Massachusetts Institute of Technology

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Fundamentals of Systems Engineering

Prof. Olivier L. de Weck

Session 11

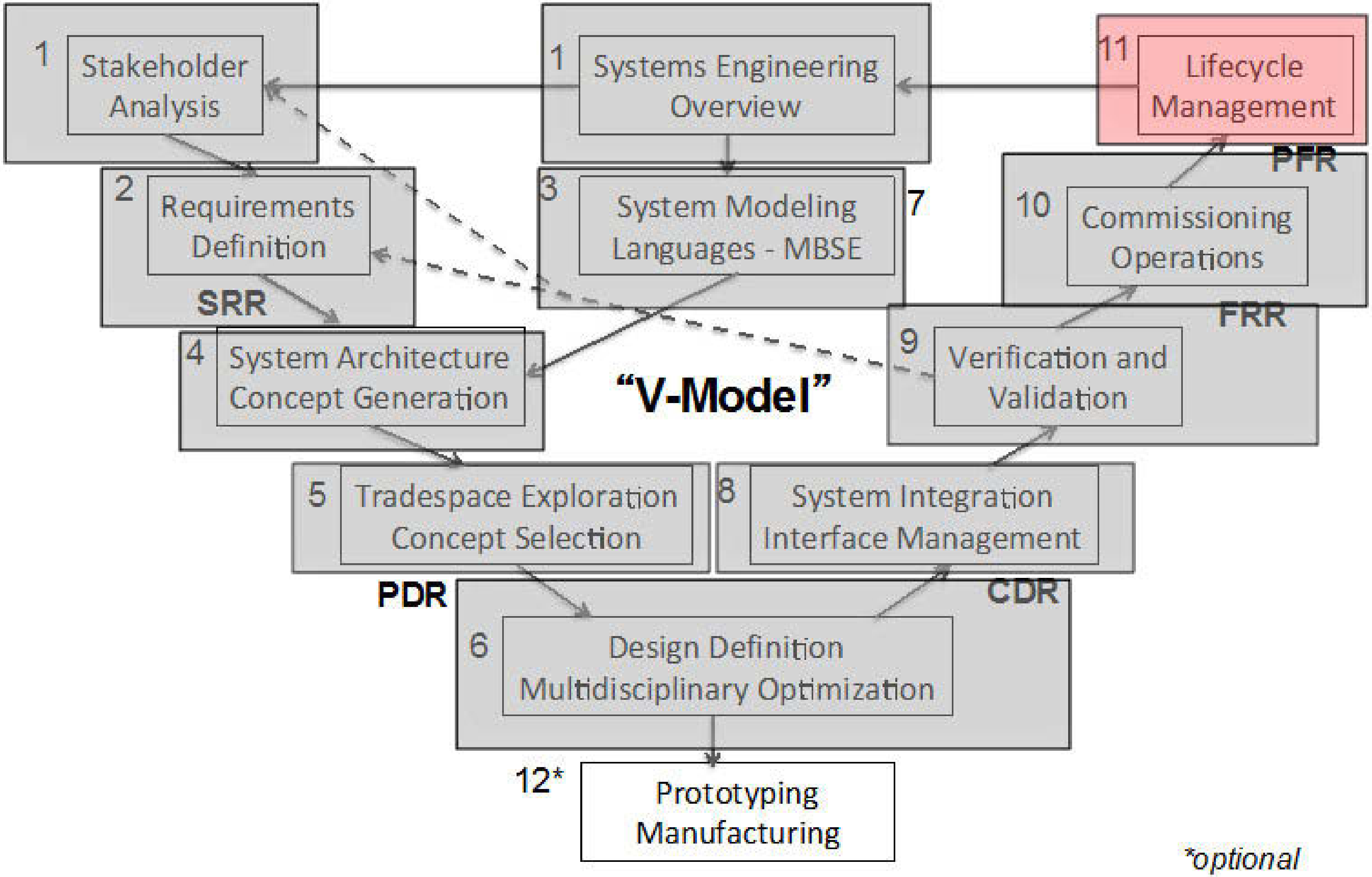
Lifecycle Management

General Status Update

Assignment	*Topic*	*Weight*
A1 (group)	Team Formation, Definitions, Stakeholders, Concept of Operations (CONOPS)	12.5%
A2 (group)	Requirements Definition and Analysis Margins Allocation	12.5%
A3 (group)	System Architecture, Concept Generation	12.5%
A4 (group)	Tradespace Exploration, Concept Selection	12.5%
A5 (group)	Preliminary Design Review (PDR) Package and Presentation	20%
Quiz (individual)	Written online quiz	10%
Oral Exam (individual)	20' Oral Exam with Instructor 2-page reflective memorandum	10%

The "V-Model" of Systems Engineering

16.842/ENG-421 Fundamentals of Systems Engineering



Numbers indicate the session # in this class

Outline for Today

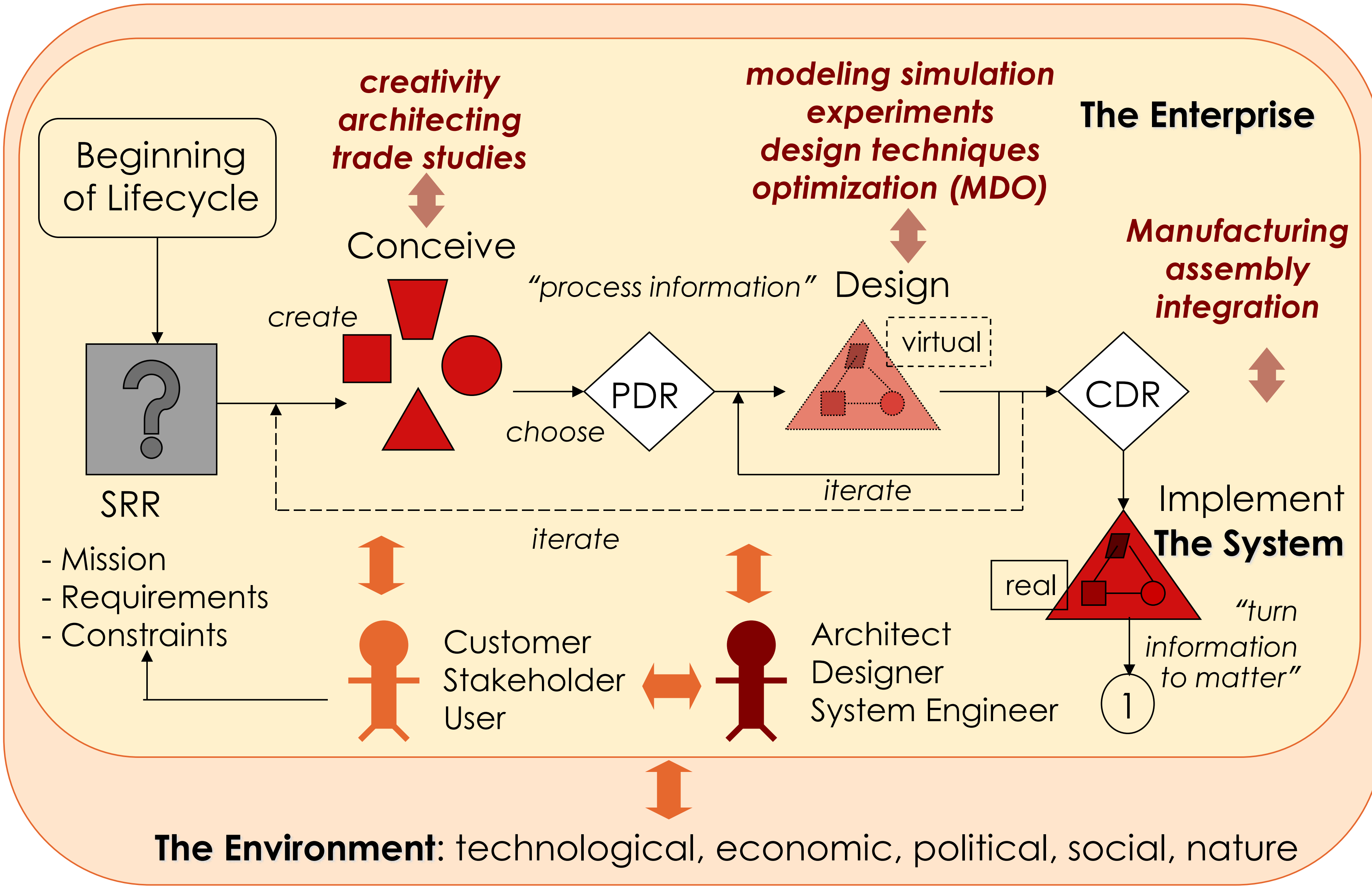
- Definition of Lifecycle Management
- Lifecycle Properties, i.e. the "Illities"
- A Case Study
  - Reconfiguration of Communications Satellite Constellations
- Summary of Key Concepts taught in this class
- Career / Study Recommendations regarding SE

