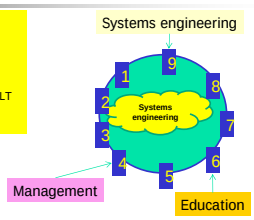
Version 090616 INCOSE -IL

The forthcoming Seldon crisis[1] in systems engineering

Applying systems thinking
to
systems engineering
Dr. Joseph Kasser DSc, CEng, CM, INCOSEF, CMALT



1. Asimov I, Foundation, Gnome Press, 1951

Agenda

- Content
  - A Seldon crisis
  - The systems approach is the current way to tackle major problems
  - The Seldon Crisis
  - Observations on systems engineering
  - History and evolution of systems engineering
  - Recommendations
- Format
  - Rhetorical questions
- Questions and discussion

Seldon Crisis*

- A Seldon Crisis usually involves both an external pressure (such as threat of attack) and an internal pressure (such as threat of revolt).
- Both pressures will come to a head simultaneously, and be resolved with the same action.

* Wikipedia, last accessed 15 January, 2009

The good news

- The global perception of "systems engineering" as the way to tackle problems posed by the cost-effective and timely acquisition and operation of the complicated socio-technical systems that underpin 21st century civilization has produced an unprecedented demand for systems engineers.
- The demand
  - transcends nations and types of systems.
  - has resulted in the growth in the number of universities offering Master's degrees in systems engineering since 1990.
- **Systems engineering has a lot of credibility**

The bad news – the Seldon Crisis

- **External**
  - In one to five years the current international support in government and industry for systems engineering will probably begin to wane.
    - Cost and schedule overruns will continue
  - Once such support begins to wane
    - Systems engineering will be consigned to fad history in the manner of Business Process Reengineering, Total Quality Management, Management by Objectives, etc.
    - Academic institution enrolments will go down
    - Operations Research may be the next fad!
  - BTW: Systems engineering is **not** listed in the 2010 draft U.S. Bureau of Labor statistics classification of professions
- **Internal**
  - Lack of consensus on a definition, roles, body of knowledge
  - Still having difficulty differentiating itself as a profession
  - Making things too complicated

Reasons for pronouncement

- **Share overview of findings and some insights from research**
  - 1995-2007 looked at systems engineering
    - Published results mostly in INCOSE/SETE*
  - 2007 Created world's first immersion course in systems engineering at Cranfield University **
    - Funded by a grant from The Leverhulme Trust
  - 2008- Creating an Executive Master's degree in Systems Engineering at NUS

•http://therightrequirement.com/pubs/publications.htm
•Kasser, J.E., John P., Tipping K, and Yeoh L.W., "Systems engineering a 21st century introductory course on systems engineering: the Seraswati Project", *Proceedings of the Asia Pacific Conference on Systems Engineering*, Keio University, Japan, 2008.

Initial observations

- Systems engineering is poorly practiced (in general)
- Systems engineering is poorly taught (in general)
- No universally accepted definition and body of knowledge
- No universal agreement on role of systems engineer
- Systems engineering has failed to meet its promises of the 50's and 60's
- Overlap with other professions
- Dichotomy on systems of systems and complex systems
- **Growing demand for certification of competencies**
- **No approved standards / Standards for systems engineering**

Poorly practiced -1

- Inadequate systems engineering **in the early design and definition stages** of a project has historically been the cause of major program technical, cost, and schedule problems.
  - **2003** United States of America Department of Defense report on the acquisition of national security space programs
- In the March-April 2005 issue of Defense AT & L (pages 14-17), Michael W. Wynne, acting under secretary of defense for acquisition, technology and logistics, and Mark D. Schaeffer, principal deputy, defense systems and director, systems engineering, Office of the USD(AT & L), called for the revitalization of systems engineering across the Department of Defense. "Analyses of a sampling of major acquisition programs show a definite linkage between escalating costs and the ineffective application of systems engineering,"
  - http://findarticles.com/p/articles/mi_m0QMG/is_3_34/ai_n13790803

Poorly practiced -2 but need not be

Cost and Schedule Outcomes Sorted by Percent of Product Development Remaining

Programs	Percent cost growth*	Schedule growth, in months	Percent of development remaining
Aerial Common Sensor	45%	24	85%
Future Combat System	48%	48	78%
Joint Strike Fighter	30%	23	60%
Expeditionary Fighting Vehicle	61%	48	49%
C-130 Avionics Modernization Program	122%	Delays anticipated	Undetermined
Global Hawk (RQ-4B)	166%	Delays anticipated	Undetermined

Sources: DOD (data); GAO (analysis and presentation).

*Cost growth is expressed as the percent change in program development cost estimates in 2005 base year dollars.

Data from GAO Report 06-368, 2006

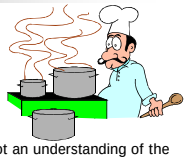
Bragging a little here: JSF **overrun predicted** in Kasser J.E., "Writing Requirements for Flexible Systems", *Proceedings of the INCOSE-UK Spring Symposium* May 2001.

