tools for managing complexity based on the theory
- ***The problem***
  - How to develop
    1. a theory for managing complexity and
    2. the tools for managing complexity based on the theory

Definition: System (SOI)

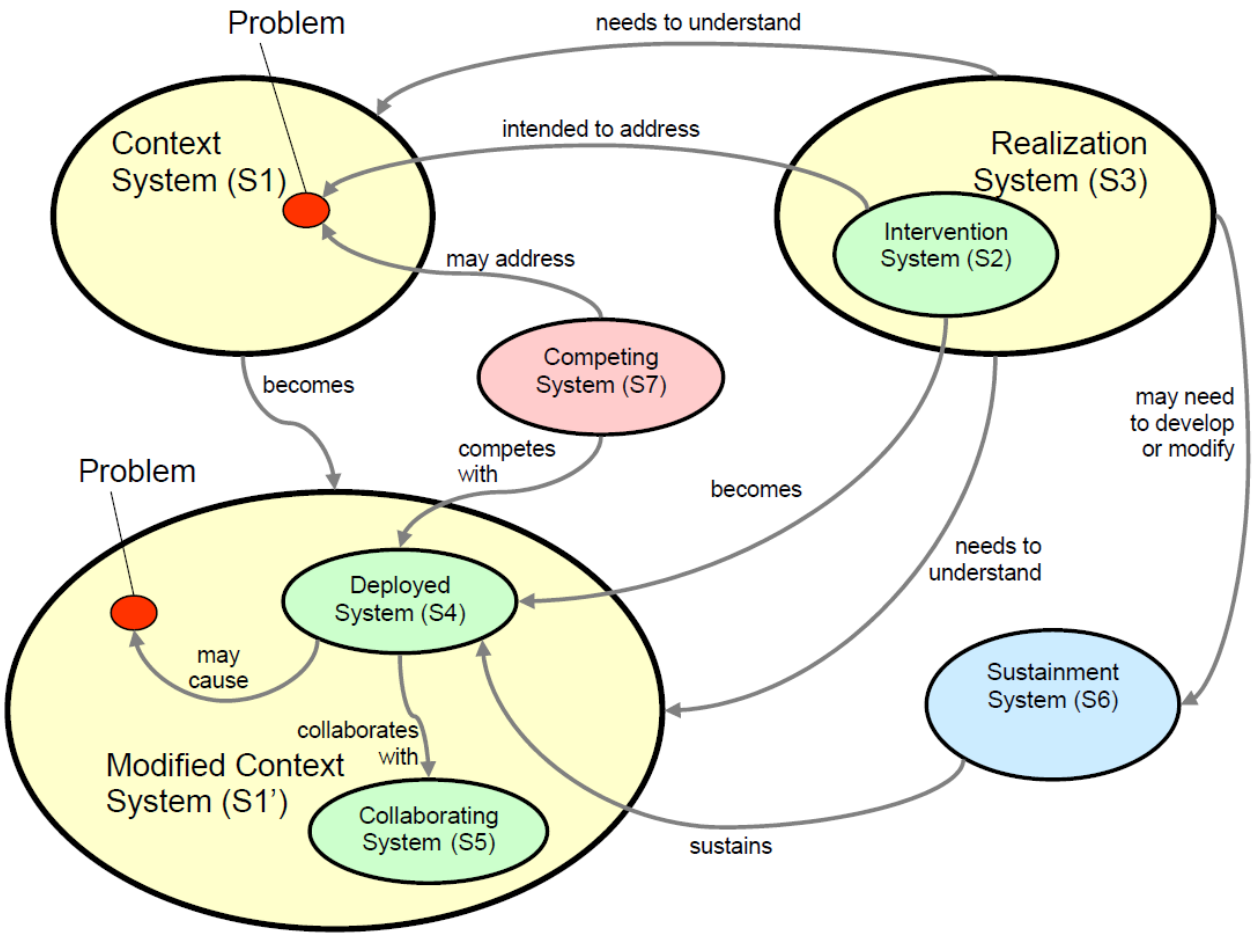
- *A system is an abstraction from the real world of a set of objects, each at some level of decomposition,* at some period of time*, in an arbitrary boundary, crafted for a purpose*" (Kasser, 2013a) pages 251 to 252).
  - Product
  - Process
  - Organization
  - Situation



Topics

- The undesirable situation
- **Previous attempts to manage complexity**
  - **In the INCOSE Symposia proceedings**
- The Nine-System Model
- Examples of the Nine-System Model
- Benefits of the nine systems approach
- Questions and discussion

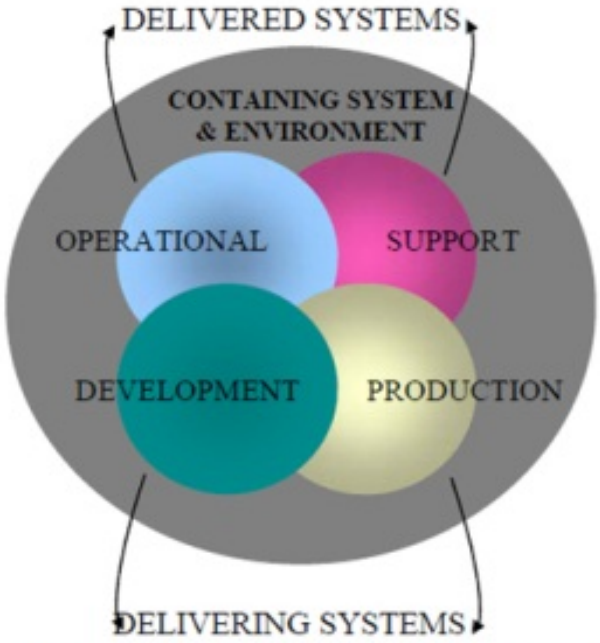
2004: Martin's 7 samurai*



* Martin 7 samurai, INCOSE 2004

2005 Whole System Model

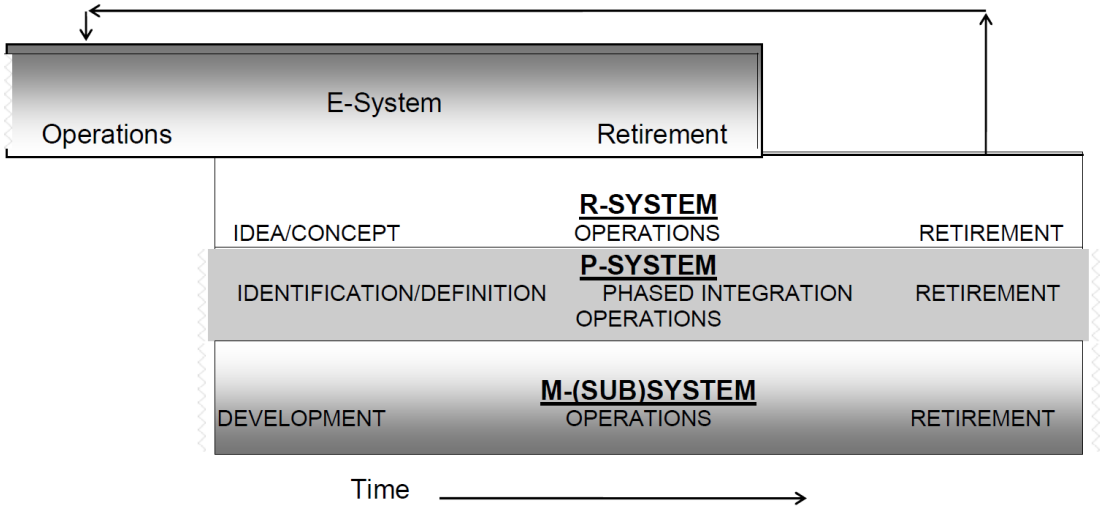
- Operational system
  - The system which goes into service
- Support system
  - The system which supports the Operational system in service
- Production system
  - The system which manufactures the relevant parts of the Operational and support systems
- Development system
  - The system, which develops the Operational, Support and Production systems
- Containing system
  - The related systems and the environment in which the above systems interact