Lifecycle Management

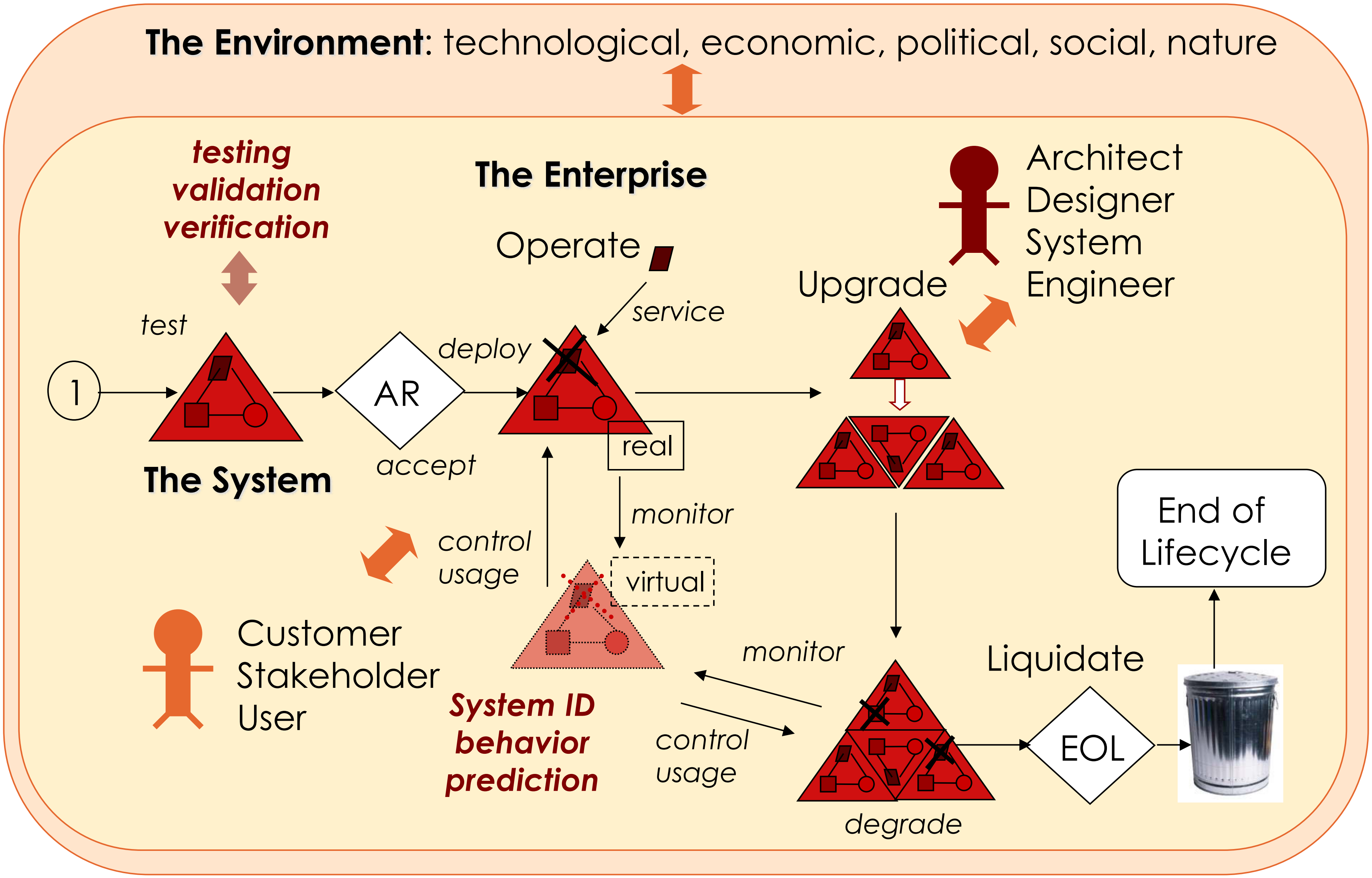
- **Lifecycle Management** is the active engagement of all stakeholders with a system between the time when it first starts to operate until the time of its decommissioning, in order to maximize the value gained from the system's existence. Lifecycle management starts from the beginning.

- Lifecycle Management can include activities such as:
  - Daily Operations and Monitoring
  - Training and Certification of Operators
  - Servicing, incl. Preventative and Corrective Maintenance
  - Dealing with small and large failures, recalls, anomalies etc…
  - Protecting the system from random or targeted attacks (cyber-physical)
  - Sharing and archiving the data produced by the system
  - Upgrading and retrofitting the system as needed
  - Cross-strapping the system with other systems in a federation of systems
  - Reducing the resource consumption and environmental burden
  - Decommissioning the system when it is time to do so
  - Etc..

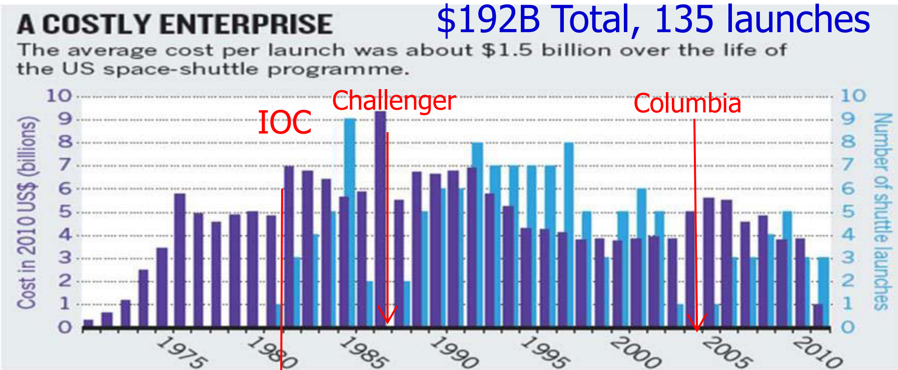
System Engineering Lifecycle (Part 1/2)
Conception, Design, Implementation



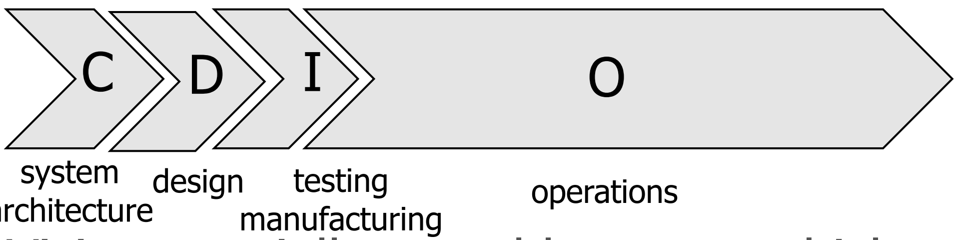
Systems Engineering Lifecycle (Part 2/2)
Operate, Upgrade, Liquidate



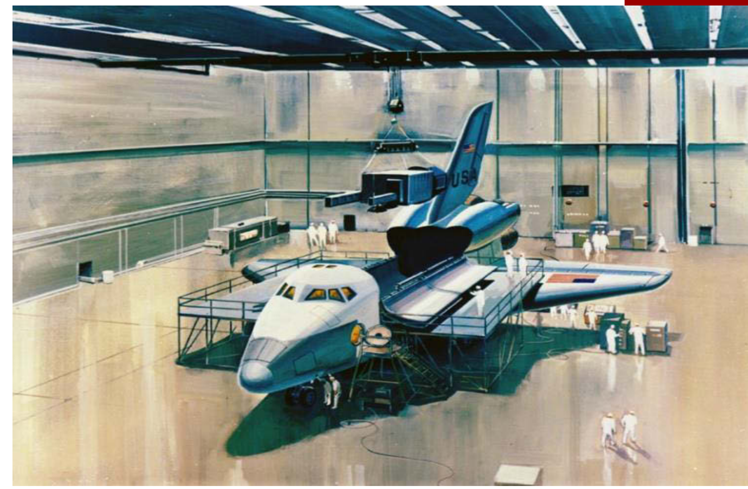
Space Shuttle Lifecycle (1971-2011)



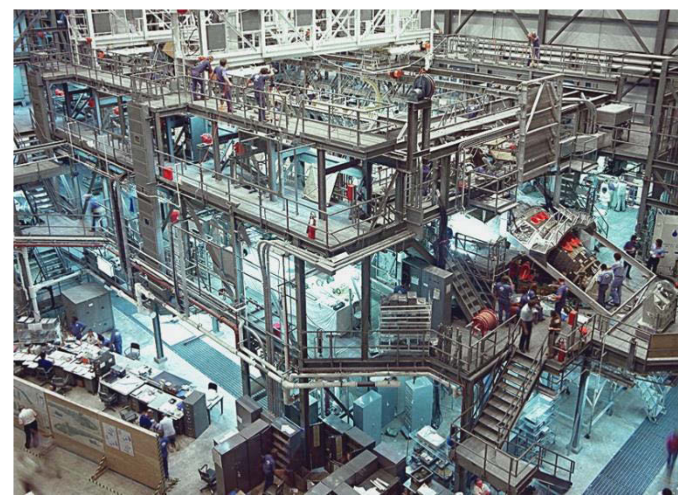
Roger Pielke Jr & Radford Byerly, Shuttle programme lifetime cost, *Nature* 472, 38 (07 April 2011)