Master's degree

- **A Master's degree programme is a man-made system**
- **A man-made system is a solution to a problem**
- Two simple questions to systems engineering academics
  1. What are the requirements which your degree was designed to meet?
     - No answer (except twice)
  2. How do you show that the degree meets the requirements?
     - Student evaluations
       - Evaluate 'knowledge taught right' not 'right knowledge taught'

Benchmarking findings of Master's degrees (2007/8)

- Knowledge component
  - Systems engineering process
  - Requirements
  - Architecting
  - Remainder varies according to institution
    - Faculty expertise
  - Seem to be teaching cookbook approach, not an understanding of the basics
  - Missing critical parts
- Skills component
  - Difficult to determine
- Students graduate with different knowledge and skills from each institution
- Reinforces need for standards and a Body of Knowledge



Systems engineering is poorly taught (in general)

- We focus on what is easy to teach
  - We teach parts without relating them
  - We show relationships but don't go into details
  - We teach 'what' but now 'how'
  - We don't teach the basic building blocks of solutions
  - We ignore the gaps
  - We teach things that are not representative of reality
  - We ignore the paradigm of change
    - Get all requirements up front
- We don't use optimal pedagogy or technology
- We teach process or doing it by numbers
  - Declarative and procedural knowledge

Knowledge*

- **Declarative knowledge** - knowledge that can be declared in some manner.
  - It is "knowing that" something is the case.
  - Describing a process is declarative knowledge.
- **Procedural knowledge** - "knowing how" to do something and must be demonstrated.
  - Performing the process demonstrates procedural knowledge.
- **Conditional knowledge** - "knowing when and why" to apply the declarative and procedural knowledge.

We don't seem to be teaching this

* A. E. Woolfolk, "Chapter 7 Cognitive views of learning," in *Educational Psychology*, 7th ed. Boston: Allyn and Bacon, 1998, pp. 244-283.

Top 5 systems engineering issues in 2003*

"It is a poor workman who blames his tools"

1. Lack … ming, acc… Syst…
2. Adequat… …ly not availab… …n Government and industry for all… …ation on major programs
3. Insufficient systems engineering tools and environments to effectively execute systems engineering on programs
4. Requirements definition, development and management is not applied consistently and effectively
5. **Poor initial program formulation**

* As noted in the 2003 Task Group Report by the US National Defense Industrial Association (NDIA) Systems Engineering Division

Systems engineering tools

Why?

- 1950's and 1960's
  - Probability
  - Single thread – system logic
  - Queuing theory
  - Game theory
  - Linear programming
  - Group dynamics
  - Simulation
  - Information theory
- 2000's*
  - **PowerPoint**
  - Databases
    - DOORS
    - CORE
  - Word processors
  - Spreadsheets
  - Drawing tools
    - Visio

* Jenkins, Steve, A Future for Systems Engineering Tools, *PDE 2005,* The 7th NASA-ESA Workshop on Product Data Exchange (PDE)
http://www.marc.gatech.edu/events/pde2005/presentations/0.2-jenkins.pdf

Systems thinking is not taught very well

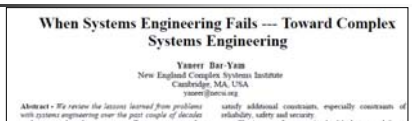
- We teach
  - Need for systems thinking and its history
  - When you are doing it, you'll know it
- Mind the gap!
  - Systems dynamics, Checkland's SSM
  - The Fifth Discipline
    - Linear thinking is bad [is it in every instance?]
  - Vendor/trainers "My approach will solve all your problems"
- We don't teach
  - When, where and how to apply systems thinking
- Basic Influencing literature
  - Generally coming from OR community, not SE community
    - IS 1990/2008 301 documents 1383 instances (includes contents pages)

Body of Knowledge – Not!

- No universally recognized body of knowledge (BoK) for systems engineering
- Stevens BoK
  - A Reference Curriculum for a Graduate Program in Systems Engineering (Insight, Vol. 10, No. 3)
    - Rashmi Jain, Alice Squires, Dinesh Verma, and Anithashree Chandrasekaran
- INCOSE publications
  - Symposium proceedings, Journal, Handbook
- Standards
  - MIL-STDs, ISO 15288 etc.
- Text books

In the ABET accreditation of degrees in systems engineering (SE), what is the SE knowledge and skill component to be graded against?

Complex systems



When Systems Engineering Fails --- Toward Complex Systems Engineering

Yaneer Bar-Yam
New England Complex Systems Institute
Cambridge, MA, USA
yaneer@necsi.org

- Quotes Chaos 1995 study suggesting systematic reason for project failure
- Suggests inherent complexity is reason for difficulties – **wrong!**
  - complexity was not a cause of project failure in Chaos study – poor management was
- Quotes own prior work "*for all practical purposes adequate testing of complex engineered systems is impossible*"
  - Only applies to the way they are designed today [JEK]
- Suggests evolutionary process for engineering large complex systems – **right!** But it applies to engineering any type of system

Published in Systems, Man and Cybernetics, 2003. IEEE International Conference on, 2003
necsi.edu/projects/yaneer/E3-IEEE_final.pdf

Two Types of Complexity

- **Real world complexity** - in which elements of the real world are related in some fashion, and made up of components.
  - We try to abstract out real world complexity
- **Artificial complexity** – elements of the real world that **should** have been abstracted out when drawing the internal and external system boundaries, since they are not relevant to the system (problem at hand).
  - Artificial complexity gives rise to **complicatedness** in the manner of Rube Goldberg or W. Heath Robinson.

Representation of the system

Processes and products are systems

Complicated example in Rube Goldberg cartoon

Focus in on a toolbox of methodologies*

OR not SE!

Towards a System of Systems Methodologies

M. C. JACKSON and P. KEYS

Department of Operational Research, University of Hull

This paper sets out to consider O.R. as a problem-solving methodology in relation to other systems-based problem-solving methodologies. A 'system of systems methodologies' is developed as the interrelationship between different methodologies is examined along with their relative efficacy in solving problems in various real-world problem contexts. In a final section the conclusions and benefits which stem from the analysis are presented. The analysis points to the need for a co-ordinated research programme designed to deepen understanding of different problem contexts and the type of problem-solving methodology appropriate to each.