These systems need to be developed to meet their individual requirements but are strongly linked

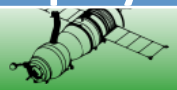
2006: Systems project

- Four systems
  - The Existing system
  - The Required system
  - The Producing system
  - The Maintenance and Support system



Comparing the models:1

Systems addressed by the models	7 Samurai	WSM	SP
Existing “as-is” situation	Context (S1)	-	-
Existing system in “as-is” situation	-	-	E-system
Process to develop conceptual solution system	-	-	-
Conceptual solution system at time development begins (FCFDS)	Intervention (S2)	-	R-System
Process to plan transition from existing situation to situation in which the solution system will be deployed	Realization (S3)	Production	P-System
Process to realize solution system	Realization (S3)	Production	P-System
Solution system at and after time of deployment	Deployed (S4)	Operational	R-System
[new] situation after solution system has been deployed	-	-	-



Comparing the models:2

Systems addressed by the models	7 Samurai	WSM	SP
Adjacent systems operating in association with the solution system at and after time of deployment	Collaborating (S5)	-	-
System or systems that keeps the solution system operational at and after deployment	Sustainment (S6)	Support	M-System
Process to determine situation after deployment of solution system contains no undesirable elements	Implied Realization (S3)	Implied Production	Implied P-System
Resources to be applied to realize the solution system	Realization (S3)	Development	P-System
Alternative solution systems	Competing (S7)	-	-
Enterprise and environment	Realization (S3)	Containing	-

Conclusions

- Each model is a different set of systems.
- Each model is incomplete since other models contain systems that the model does not.
- Systems present in one model are not present in another model.
- Each model invokes the temporal perspective (considers the time to realize the solution system) but in different ways.
- The situation after the solution system has been deployed is not considered in any of the three models
  - Martin does refer to it as a *modified context system* (S1').

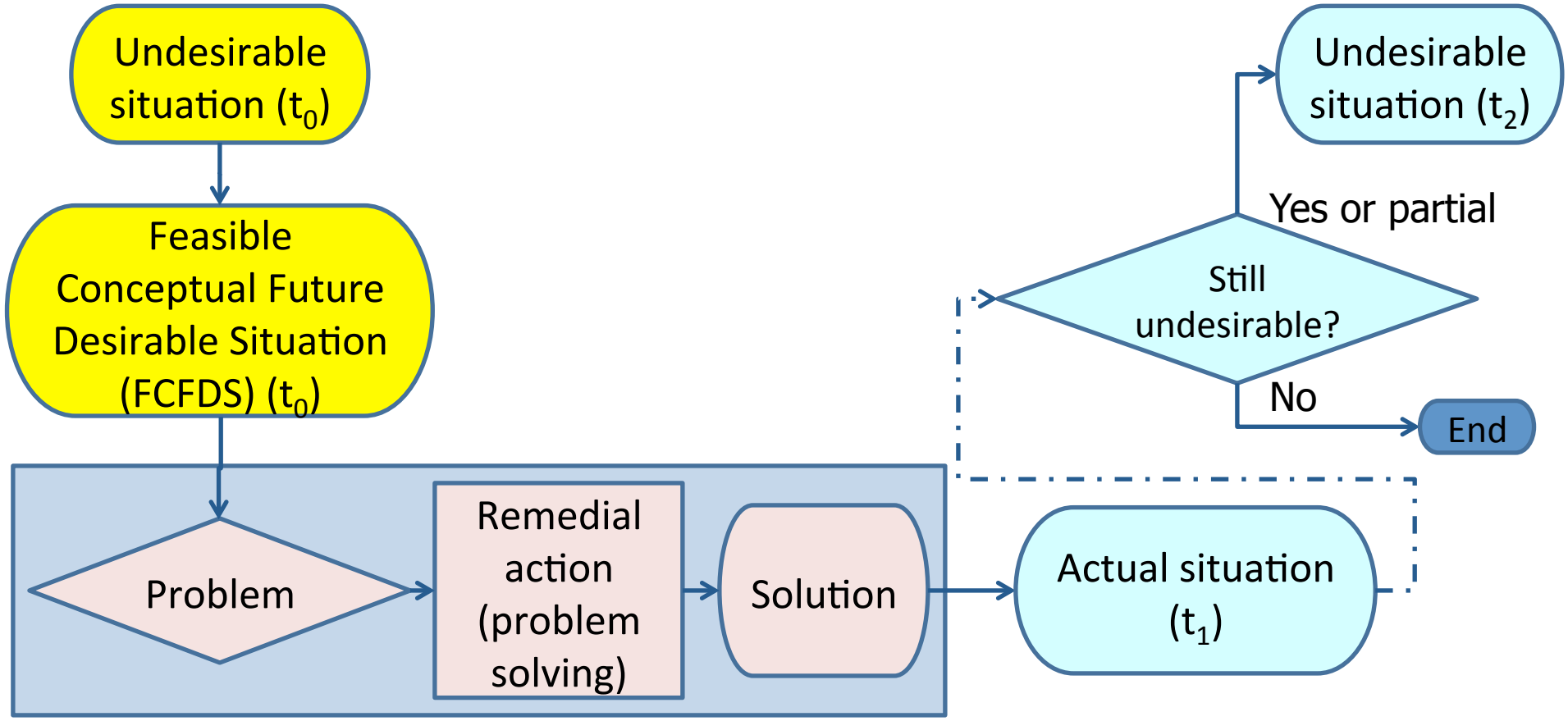
Topics

- The undesirable situation
- Previous attempts to manage complexity
- **The Nine-System Model**
- Examples of the Nine-System Model
- Benefits of the nine systems approach
- Questions and discussion