What we wanted



What we got



- Vision: partially reusable space vehicle with quick turnaround and high flight rate
- Actual: complex and fragile vehicle with average cost of about $1.5B/flight (20,000 workforce)
- Why?
  - Overoptimism
  - Congress capped RDT&E at $B5.15 (1971)
    - Focus on achieving launch performance (24 mt LEO)
    - Maintainability needed to be "designed-in"
    - No realistic lifecycle cost/value optimization done

ISO 15288 – Most important standard for lifecycle

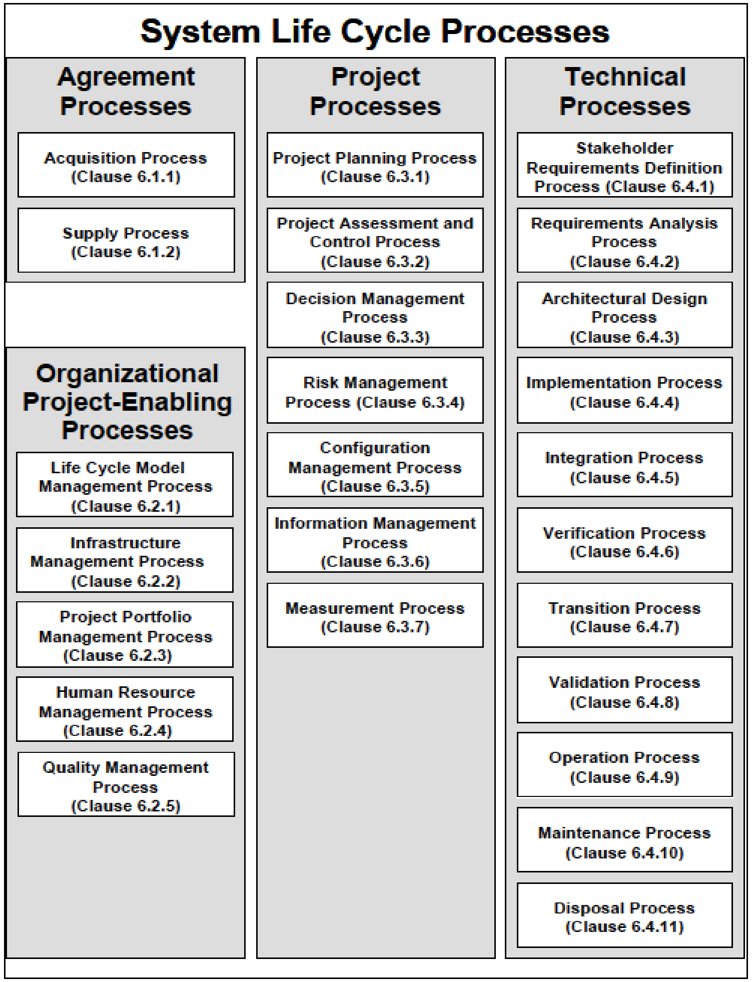


Figure 4 — The system life cycle processes


INTERNATIONAL STANDARD

ISO/IEC 15288

IEEE Std 15288-2008

Second edition
2008-02-01

Systems and software engineering — System life cycle processes

Ingénierie des systèmes et du logiciel — Processus du cycle de vie du système

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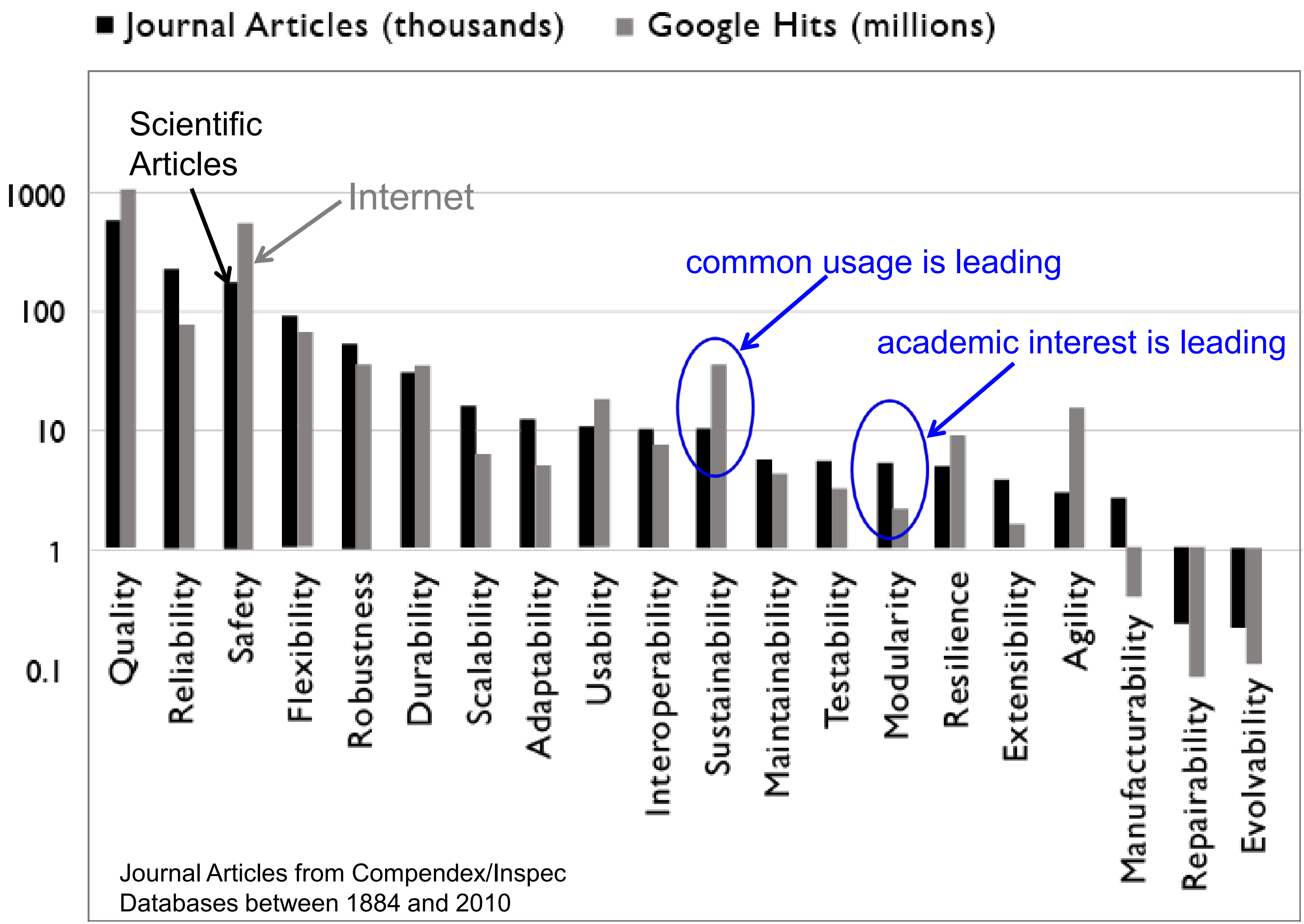
Reference Paper

- de Weck O.L., Ross A., Rhodes D., "*Investigating Relationships and Semantic Sets amongst System Lifecycle Properties (Ilities)*", 3rd International Engineering Systems Symposium, CESUN 2012, TU Delft, The Netherlands, June 18-20, 2012

What are the "Illities"?

- **Complex Engineering Systems live for decades or centuries**
- The *ilities* are desired properties of systems, such as flexibility or maintainability (usually but not always ending in "ility") that often manifest themselves after a system has been put to initial use.
- These properties are not the primary functional requirements of a system's performance, but typically concern wider system impacts with respect to time and stakeholders than embodied in those primary functional requirements
  - Most research has looked at the Illities – one at a time.
- Research Questions:
  - **What are the most prevalent or most important (top 20) Ilities in the scientific literature and in common use?**
  - **What are the relationships amongst Ilities? Do they form semantic sets?**
  - **Can we use this information for better system design?**
- Approach:
  - Method 1: Prevalence Analysis using Literature/Web Survey
  - Method 2: Human Cognitive Experiments using Hierarchy Exercise