So why do we need complex systems engineering?

- Problem solver needs a methodology for [selecting the appropriat methodology for] solving a problem
- "**Classification of a system as complex or simple will depend on the user and on the purpose he has for considering the system"**
- "Systems engineering has been defined by Jenkins 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*."**

* M.C. Jackson and P. Keys, 1984, J. Operations Research Society, Volume 35, Number 6, p 473-486, Published in Great Britain

** G.M. Jenkins, (**1969**) The systems approach. In Systems Behaviour, J. Beishon and G Peters, Ed., 2nd Edn. P 82, Harper & Row, London

DoD 5000 Guidebook 4.1.1

- The successful implementation of proven, disciplined systems engineering **processes** results in a total system solution that is
  - Robust to changing technical, production, and operating environments;
  - Adaptive to the needs of the user; and
  - Balanced among and program budgets.
- Is this true?
- GIGO ?

The systems engineering process

- *"The systems engineering process in commercial and defense applications is similar because of the common process standards that they share."*
- Question
  - What process is documented in the Standards?
    - Answer: The systems engineering process?
    - Question: Is it?

System Life cycle functions

Functional view turns into a process. Note as a process time seems to be running backwards?

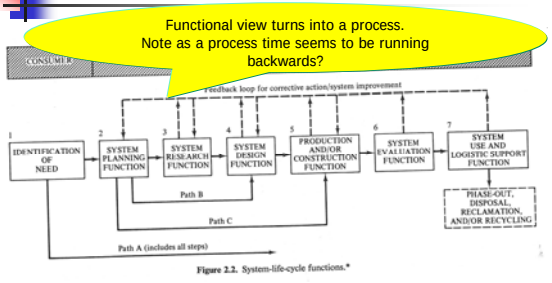
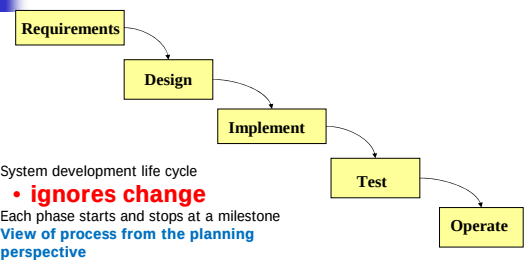


Figure 2.2. System-life-cycle functions.*

Blanchard and Fabrycky, Systems Engineering and Analysis 1981

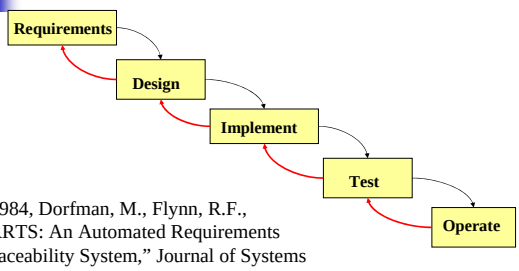
Waterfall* representation of series of activities



- System development life cycle
  - **ignores change**
- Each phase starts and stops at a milestone
- **View of process from the planning perspective**
  - **Looking towards the future**

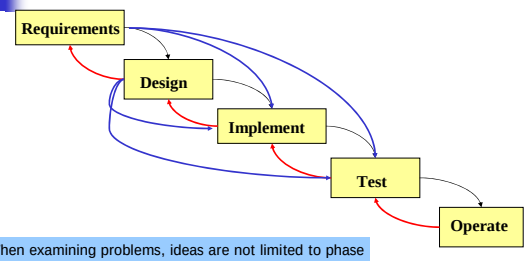
* Royce, W. W., "*Managing the Development of Large Software Systems*", proceedings of IEEE WESCON, 1970.

Waterfall - modified view*



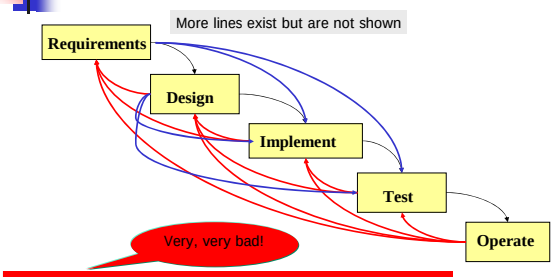
*1984, Dorfman, M., Flynn, R.F., "ARTS: An Automated Requirements Traceability System," Journal of Systems and Software, Vol. 4, pp. 63-74.

Waterfall – with feed forward



When examining problems, ideas are not limited to phase

Waterfall - chaotic view



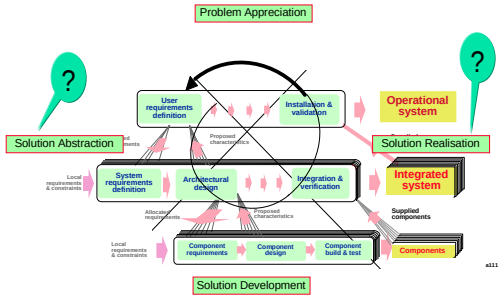
Students have shown this as the lifecycle of choice for their project

Spiral methodology

- Focus on risk management
- Changes in requirements **is** incorporated in concept
  - Not emphasized
  - Overlooked
- Mini waterfalls
- No system framework at beginning

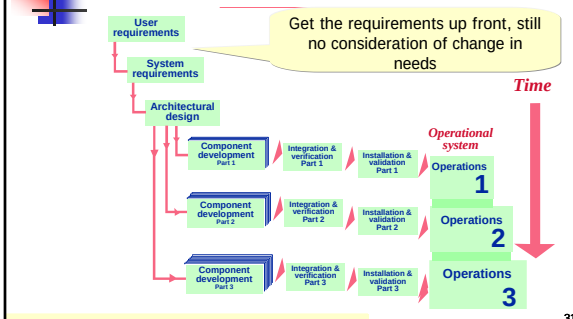
Boehm 1988, drawing from Wikipedia, 16 January 2009

The Spiral Model - The DERA View



Complicated – do students really understand this?