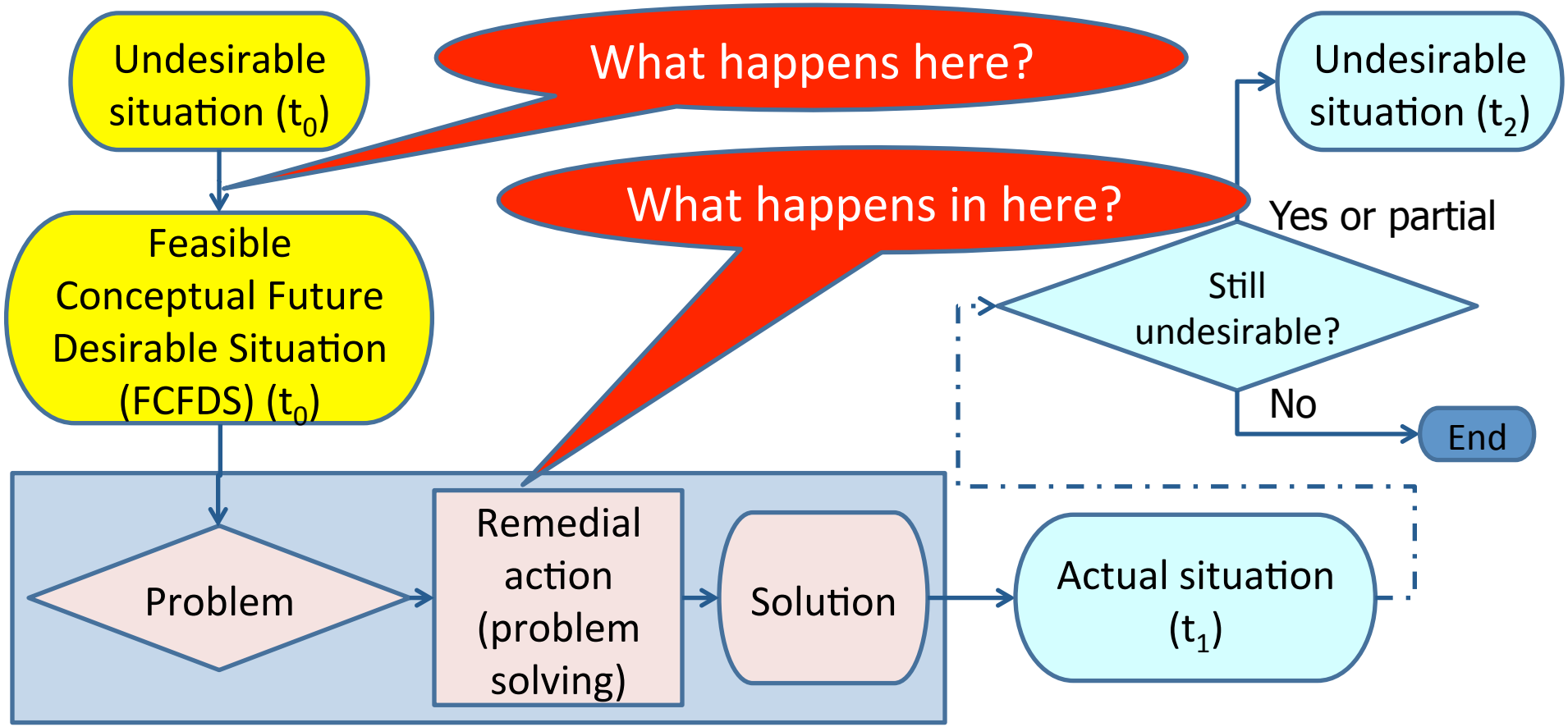
The Nine-System model

- Makes complexity manageable
  - Principles of hierarchies
  - Does not reduce complexity
- Fractal or self similar
- Multiple views of each system from 8 standard perspectives
  - Holistic Thinking Perspectives
- Provides a framework to fill in the gaps in the other models
- Based on a set of rules stated in the paper
- Explained from three perspectives

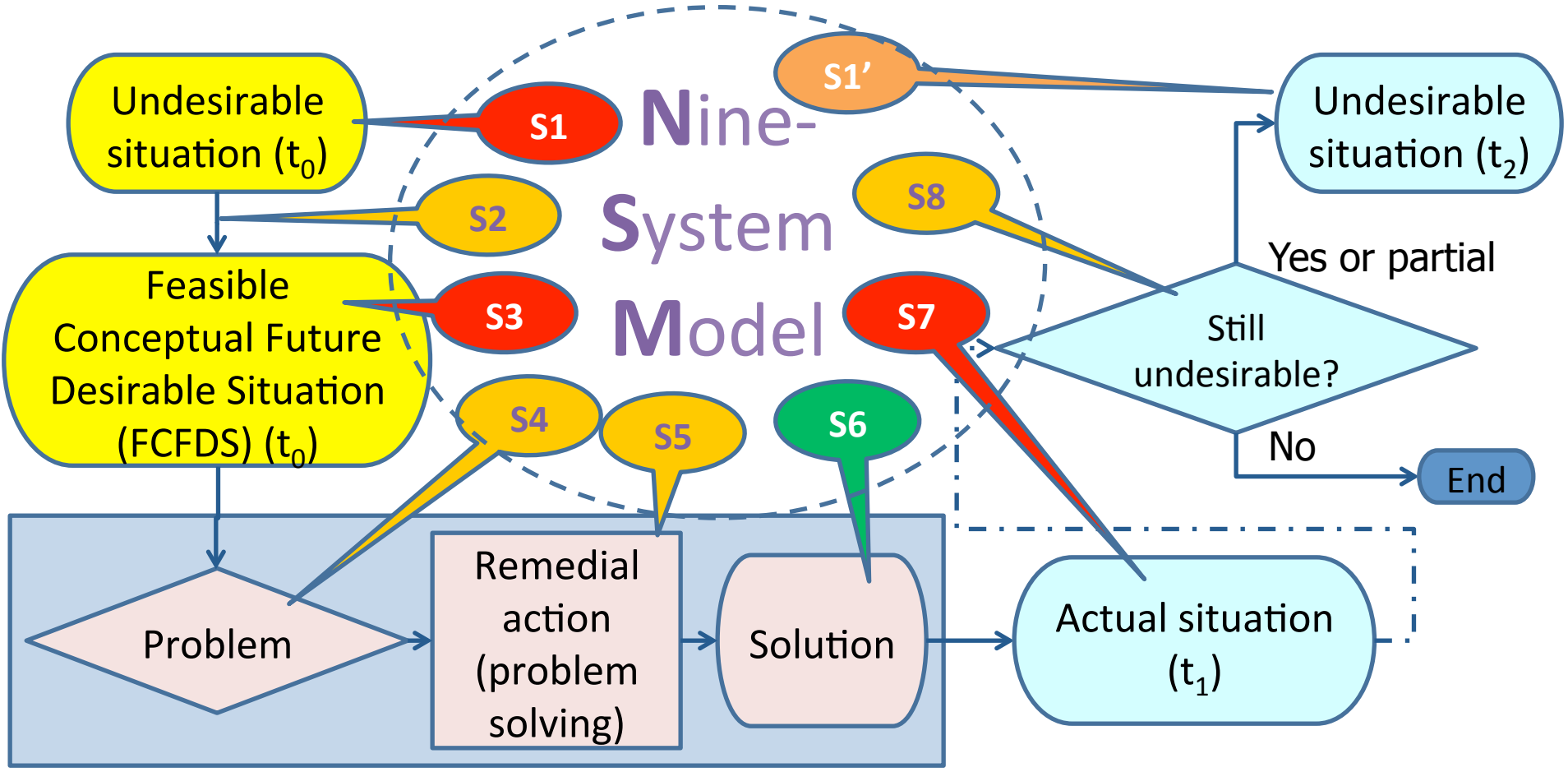
Holistic systems approach to managing problems and solutions