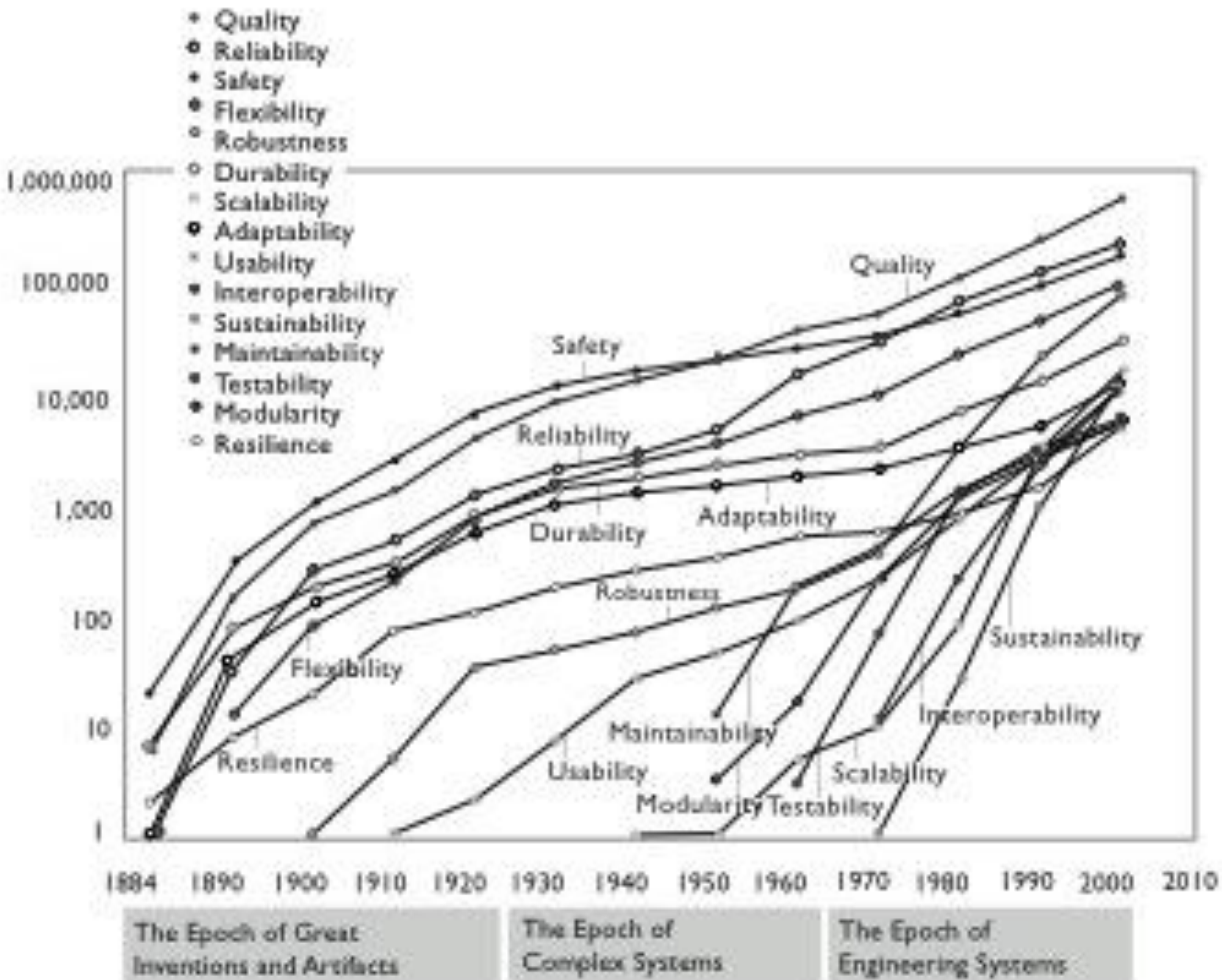
Prevalence Analysis



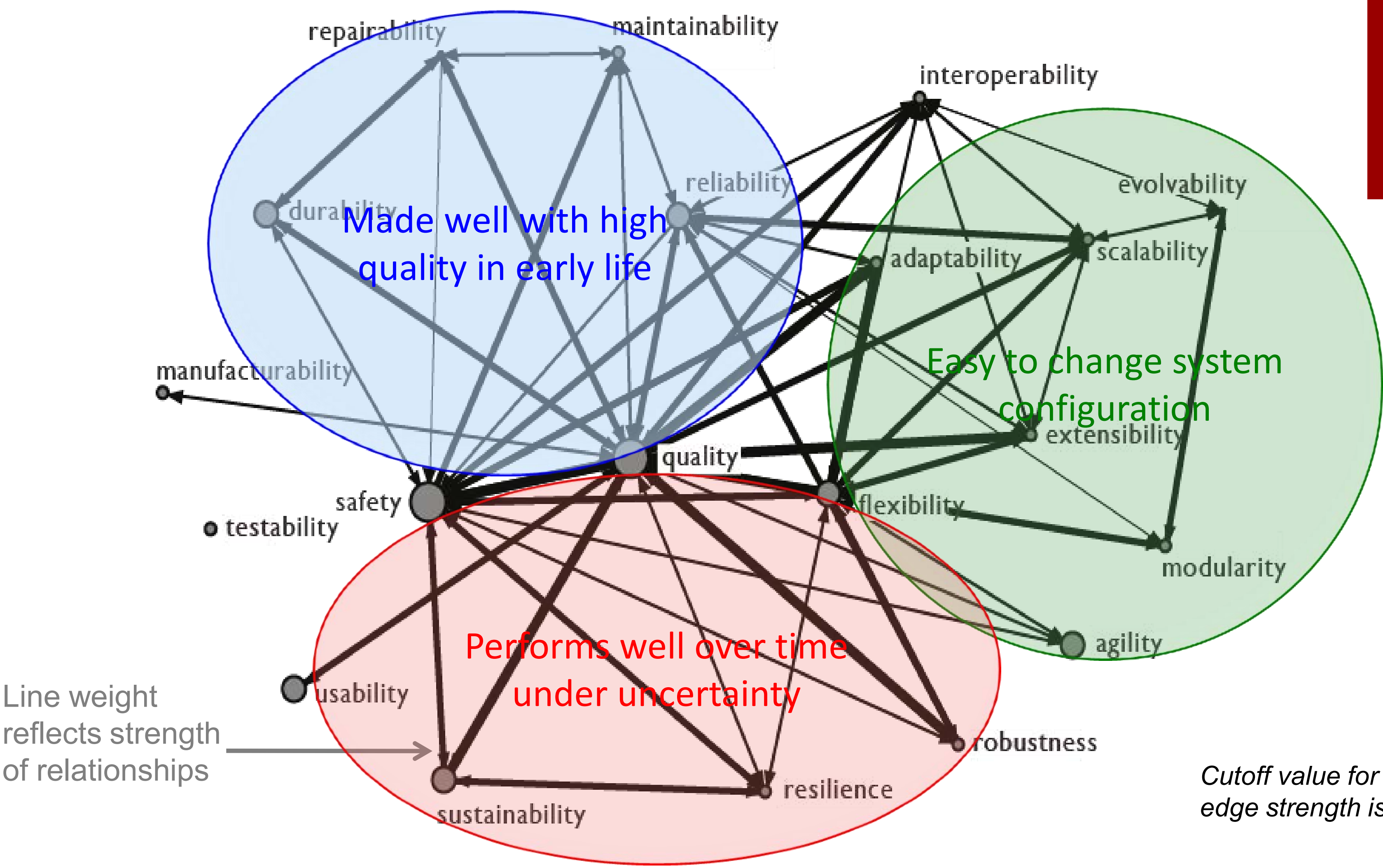
Cumulative Research in Ilities over Time

Cumulative number of journal articles where an Ility appears in the title or abstract of the paper (1884-2010). Source: Inspec and Compendex, accessed via Engineering Village http://www.engineeringvillage.com

Fig. 4-2



1: Relationships amongst the Ilities



Cutoff value for edge strength is 0.1

Network structure with classical engineering ilities at the core and newer emerging ones at the periphery based on co-occurrence

Source: web keyword 2-tupel correlation analysis, August 2010

2: Human "Experiments" with Hierarchy

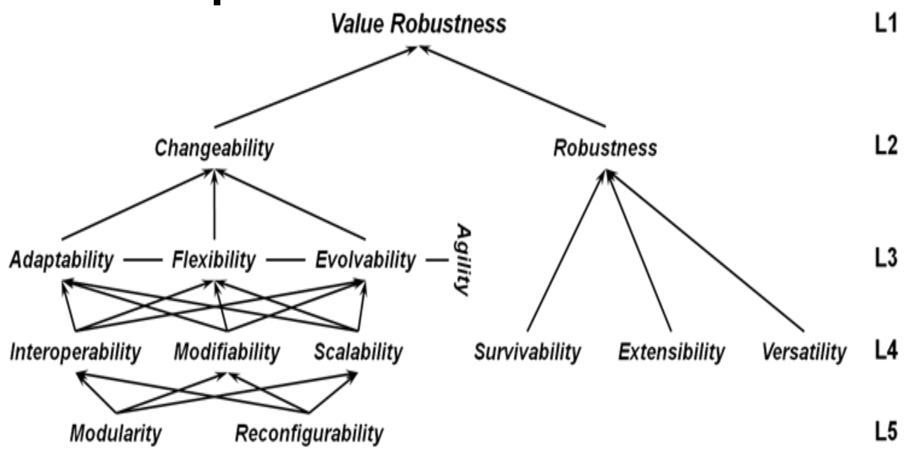
- Humans have deep, but possibly varied, semantic notions of a hierarchy of Ilities
  - Elicit means-ends-hierarchy through direct elicitation and group discussion and interviews
  - Two rounds
  - **Round 1**: 4 groups with 2-4 members each. Find parent-child relationships. Describe means → ends relations
  - Interviews
  - **Round 2:** Revise group findings based on inputs from other groups at the end of round 1
  - Constructed combined means-ends hierarchy

12 experienced system designers and researchers were presented with a list of 15 ilities like this one