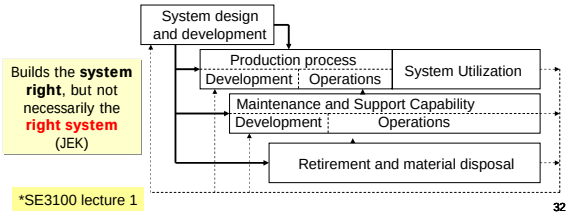
Incremental Model



Students are used to seeing time running horizontally

Concurrent Engineering*

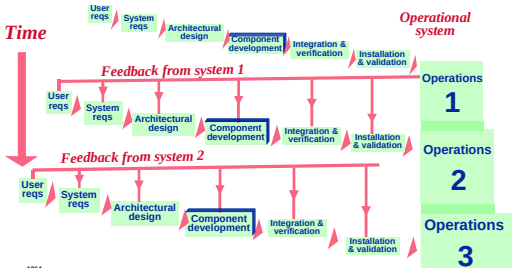
- Life-cycle issues are considered together, e.g., design and production issues. Production issues are addressed during design phase.



Builds the **system right**, but not necessarily the **right system** (JEK)

*SE3100 lecture 1

Evolutionary Development



First consideration of some changes in requirements, concept of external changes not shown

The "V" Model

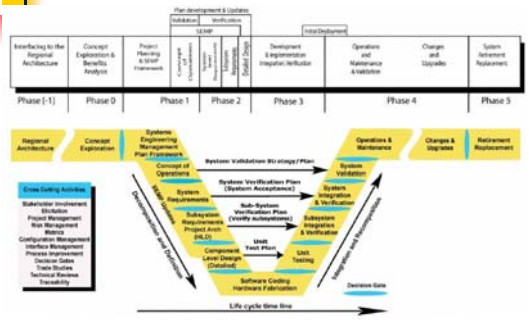


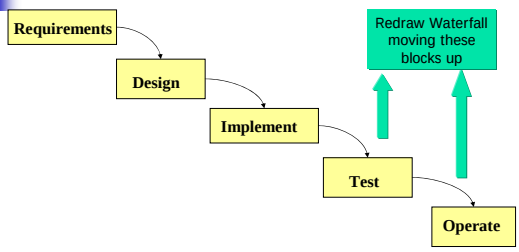
Figure 1-2 ITS Project Life cycle Phases and the Life cycle Tasks in this Guidebook

Defects in the V Model

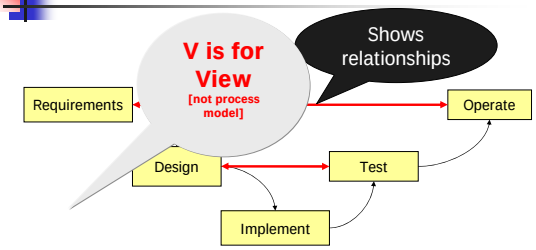
- **Lacks 'prevention of defects*'**
  - Definition of successful test?
  - Design works from requirements
  - T&E work from the need
  - T&E identify defects and plan to find them after they have been built into the system
  - Why not prevent the defects?
- **Does not cope with change**

* Kasser, J. E., "Eight deadly defects in systems engineering and how to fix them ", *Proceedings of the 17th International Symposium of the INCOSE*, San Diego, CA, 2007.

Waterfall representation of series of activities



Waterfall representation in V format



V is a representation of the Waterfall model,

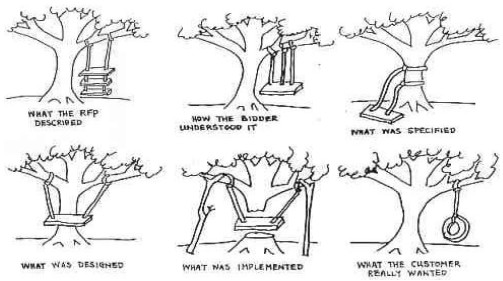
Does not cope with change

The systems engineering process

- According to Brian Mar - most systems engineers accept the following basic core concepts:*
  1. Understand the whole problem before you try to solve it
  2. Translate the problem into measurable requirements
  3. Examine all feasible alternatives before selecting a solution
  4. Make sure you consider the total system life cycle.
     a. The birth to death concept extends to maintenance, replacement and decommission.
     b. If these are not considered in the other tasks, major life cycle costs can be ignored.
  5. Make sure to test the total system before delivering it.
  6. Document everything.
- If so, then why is the following graphical model still current?
  - See next slide

*Brian Mar, INCOSE Fellows consensus on systems engineering

The systems engineering process (<1970 → 2009)



Two external perspectives:

The problem solving process

1. Problem Definition*	1. Identify and Select the Problem**
2. Problem Analysis.	2. Analyze the Problem
3. Generating possible Solutions.	3. Generate Potential Solutions
4. Analyzing the Solutions.	4. Select and Plan the Solution
5. Selecting the best Solution(s).	5. Implement the Solution
6. Planning the next course of action (Next Steps)	6. Evaluate the Solution

* http://www.gdrc.org/decision/problem-solve.html (accessed 11 Jan 2009)

** http://www.c-pal.net/course/module3/pdf/Week3_Lesson21.pdf (accessed 11 Jan 2009)

I didn't understand

- The systems engineering process seemed to be the problem solving process
  - Semantics - levels of detail in each step differ
- Similar process steps in other disciplines
  - Were they doing
    - Systems engineering, or problem solving?