Holistic systems approach to managing problems and solutions



Holistic systems approach to managing problems and solutions

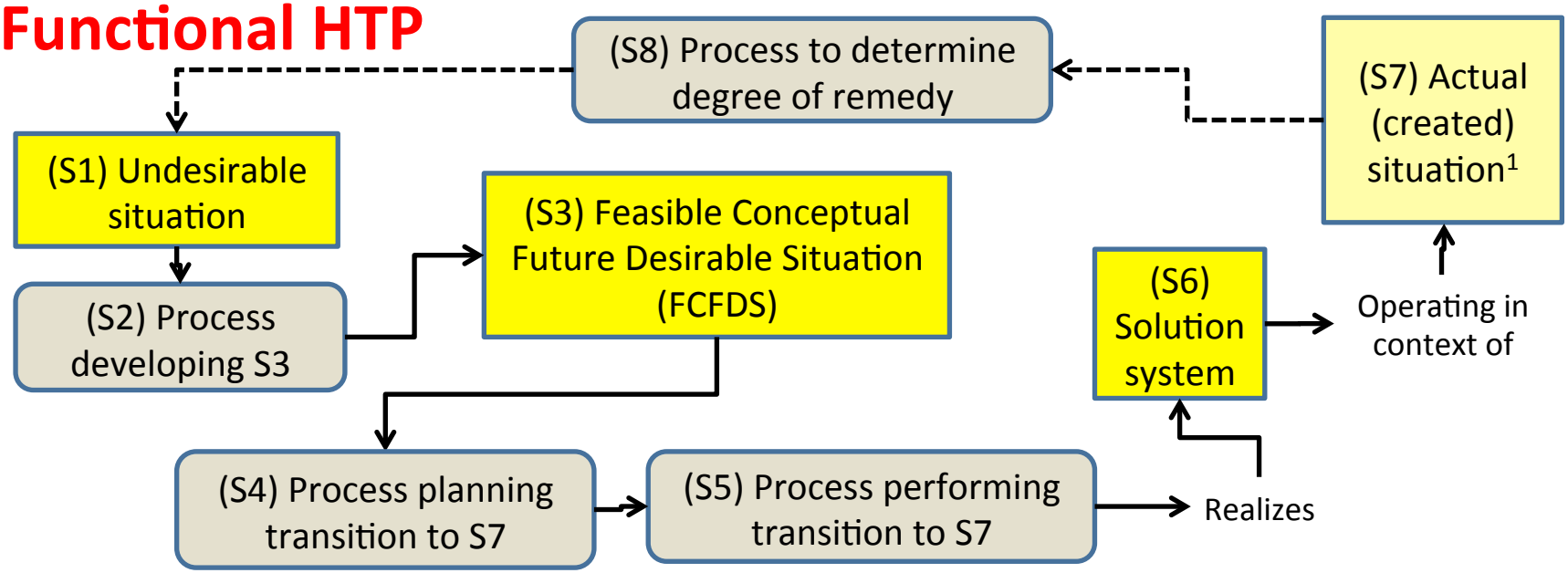


The 9 systems:
situations, systems & processes

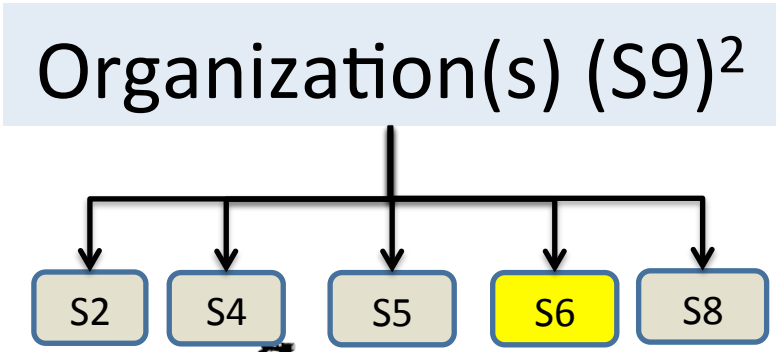
1. Undesirable or problematic **situation**
   - Baselined at t_0, but will evolve during realization of solution system
2. **Process** to develop the FCFDS
3. Future conceptual feasible desirable situation (FCFDS) that remedies the undesirable **situation**
4. **Process** to plan the transition from the undesirable situation to the FCFDS
5. **Process** to realize the transition by providing the solution system
6. Solution **system** that will operate within FCFDS
   - Mission and support functions
7. Actual or created **situation** at t_1
   - In which solution system operates
8. **Process** to determine that the realized solution remedies the evolved undesirable situation
9. **Organization**(s) containing the **processes**

The Nine-System model

Functional HTP



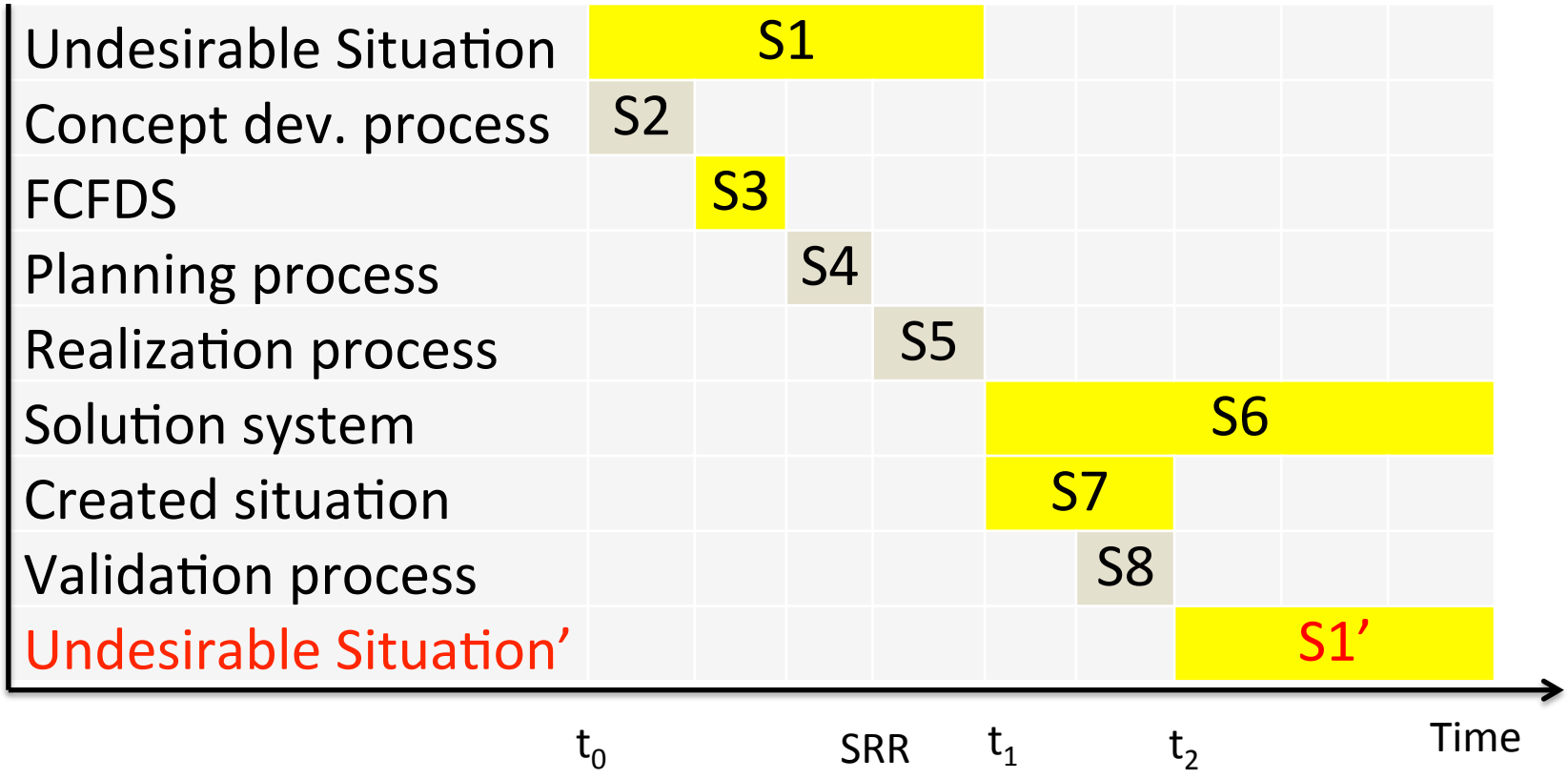
Structural HTP



1. The solution systems and the adjacent systems are subsystems in the actual situation
2. Considered as one [class of] system but generally is at least two organizations