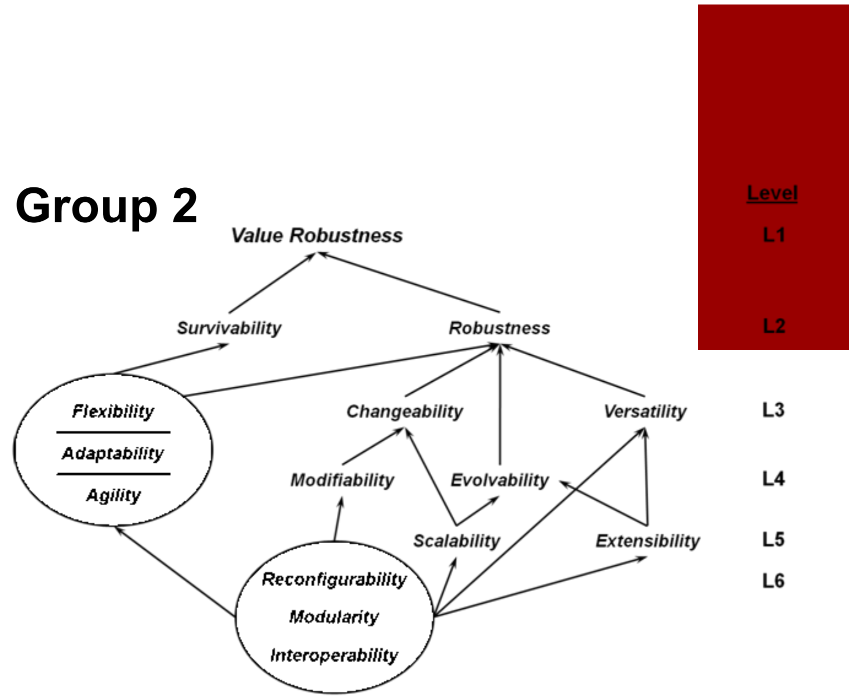
Ility Name	Definition ("ability of a system…")
adaptability	to be changed by a system-internal change agent with intent
agility	to change in a timely fashion
changeability	to alter its operations or form, and consequently possibly its function, at an acceptable level of resources
evolvability	design to be inherited and changed across generations (over time)
extensibility	to accommodate new features after design
flexibility	to be changed by a system-external change agent with intent
interoperability	to effectively interact with other systems
modifiability	to change the current set of specified system parameters
modularity	degree to which a system is composed of modules (not an ability-type ility)
reconfigurability	to change its component arrangement and links reversibly
robustness	to maintain its level and/or set of specified parameters in the context of changing system external and internal forces
scalability	to change the current level of a specified system parameter
survivability	to minimize the impact of a finite duration disturbance on value delivery
value robustness	to maintain value delivery in spite of changes in needs or context
versatility	to satisfy diverse needs for the system without having to change form (measure of latent value)

What is their relationship?
Do they form a hierarchy?

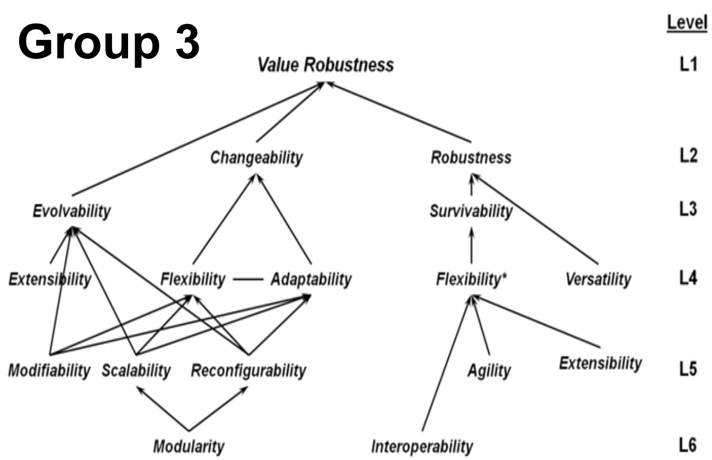
Group 1



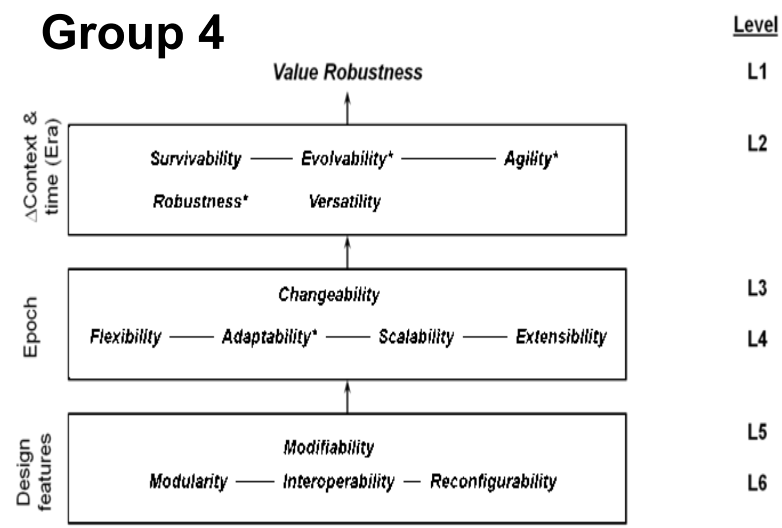
Group 2



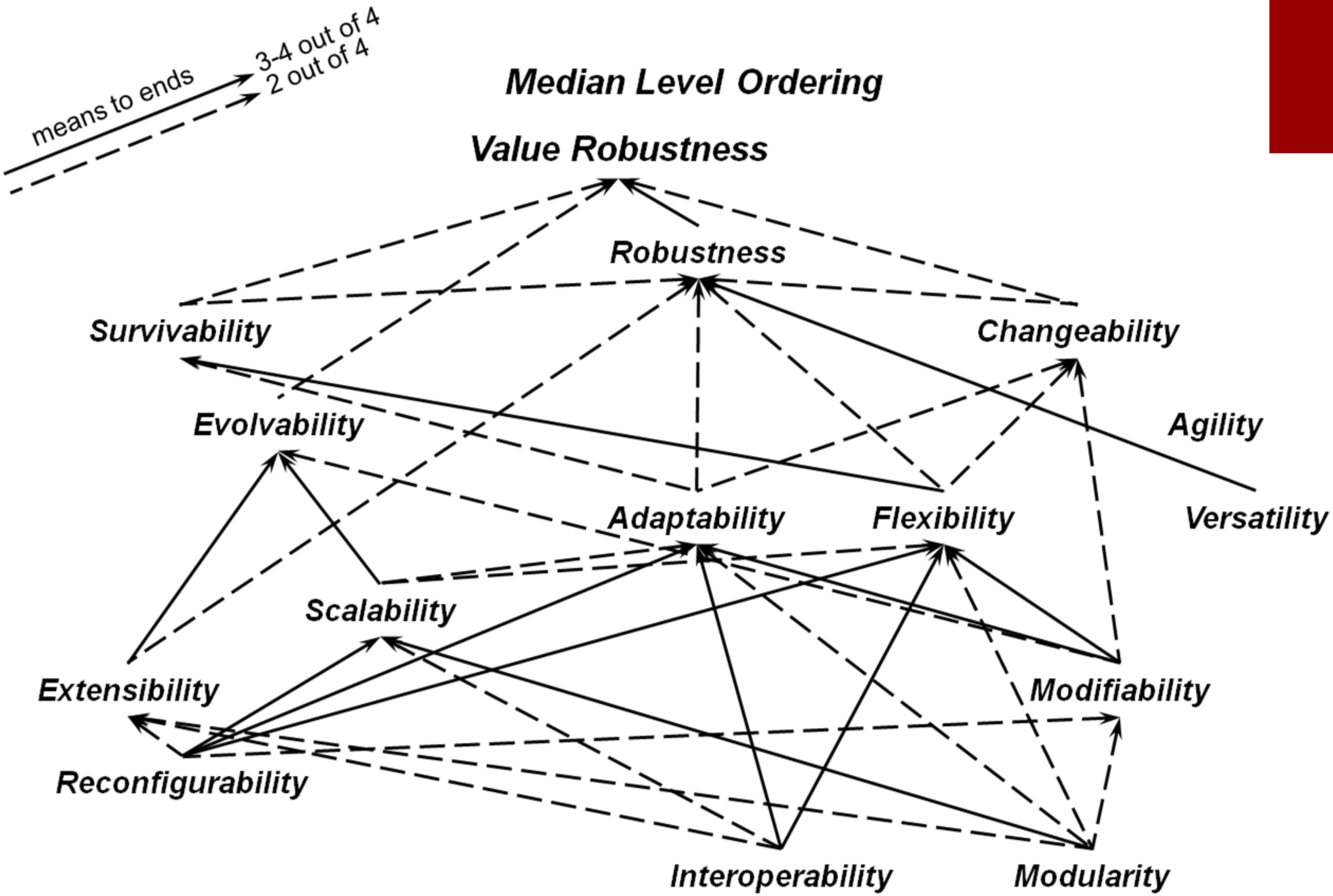
Group 3



Group 4



Combined Means to Ends Hierarchy



Summary of Lifecycle Properties

- Lifecycle properties (Ilities) are critical for long term value
- Despite differences, the two methods led to similar high-level conclusions regarding the relationships amongst Ilities:
  - Some ilities are closely related to each other and form semantic sets that are tied together by both synonymy and polysemy relationships.
  - System value is heavily driven by the ability of a system to be robust (despite internal and exogenous disturbances), flexible or changeable and resilient or survivable over time.
  - A hierarchy of ilities with two or three levels appears to exist whereby some ilities, such as modularity and interoperability appear at lower levels and serve as enablers of higher level ilities.
- Future work will apply both methods to larger sets of ilities, with larger groups of test subjects and will use consistent sets of ilities