499 Systems engineering management

- **Purpose to develop a Systems Engineering Management Plan**
  - **Not doing systems engineering**
- **Provided two templates to be tailored**
- **Tailoring does not seem to have taken place**
- **MIL-STD 499A Systems Engineering Management**

MIL-STD's freely available at http://www.everyspec.com

EIA-632

- Process for engineering a system
- Not for systems engineering


EIA STANDARD

Processes for Engineering a System

EIA-632

ELECTRONIC INDUSTRIES ALLIANCE

GOVERNMENT ELECTRONICS AND INFORMATION TECHNOLOGY ASSOCIATION ENGINEERING DEPARTMENT

43

IEEE-1220

- Management of the systems engineering process
- Not doing systems engineering


IEEE Standard for Application and Management of the Systems Engineering Process

44

ISO-IEC 15288

- Process
- Purchase price*
  - CHF 168,000
- 15288:2008
- Revised from 2002 version

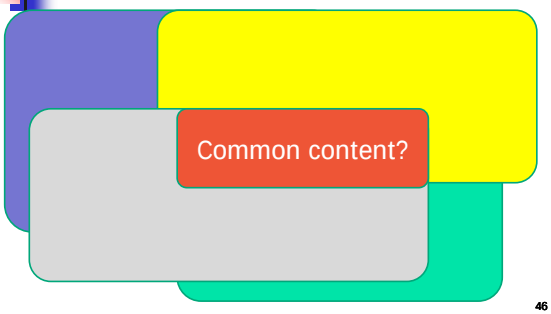

INTERNATIONAL STANDARD ISO/IEC 15288

Systems engineering -- System life cycle processes

* http://www.iso.org/iso/catalogue_detail?csnumber=43564

45

Common content of standards?



46

Committed costs vs. Lifecycle

Where should the focus of systems engineering Standards be?

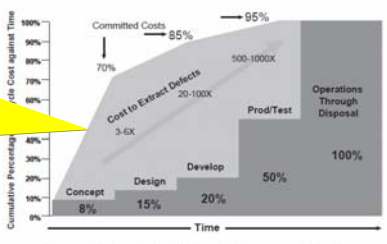


Figure 2-3 Committed Life Cycle Cost against Time[10]

DAU, 1993 quoted in INCOSE Systems Engineering Handbook 3.1 (2nd Printing) modified

47

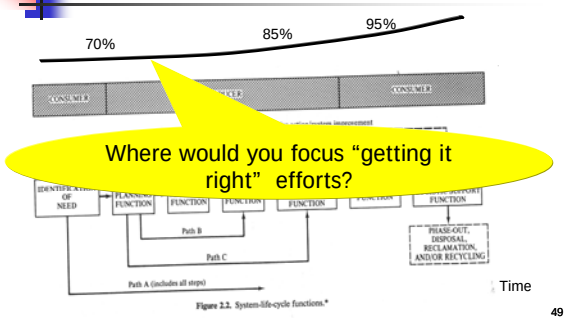
Focus of Standards – chronological perspective

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

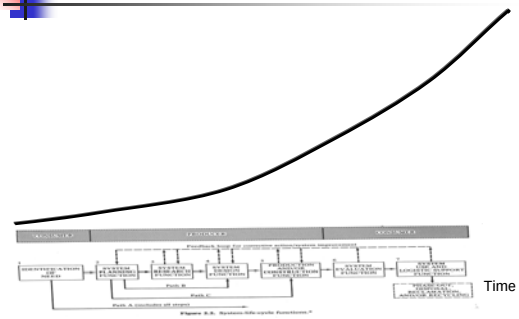
Based on Table 5 in Honour E.C., Valerdi R., "Advancing an Ontology for Systems Engineering to Allow Consistent Measurement", CSER 2006

48

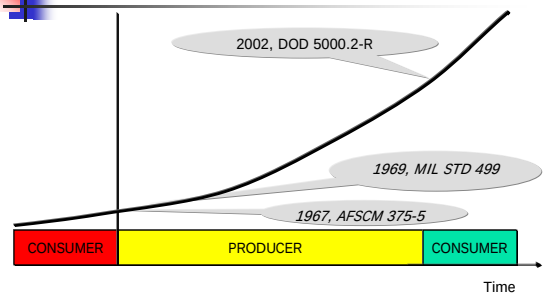
Allocation of committed cost based on decisions



Cost to repair a defect



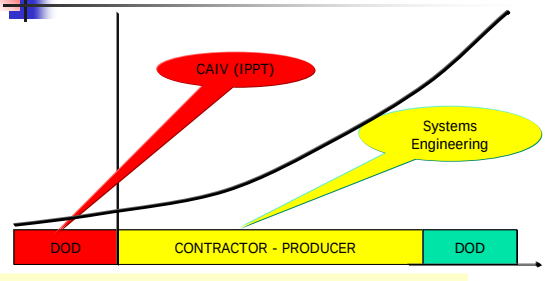
Degree of micromanagement in "systems engineering" Standards



DoD Directive 5000

- DoD Directive 5000.1 required ***Systems Engineering***.
  - "Acquisition programs shall be managed through the application of a systems engineering approach that optimizes total system performance and minimizes total ownership costs. A modular open-systems approach shall be employed, where feasible"
- DoD Instruction 5000.2 emphasized the use of systems engineering
- DoD 5000.2-R **gutted** systems engineering