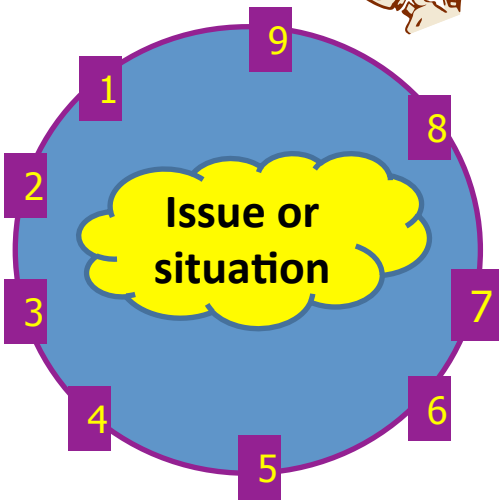
The Nine-System model

Temporal HTP



Holistic thinking perspectives

1. Big picture
   - Purpose, adjacent systems
2. Operational
   - Missions which the system performs
3. Functional
   - Functions performed by the system (used in missions)
4. Structural
   - Technology, hardware, resources comprising the system
5. Generic
   - Pertinent information from similar systems
6. Continuum
   - Pertinent differences between system and similar systems
7. Quantitative
   - Numerical information, pertaining to other perspectives
8. Temporal
   - Past present and future aspects of the system
9. Scientific
   - Conclusions, inferences about the problems

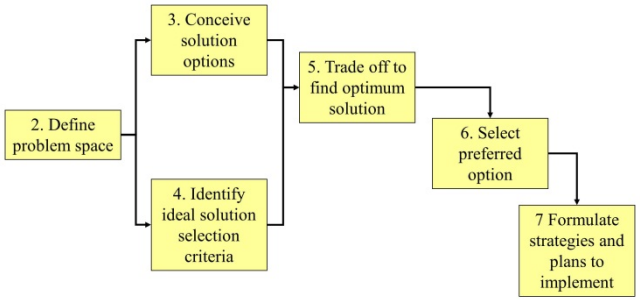


S1. Undesirable situation

- Perceived from holistic thinking perspectives
- As-is
- Baselined at t_0
  - Eight descriptive perspectives
    - Observations
    - Assumptions
  - Scientific perspective
    - Causes of undesirability
      - May be more than one
    - Statement of problem
      - A hypothesis of the cause of the undesirable situation

S2. Process: early stage

- Develops Feasible Conceptual Future Desirable Situation (FCFDS)
- Develops CONOPS of solution system operating within FCFDS
- Uses Steps 2-6 in Hitchins' systems engineering approach to problem solving
  - Hitchins, 2007

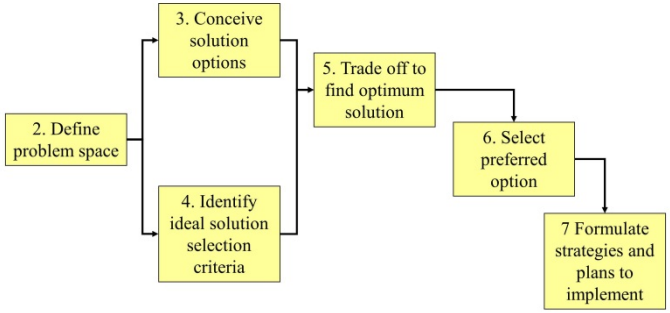


S3. FCFDS

- Begin with the end in mind
  - 7 Habits of …, Covey, 1989
- Assumption
  - FCFDS will remedy the undesirable situation
- Sometimes consensus on FCFDS may be achieved without consensus on the underlying cause of the undesirable situation
- Described from eight descriptive HTPs

S4. Process: planning the transition

- Planning/creating the process that will provide the solution system
  - Assembled from activities documented in textbooks, Standards, experience, etc.
  - Following a Standard (cf. use of COTS)
  - Build/buy decisions
  - Creates SEMP and TEMP
- Step 7 in Hitchins systems engineering process
- Creating the matched set of specifications for the solution system
- Generally terminates with a SRR

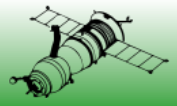


S5. Process: providing the transition

- Commonly known as the
  - 'system development process (SDP)'
  - 'system development lifecycle (SDLC)'
  - "systems engineering process (SEP)"
- Three streams of work
  1. Management
  2. Development/production
  3. Development Test and Evaluation (DT&E)
- May require several iterations
  - Temporal perspective
- Must be able to cope with changes in need before process terminates

S6. Solution system

- Conceived as part of FCFDS
- Realized in providing actual situation
- May comprise more than one system
- Contains mission and support functions
- Conforms to 7 principles paper
  - Kasser and Hitchins, 2011
- May be provided in stages or Builds
- Contains a mixture of technology and people



S6: HTPs

- Operational perspective
  - Interactions with adjacent systems
  - What the system does (Scenarios)
- Functional perspective
  - Internal Mission and support functions
- Structural perspective
  - Technology and physical components
- Quantitative perspective
  - Numbers associated with functions and other aspects
    - costs, reliability, etc.

S7. Actual (created) situation

- Realization of the FCFDS
  - Situation at time solution system is realized
- Contains solution system and adjacent systems operating interdependently
- May only partially remedy original undesirable situation
- May not remedy new undesirable aspects that show up during time taken by realization process
- May contain unanticipated undesirable emergent properties from solution system and its interactions with adjacent systems in the situation
- May be realized in partial remedies

S8. Process closing stage

- Determines if the solution system, operating in its context, remedies the new evolved undesirable situation at t_1.
- Operational Test and Evaluation (OT&E)
- Acceptance test at end of first iteration
- Evolves into change management process
  - Triggers new iteration via change process to modify/upgrade solution system
  - May lead to disposal phase

S9. System containing processes

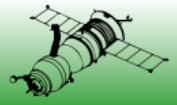
- Organizations
  - Generally at least two organizations
    - Customer and contractor
  - Grouped as one system because of common features
    - Each organization is an instance of a class of systems
- Provides personnel and other resources to process systems

Topics

- The undesirable situation
- Previous attempts to manage complexity
- The Nine-System Model
- **Examples of the Nine-System Model**
- Benefits of the nine systems approach
- Questions and discussion

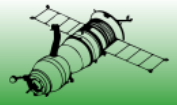
Example: The 9 systems of the Apollo program

1. Undesirable or problematic situation
   - Perception that Soviet Union is ahead of US in space
2. Process to develop the FCFDS – NASA's early stage systems engineering
3. Future FCFDS that remedies the undesirable situation
   - Perception that US is ahead of Soviet Union in space
4. Process to plan the transition from the undesirable situation to the FCFDS (in NASA)
5. Process Realize the transition by providing the solution system (in Contractors, NASA and DCAS)
6. Solution system that will operate within FCFDS
   - Ground, space and lunar systems
7. Actual or created situation
   - APOLLO landings
8. Process to determine that the realized solution remedies the evolved undesirable situation
   - US publicly lands on the moon before Soviet Union
9. Organization(s) containing the processes
   - NASA orchestrating situation and systems
   - Contractors producing systems and subsystems
     - DCAS performing Quality Control on products