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Communications Satellite Constellation Case

- Iridium and Globalstar
- Integrated Lifecycle Modeling
- **Flexibility / Scalability:** Staged Deployment Approach

de Weck, O.L., de Neufville R. and Chaize M., "Staged Deployment of Communications Satellite Constellations in Low Earth Orbit", *Journal of Aerospace Computing, Information, and Communication*, 1 (3), 119-136, March 2004

Existing Big LEO Systems

	Iridium	Globalstar
Time of Launch	1997 – 1998	1998 – 1999
Number of Sats.	66	48
Constellation Formation	polar	Walker
Altitude (km)	780	1414
Sat. Mass (kg)	689	450
Transmitter Power (W)	400	380
Multiple Access Scheme	Multi-frequency – Time Division Multiple Access	Multi-frequency – Code Division Multiple Access
Single Satellite Capacity Global Capacity Cs	1,100 duplex channels 72,600 channels	2,500 duplex channels 120,000 channels
Type of Service	voice and data	voice and data
Average Data Rate per Channel	4.8 kbps	2.4/4.8/9.6 kbps
Total System Cost	$ 5.7 billion	$ 3.3 billion
Current Status	Bankrupt but in operation. IridumNEXT under development (2017)	Bankrupt but in operation. Globalstar now publicly traded and valued at $1.87B

Individual
Iridium Satellite

Individual
Globalstar Satellite

Motivation: Iridium Satellite System

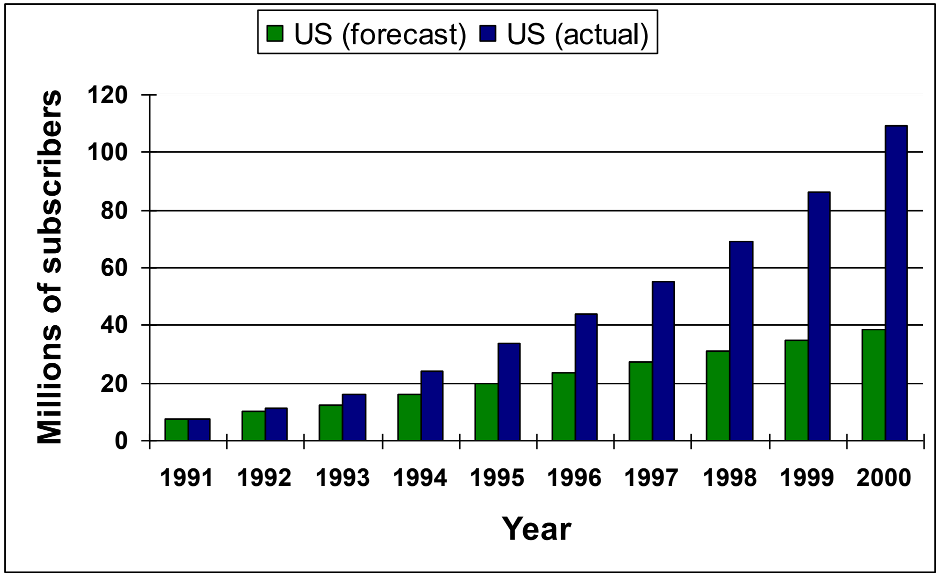
'Motorola unveils new concept for global personal communications: base is constellation of low-orbit cellular satellites',

Motorola Press Release on Iridium, London, 26 June 1990.

'Last week, Iridium LLC filed for bankruptcy-court protection. Lost investments are estimated at $5 billion.'

Wall Street Journal, New York, 18 August 1999.

- Difficult to properly size capacity of large system
- Market assumptions can change when 7-8 years elapse between conceptual design and fielding (1991-1998)



Iridium Satellite

Satellite System Economics

Lifecycle cost

$$CPF = \frac{\overbrace{I\left(1+\frac{k}{100}\right)^{T} + \sum_{i=1}^{T} C_{ops,i}}^{\text{Lifecycle cost}}}{\underbrace{\sum_{i=1}^{T} C_s \cdot 365 \cdot 24 \cdot 60 \cdot L_{f,i}}_{\text{Number of billable minutes}}}$$

Number of billable minutes

Cost per function [$/min]
Initial investment cost [$]
Yearly interest rate [%]
Yearly operations cost [$/y]
Global instant capacity [#ch]
Average load factor [0…1]
Number of subscribers
Average user activity [min/y]
Operational system life [y]

Numerical Example:

$I = 3$ [B$]
$k = 5$ [%]
$C_{ops} = 300$ [M$/y]
$T = 15$ [y]

$C_s = 100{,}000$ [#ch]
$N_u = 3 \cdot 10^6$
$A_u = 1{,}200$ [min/y]

$$CPF = 0.20 \text{ [\$/min]}$$

$$L_f = \min \begin{cases} \dfrac{N_u \cdot A_u}{365 \cdot 24 \cdot 60 \cdot C_s} \\ 1.0 \end{cases}$$

But with $N_u = 50{,}000$
$\longrightarrow CPF = 12.02$ [$/min]
Non-competitive

Design (Input) Vector X

Astro-dynamics
- Constellation Type: C
- Orbital Altitude: h
- Minimum Elevation Angle: e_{min}

Satellite Design
- Satellite Transmit Power: P_t
- Antenna Size: D_a
- Multiple Access Scheme MA:

Network
- Network Architecture: ISL

Design Space

Polar, Walker	
500,1000,1500,2000	[km]
2.5,7.5,12.5	[deg]
200,400,800,1600,2400	[W]
1.0,2.0,3.0	[m]
MF-TDMA, MF-CDMA	[-]
yes, no	[-]

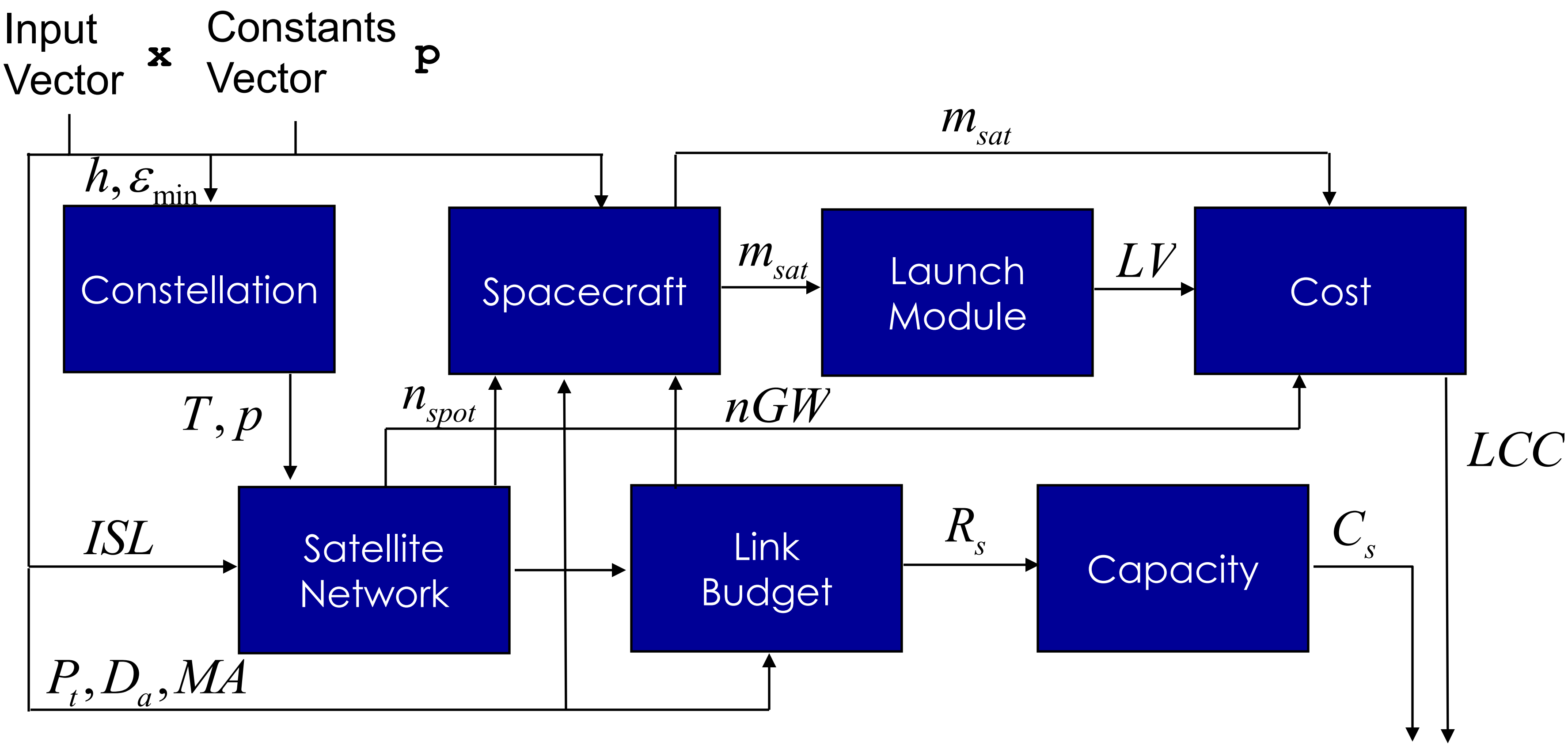
$$X_{1440} = \begin{pmatrix} \text{C: 'walker'} \\ \text{h: 2000} \\ \text{emin: 12.5000} \\ \text{Pt: 2400} \\ \text{DA: 3} \\ \text{MA: 'MFCD'} \\ \text{ISL: 0} \end{pmatrix}$$