DOD 5000.2R scope reduction of systems engineering



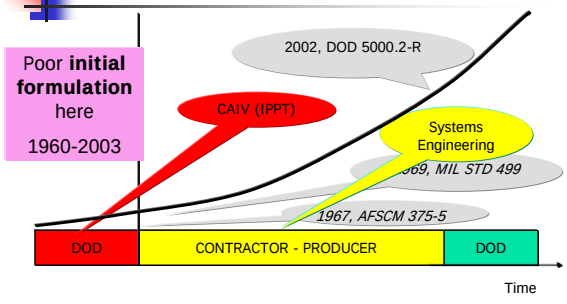
DOD took systems engineering out of initial program formulation instead of fixing systems engineering. But systems engineering [contractor] is still getting the blame for problems due to poor DOD IPPT

DOD IPPD*

- In broad terms, the objectives of the Concept Exploration phase are fourfold:
  1. to perform concept studies to investigate different solutions,
  2. to evaluate these different concepts,
  3. to perform tradeoff studies, and
  4. to define the requirements for the remainder of the acquisition program.
- IPPD activities involve organizing the different functions to work concurrently and collectively so that all aspects of the life cycle for the various concepts are examined and a balanced concept emerges.

*DOD IPPD handbook, 1998

"Systems Engineering" Standards are focused on wrong problem



Standish Report 1994* Top 10 reasons for ...

Where is "**process**" mentioned?
Focus is on people!

Proj

1. User involvement
2. Executive management support
3. Clear statement of requirements
4. Proper planning
5. Realistic expectations
6. Smaller project milestones
7. Competent staff
8. Ownership
9. Clear vision & objectives
10. Hard-working, focused staff

1. Incomplete requirements
2. Lack of user involvement
3. Lack of resources
4. Unrealistic expectations
5. Lack of executive support
6. Changing requirements and specifications
7. Lack of planning
8. Didn't need it any longer
9. Lack of IT management
10. Technology illiteracy

* http://www.cs.nmt.edu/~cs328/reading/Standish.pdf

The focus is on **people** not process

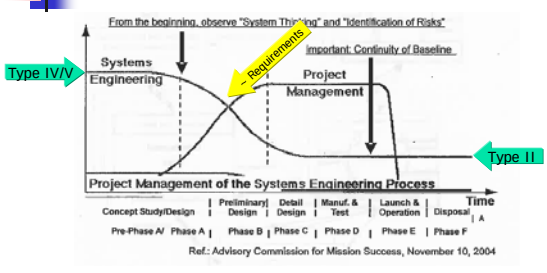
- Literature
  - Is full of advice as to how to make projects succeed
  - Has little if anything to say about the proliferating process standards
- Conditional knowledge

Five types of systems engineers and project managers (engineer-leaders)

- **Type V** - who can "define the problem" * and then determine "what" needs to be done to implement an optimal solution
- **Type IV** - who can "define the problem"
- **Type III** - who can be given the problem and then determine "what" needs to be done to implement an optimal solution
- **Type II** – who can be told "what" needs to be done to implement a solution and can work out "how" to do it
- **Type I** – (apprentices) who can be told "how" to implement a solution and can then do it

* Wymore, Model Based Systems Engineering, 1993 p 2

Systems engineering/project management staffing levels



JAXA Basics of Systems Engineering (draft), Version 1B, 2007

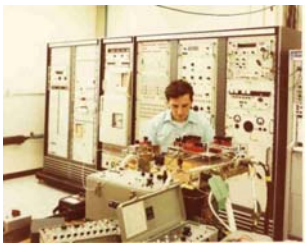
In general - situation in 50's and 60's

- In the concept study design phase
  - Single system context
  - Type IV/Vs identify real problem
  - Type III's and V's design both solution system and implementation process
  - Operations research was a tool used by systems engineers
    - Systems engineering was a tool used in operations research
- In the preliminary design phase
  - Type II's implement solution system using implementation process
  - Most Type III+'s move on to next project
- In the rest of system life cycle
  - Type II's implement solution system using implementation process, Type III+ are available sometimes to help with problems that arise

Late 1960's and its legacy

- Type III, IV and V's are laid off
- Type II's are left
- Type II's write Military Standards to document what they are doing
  - Focus changes from 'problem focus' (III, IV and V) to 'document and follow the process' (II)
- Type II systems engineering is taught to the next generation and becomes "systems engineering"
  - Potential Type III, IV and V learn Type II systems engineering
  - Elimination of MIL-STD's did not change the paradigm
- Type IV/V improvements to the Type II process paradigm reaches point of diminishing returns

NASA: systems approach works on Apollo



Singapore: systems approach works*

- Social System
  - Public Housing
- Economic System
  - Industrial Development
- Defence System
  - Air Defence

Lessons learned include - Large Scale Systems must be Designed for Changes Throughout the Life of the System

Dr Goh Keng Swee
- Minister
- Visionary
- Economist
- Systems Architect
- Systems Engineer

*LUI Pao Chuen, Singapore: An Example of Large Scale Systems Engineering, APSEC, 23 March 2007.