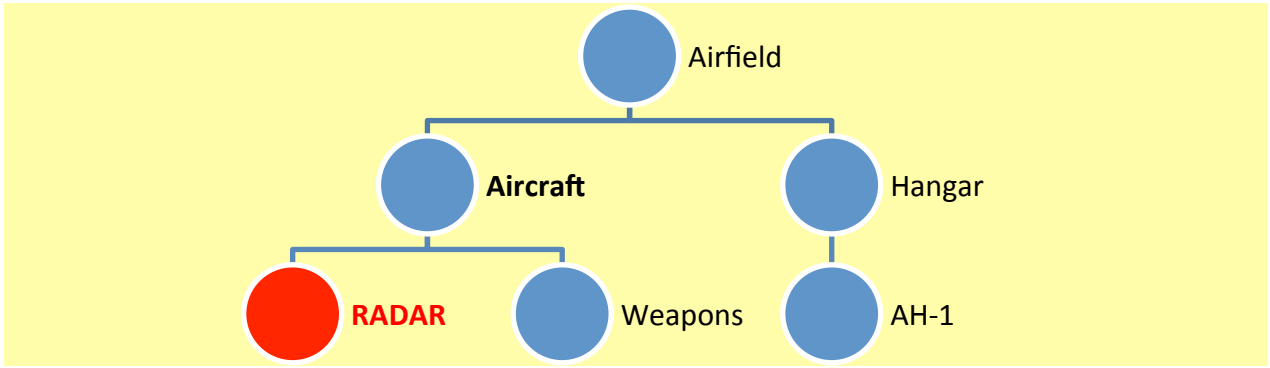


Example: The 9 systems in aerial reconnaissance

1. Undesirable situation
   - Need for accurate and timely information about something happening in a remote location
2. Process to develop the FCFDS
3. Future FCFDS that remedies the undesirable situation
   - Accurate and timely information is being provided
4. Process to plan the transformation from the undesirable situation to the FCFDS
5. Process to realize the transformation from the undesirable situation to the FCFDS by providing the solution system (purchase COTS or develop)
6. Solution system
   - UAV and associated ground support equipment
7. Actual or created situation
   - UAV operational returning accurate and timely information to personnel
8. Process to compare actual or created system with the FCFDS
9. Organization(s) containing the processes
   a) Defence force
   b) Contractor or vendor



Applies in each level of hierarchy



Aircraft

(S7) Actual (created) situation

(S8) Remedy?

(S1) Undesirable situation

(S2) Process

(S3) FCFDS

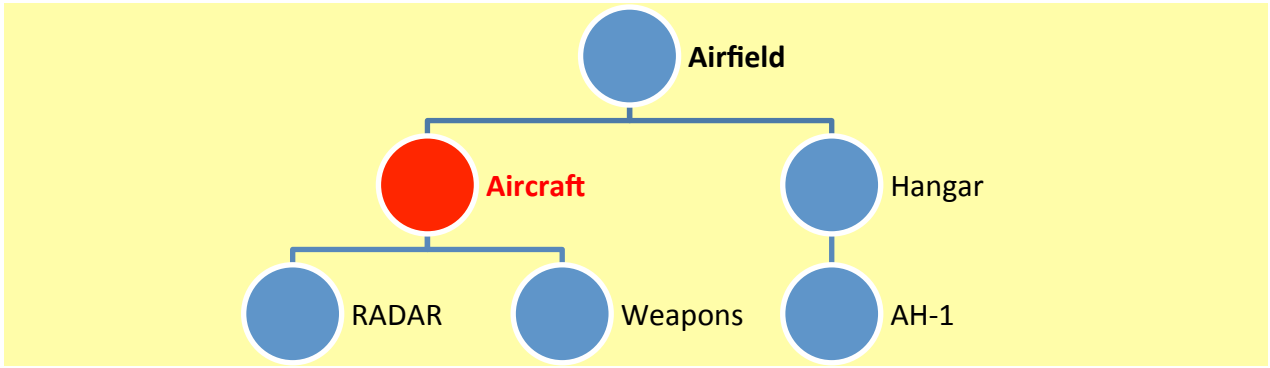
(S4) (S5) Processes

(S6) Solution system

Operating in context of

RADAR

Applies in each level of hierarchy



Airfield

(S7) Actual (created) situation

(S8) Remedy?

(S1) Undesirable situation

(S2) Process

(S3) FCFDS

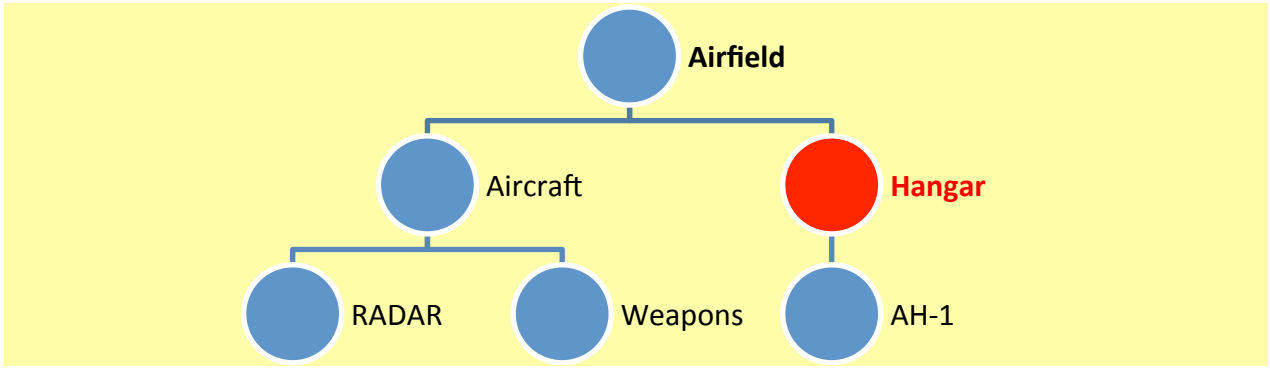
(S4) (S5) Processes

(S6) Solution system

Operating in context of

Aircraft

Applies in each level of hierarchy



Airfield

(S7) Actual (created) situation

(S8) Remedy?

(S1) Undesirable situation

(S2) Process

(S3) FCFDS

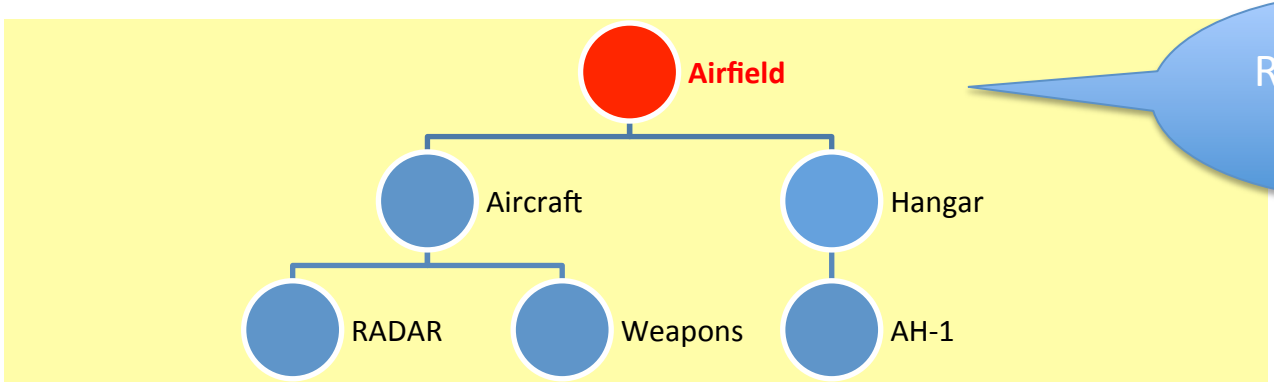
(S4) (S5) Processes

(S6) Solution system

Hangar

Operating in context of

Applies in each level of hierarchy



Reductionist view

Air Defence system

(S7) Actual (created) situation

(S8) Remedy?