This results in a <u>1440</u> full factorial, combinatorial co design space

Objective Vector (Output) J

- Performance (fixed)
  - Data Rate per Channel: R=4.8 [kbps]
  - Bit-Error Rate: $p_b=10^{-3}$
  - Link Fading Margin: 16 [dB]
- Capacity
  - C_s: Number of simultaneous duplex channels
- Cost
  - Lifecycle cost of the system (LCC [$]), includes:
    - Research, Development, Test and Evaluation (RDT&E)
    - Satellite Construction and Test
    - Launch and Orbital Insertion
    - Operations and Replenishment

Multidisciplinary Simulator Structure



m_{sat}	Satellite Mass	n_{spot}	Number of spot beams
T	Number of Satellites	nGW	Number of gateways
p	Number of orbital planes	LV	Launch vehicle selection

Output Vector **J**

Note: Only partial input-output relationships shown

Governing Equations – Satellite Simulator

a) Physics-Based Models

Energy per bit over noise ratio:

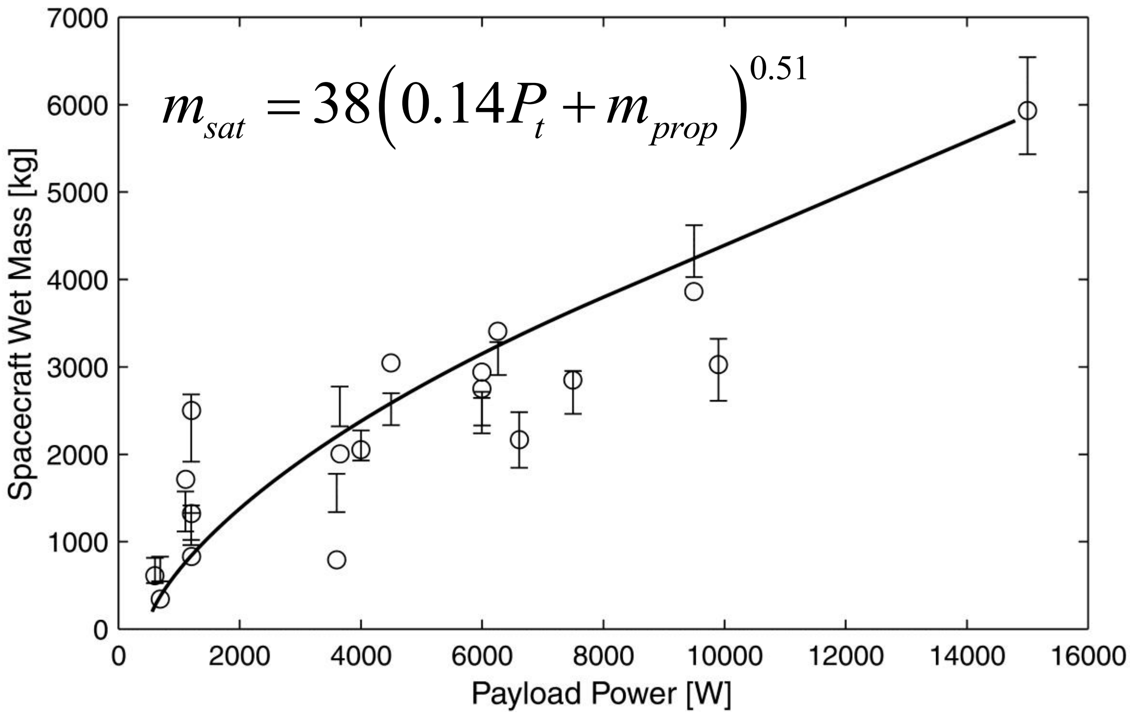
$$\frac{E_b}{N_0} = \frac{PG_rG_t}{kL_{space}L_{add.}T_{sys.}R}$$

(Link Budget)

b) Empirical Models

(Spacecraft)

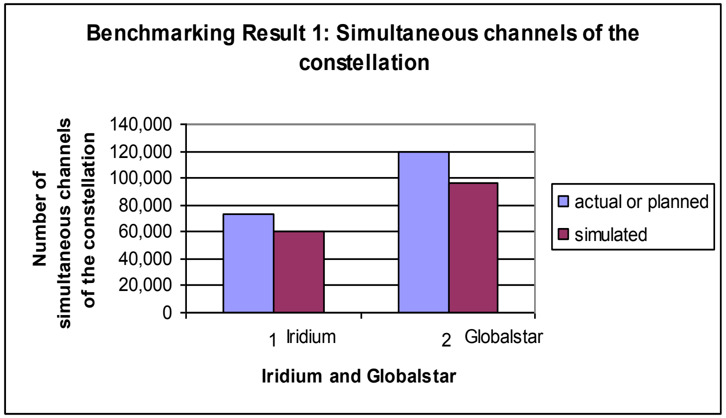
Scaling models derived from FCC database

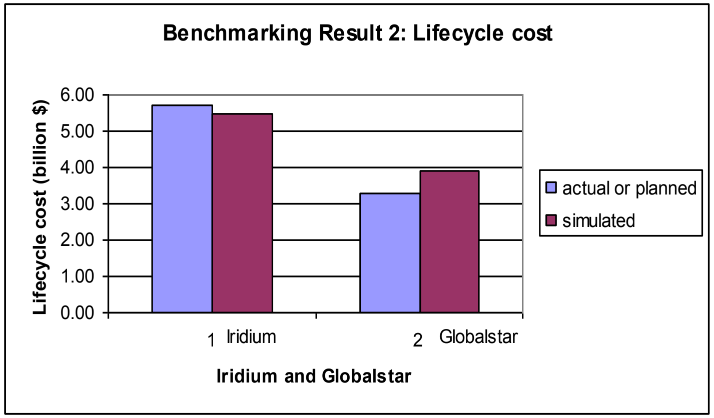


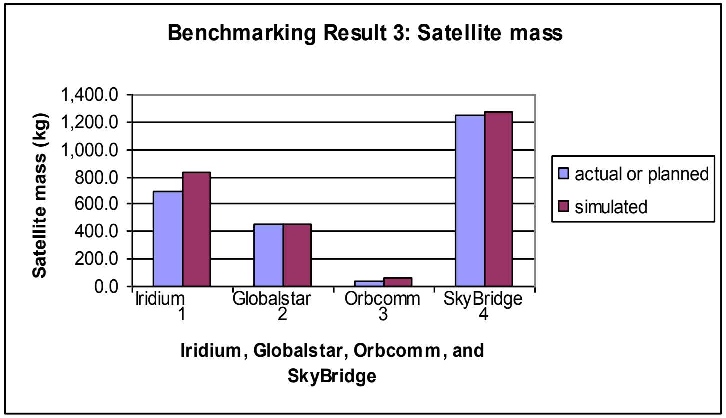
Springmann P.N., and de Weck, O.L. "A Parametric Scaling Model for Non-Geosynchronous Communications Satellites", *Journal of Spacecraft and Rockets*, May-June 2004

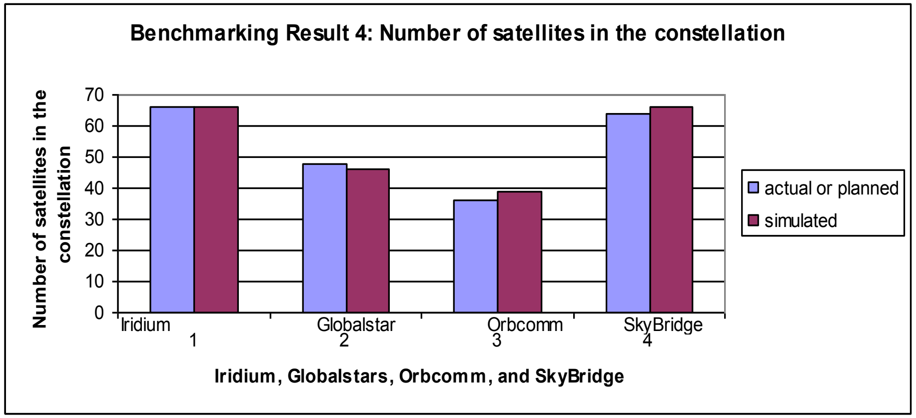
Benchmarking

Benchmarking is the process of validating a simulation by comparing the predicted response against reality.