USAF: systems approach fails

- 68 systems @ $10 Billion 1955-1969*
  - B-70 manned supersonic bomber
  - F-111A and B fighter-bomber
  - C5A heavy transport
  - Cheyenne jet combat helicopter
  - Air Force Manned Orbital Laboratory

* *Congressional Record*, Vol 115, no 59 April 15, 1969 quoted in Kenyon B. De Greene (Ed), *Systems Psychology*, McGraw-Hill Book Company, 1970 reprinted in Systems Behaviour, 3rd Edition 1988, Geoff Peters (Ed), Open Systems Group, Paul Chapman Publishing Ltd, 1972

Type II systems engineering

- Approach
  - Start with a process
  - Add bolt-on processes as needed
    - Quality assurance
    - Risk management
    - Etc.
  - Follow the process
    - Go by the book
  - Institutionalize the process in Standards
- Result
  - Continuing cost and schedule overruns
  - Failure to make good on promises of the 50's and 60's
  - Linear representations
  - We need people who can write the book
    - Type V's

More processes for the Type II cookbook approach

- Incremental modifications to acquisition process
  - Linear thinking/representation
- New processes
  - For Agile
  - For Lean
  - Type III, IV and V's are locked in Type II process mold/thinking frame
- Solution language implementation constraints
  - C4ISR, LISI
  - DODAF, MODAF

IS 2009 submission

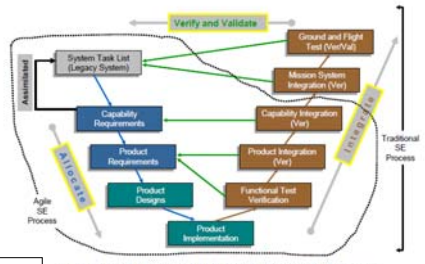


Figure 5. Modified Vee Model for Streamlined Acquisition Programs

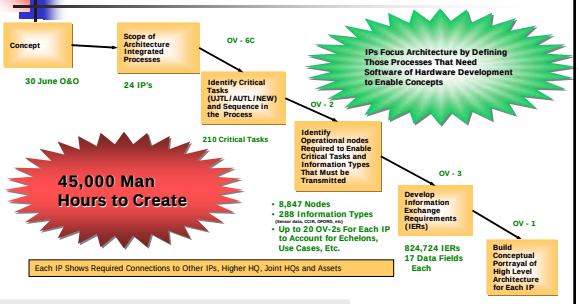
Streamlined?

DoDAF: good idea but...

- **"The purpose of the DoDAF** is to provide correct and timely information to decision makers involved in future acquisitions of communications equipment"

Volume I: **83** pages
Definitions, Guidelines, and Background
Volume II: **249** pages
Product Descriptions
Deskbook: **256** pages
Supplementary information to Framework users
CADM **696** pages
core data model
Over 1200 data elements

But it has become too expensive and complicated



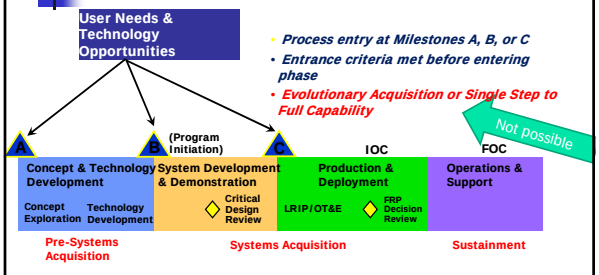
Slide source FCS System of Systems' Engineering and Integration
Scott Davis, NDIA Systems Engineering Conference 2003

DoDAF OV-1?

OV-1 Describes use of system

Use of DODAF

Linear thinking/single system: The 5000 Model*



* Bradford Brown, DoD Instruction 5000.02, 8 December 2008, Operation of the Defense Acquisition System Statutory and Regulatory Changes , DAU, Feb 2009, Version 5.4

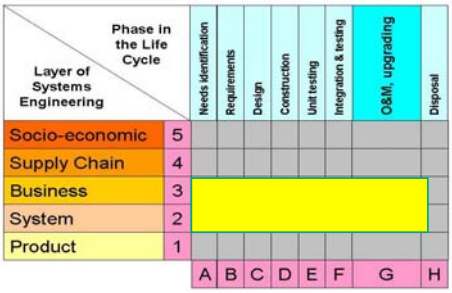
Need for representations including effect of changes

- **Programs do not fail because the requirements change, (**Kasser 2001a).
  - The tasks, products, and processes for managing change exist and have done so for over 20 years[3].
  - **Programs fail because** of poor requirements change management and the failure to reevaluate requirements in the context of
    - Changes in needs
    - Changes in technology
    - **Changes in paradigm**
      - The effect of air power on battleships was noted in World War II.
      - Today a paradigm shift is taking place due to the development of low cost guided ordnance.
      - Their effect of expensive aircraft and surface ships has yet to be fully determined

Is this still being ignored?

Notes :
2 Failure is defined as [cancelled] or [incur > 60% (cost or schedule) over-runs].
3 The US Military standards cover the ground in more than enough detail

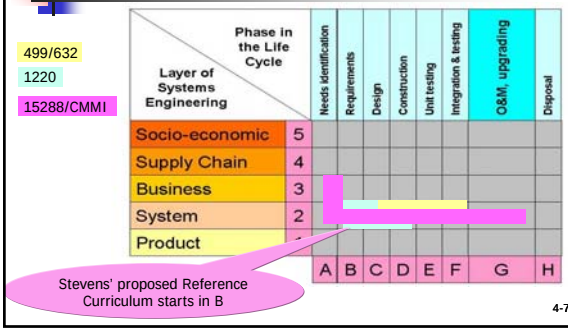
Systems engineering 1960's and 70's



73

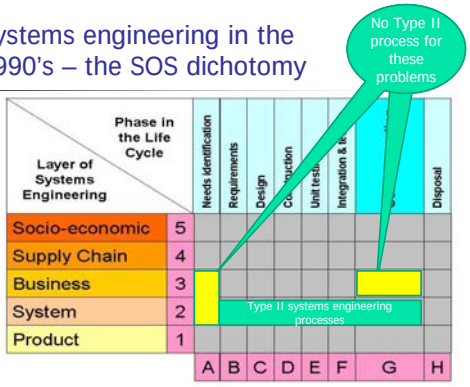
Systems engineering in the 1990's (Standards)

499/632
1220
15288/CMMI



4-74

Systems engineering in the 1990's – the SOS dichotomy



75

Why OR might replace SE

- Systems engineering is advancing up from HKMF Layer 2 to tackle problems in Layer 3
  - Using Type II process paradigm which does not work in Layer 3
- OR has been successfully solving these problems for years
- "*Operations research is concerned with the heart of this control problem – how to make sure that the whole system works with maximum effectiveness and least cost*" (Johnson, 1954) p xi*)
- Many modern systems engineers would apply this goal to systems engineering.