(S1) Undesirable situation

(S2) Process

(S3) FCFDS

(S4) (S5) Processes

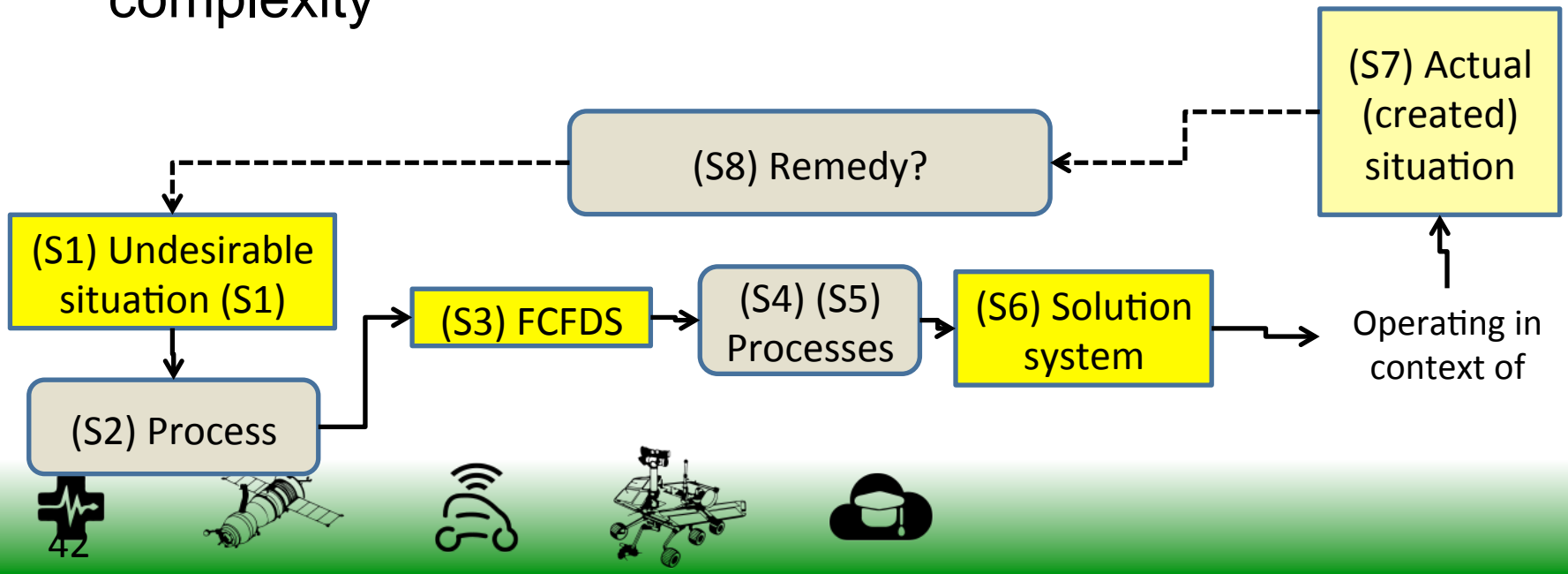
(S6) Solution system

Operating in context of

Airfield

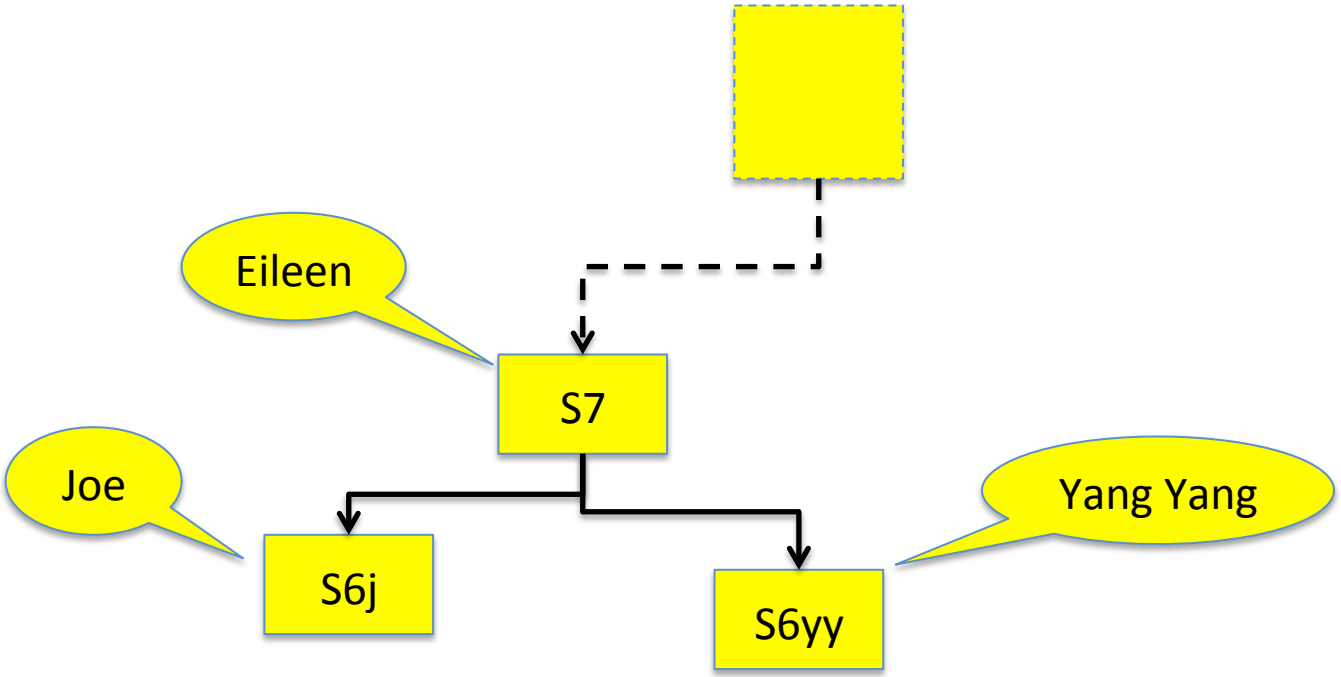
It depends

- Each system has its own 9 systems
- S6 and its adjacent systems are subsystems of S7
- S7 perceived from this view is an S6 to the systems engineers working on it
- Each systems engineer needs to be concerned with their subsystems, S6 and S7, and abstract out rest of complexity