* Johnson, E. A. (1954). The Executive, the Organisation and Operations Research. Operations Research for Management, Volume 1. J. F. McCloskey and F. N. Trefethen. Baltimore, The Johns Hopkins Press.

76

Problem – process views

- **Model-based systems engineering (MBSE)** is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases (INCOSE-TP-2004-004-02, Version 2.03, September 2007).

- **Operations research**, or simply **O.R.**, is the use of mathematical models, statistics and algorithms to aid in decision-making. It is most often used to analyze complex real-world systems, typically with the goal of improving or optimizing performance. (Wikipedia, accessed 12 January 2009)

MBSE is an 'instance' (in HKMF Layer 2) of 'class' OR – in object language

Type V's breaking the Type II mold?

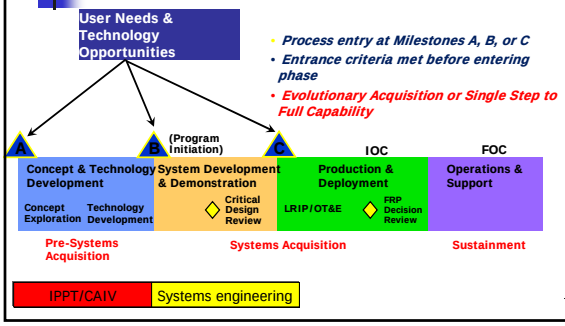
77

In conclusion...-> slide 89

- Systems approach (1960's Type V) works well
- The problems are not going away
- The question is who is going to provide cost effective solutions?
  - Systems engineering or ?
- SE Academia needs to get its act together
  - Teach the right concepts to the right people
  - Blended learning technology is increasing competition
  - Customers **are** setting requirements

78

Prescription for failure: The 5000 Model



Prescription for success*

Do we teach?

1. The idea of change
2. There are alternative ways of accomplishing things
3. Commonly accepted bases for judging the value of a systems
4. Each system has its own environment and is in fact a subsystem of some broader system(s)
5. Computational and experimental techniques

* Systems Engineering Tools, Harold Chestnut, 1965, Pages 11-23

Recommendations

- Systems engineer postgraduate degrees
  - Meet customer's requirements
  - Return to the problem solving paradigm
  - Introduce the 'paradigm of change'
- Focus on people not processes
  - Create curriculum guidelines for teaching conditional knowledge
  - Modify courses/modules to allow for early identification and production of Type III, IV and V's
- Create a Body of Knowledge
  - INCOSE Fellows are now leading such an effort
- Don't legislate, educate
- Institutionalize simplicity

Complicated - Docking in Space

Simplifying docking in space

- We filter out everything other than information pertinent to
  - Relative positions of the spacecraft
  - Relative velocity
  - Relative alignment in X, Y and Z orientation
    - Yaw and pitch

Baseball pitch*

How do we know these?

- When **modeling the movement of a pitch in baseball**, **it is sufficient to** apply Newtonian mechanics **consider**ing **only** gravity, air resistance and the velocity and spin of the ball
- **One need not worry about** electron orbits or the motions of the sun and the moon
- Forces that **are important** when studying objects of one order of magnitude **seldom have an effect** on objects of another order of magnitude.

*adapted from Langford G, SE3100 lecture 3

Institutionalize Simplicity?

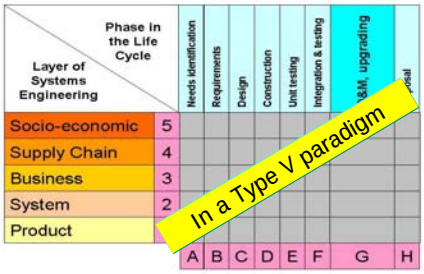
- Require all graphics to comply with Miller's rule*
  - Aids comprehension of graphic
  - Requires "**thinking** about the context"
    - Applies hierarchical decomposition
    - Structures subsystems for
      - Minimum coupling and maximum cohesion (Ward and Mellor, 1986)
      - Self-organization
    - Abstracts out non-pertinent information (KISS)
      - No more 'cut and paste' and people unwilling to question/think

George A. Miller. The Magical Number Seven, Plus or Minus Two. *The Psychological Review*, 1956, vol. 63, Issue 2, pp. 81-97

IS 2020? Option 1

Two options
for
INCOSE
International Symposium
in 2020

IS 2020? – Option 2. Providing whole optimal solutions to complicated problems



Summary

- A Seldon crisis
- The systems approach is the current way to tackle major problems
- The Seldon Crisis
- Observations on systems engineering
- History and evolution of systems engineering
- Recommendations

Questions, comments

* Bradford Brown, DoD Instruction 5000.02, 8 December 2008, Operation of the Defense Acquisition System Statutory and Regulatory Changes , DAU, Feb 2009, Version 5.4