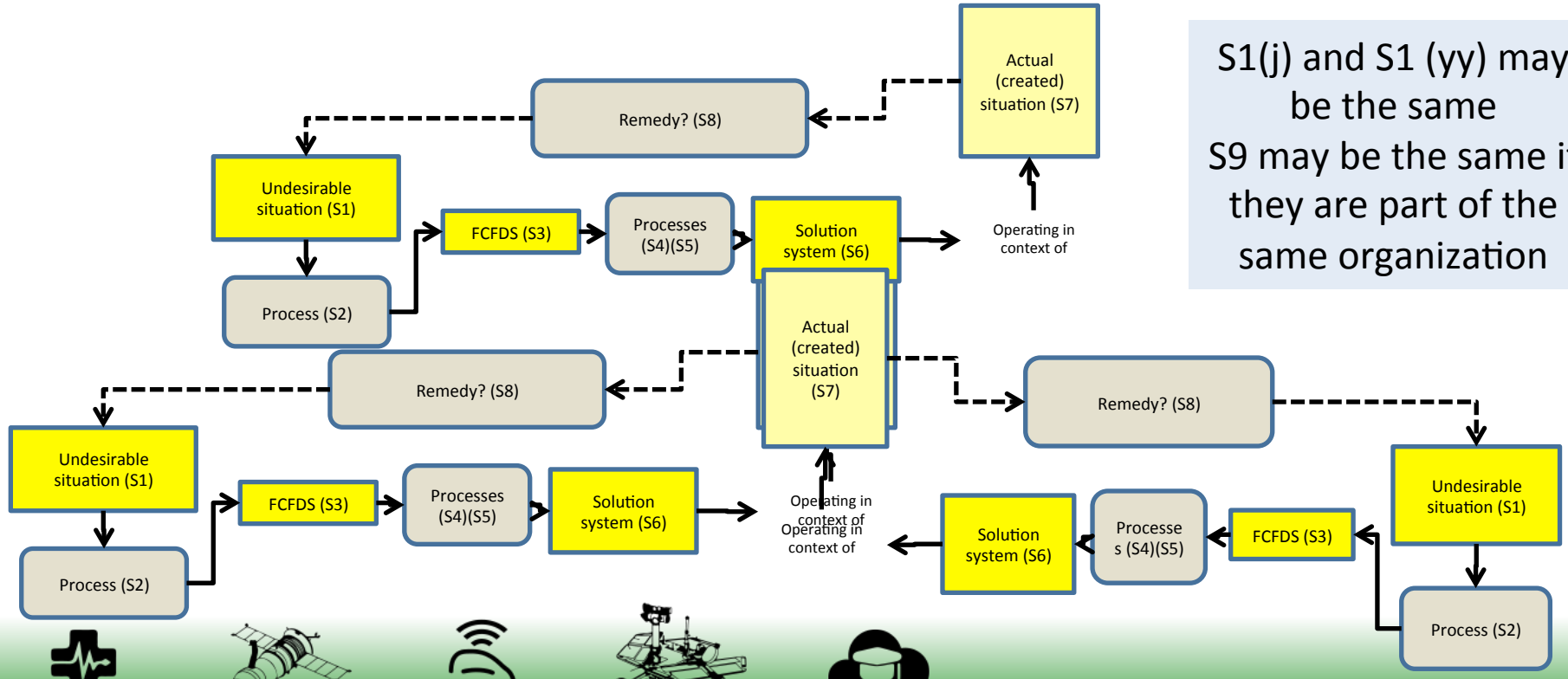
Perceptions of complexity

- **Joe** is systems engineer realizing S6 which is subsystem in S7
- **Yang Yang** is systems engineer realizing adjacent system S6yy which is also subsystem in S7
- **Eileen** is systems engineer realizing (S6e) which is also S7(j/yy)



Perceptions of complexity

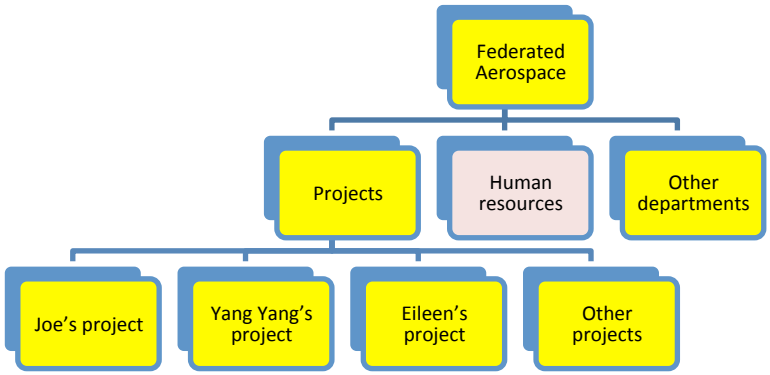
- **Joe** is systems engineer realizing (S6j) which is subsystem in S7j
- **Yang Yang** is systems engineer realizing adjacent system (S6yy) which is also subsystem in S7yy. S7j = S7yy.
- **Eileen** is systems engineer realizing (S6e) which is also S7(j/yy)



S1(j) and S1 (yy) may be the same
S9 may be the same if they are part of the same organization

More perceptions

- Federated Aerospace: Structural perspective
- Each Block is part of its own 9 systems
  - e.g. Human Resources (HR)



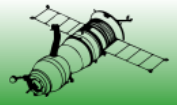
- S1 Lack of competent staff in projects and other departments
- S2 Corporate management process
- S3 Projects fully staffed with competent personnel and retaining staff
- S4/5 Hiring and prevention of leaving processes
- S6 HR personnel management system
- S7 Projects fully staffed with competent personnel and retaining staff
  - Same as S3 in this instance
- S8 Corporate management process
- S9 Federated Aerospace

Topics

- The undesirable situation
- Previous attempts to manage complexity
- The Nine-System Model
- Examples of the Nine-System Model
- **Benefits of the nine systems approach**
- Questions and discussion

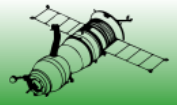
Descriptive HTPs provide templates for describing systems

- Horizontal views
  - Support systems are adjacent systems
  - All (sub)systems at a particular level in the hierarchy will have
    - Same meta or containing system
    - Slightly different list of adjacent systems
- Vertical views
  - Traceability from system – subsystem
- Next generation tools can check these in the manner of today's requirements management tools



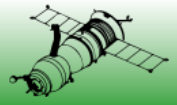
Focus of the Standards, problem-solving and the nine systems

System	MIL-STD-499	EIA-632	IEEE 1220	ISO/IEC 15288	Hitchins (2007)	SIMILAR	Problem solving process
S1					X		
S2					X		X
S3					X		X
S4	X		Partial	X	X		X
S5		X	X	X		X	X
S6		X	X			X	X
S7							X
S8						X	X
S9			Partial	X			



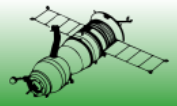
Builds in good practice

- Removes some reductionist views
  - Containing or Metasystem view built-in
- Encourages testing of solution system in context of created situation
- Abstracts out complexity
  - Minimizes tendency to make things more complex
- Clear boundaries, interfaces and lines of demarcation
- Shows aspects that tend to be ignored in current paradigm
  - Planning realization process
  - Top level system is something else's subsystem
    - E.g. airfield is part of Air Defence System (ADS)



Conclusions: Benefits of this approach

- Can be used without consensus on problem
- Simplified non-overlapping system boundaries and interfaces
- Applicable in all levels of system hierarchy
- Abstracts out complexity
  - Using principle of hierarchies
- Foundation in theory
  - Problem-solving body of literature
  - System engineering literature
- Links to existing paradigm anchor points
- Builds best practices into systems engineering

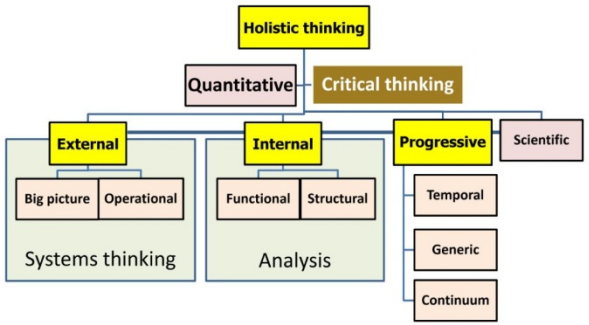


Summary

- The undesirable situation
- Previous attempts to manage complexity
- The Nine-System Model
- Examples of the Nine-System Model
- Benefits of the nine systems approach
- Questions and discussion

Questions and comments?

HOLISTIC THINKING



CREATING INNOVATIVE SOLUTIONS TO COMPLEX PROBLEMS

DR JOSEPH KASSER

A FRAMEWORK FOR UNDERSTANDING SYSTEMS ENGINEERING

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

REVISED AND UPDATED

DR JOSEPH KASSER

52