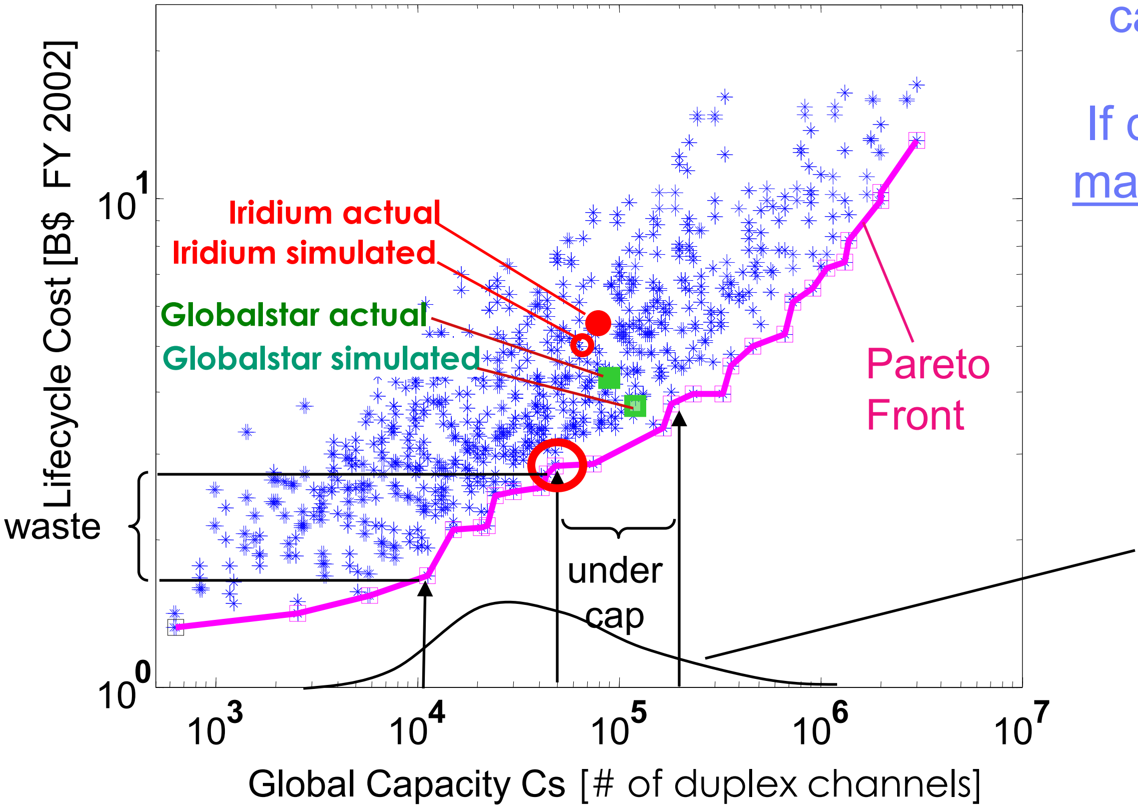






Traditional Systems Engineering

- The traditional approach for designing a system considers configurations (architectures) to be fixed over time.
- Designers look for a Pareto Optimal solution in the Trade Space given a targeted capacity.



If actual demand is below capacity, there is a <u>waste</u>

If demand is over the capacity, <u>market opportunity</u> may be missed

Demand distribution
Probability density function

$$P\{a < D \le b\} = \int_a^b f_D(\delta)\mathrm{d}D$$

$$0 \le f_D(D) \text{ for all } D$$

$$\int_{-\infty}^{\infty} f_D(\delta)\mathrm{dD} = 1$$

Staged Deployment

- Adapt to uncertain demand with a staged deployment strategy:
  - A smaller, more affordable system is initially built
  - This system has the flexibility to increase its capacity if demand is sufficient and if the decision makers can afford additional capacity
- **Economic Advantage**
  - Some capital investments are deferred to later
  - The ability to reconfigure and deploy the next stage is a real option

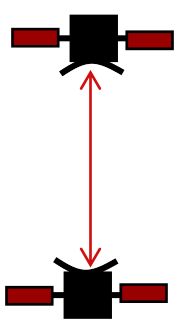
Step 1: Partition the Design Vector

$x_{flexible}$ — Astro-dynamics:
- Constellation Type: C
- Orbital Altitude: h
- Minimum Elevation Angle: ε_{min}

x_{base} — Satellite Design / Network:
- Satellite Transmit Power: P_t
- Antenna Size: D_a
- Multiple Access Scheme MA:
- Network Architecture: ISL

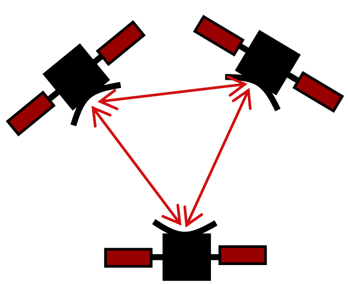
<u>Rationale:</u>
Keep satellites the same and change only arrangement in space

Stage I



```
   C:  'walker'
   h:  2000
emin:  12.5000
  Pt:  200 W
  DA:  1.5 m
  MA:  'MFCD'
 ISL:  1=yes
```

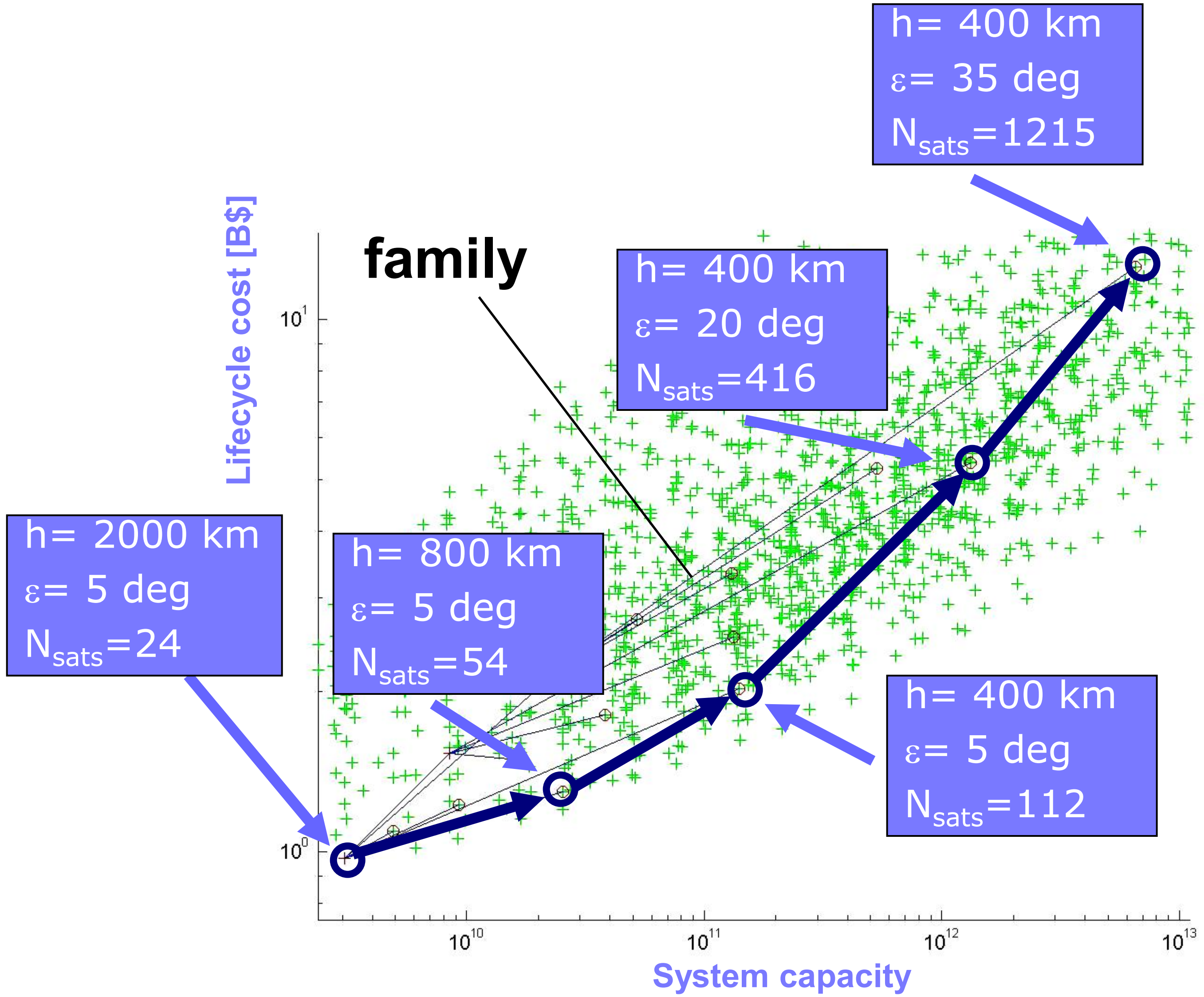
Stage II



$x^{I}_{base} = x^{II}_{base}$

```
   C:  'polar'
   h:  1000
emin:  7.5000
  Pt:  200 W
  DA:  1.5 m
  MA:  'MFCD'
 ISL:  1=yes
```

Step 2: Search Paths in the Trade Space



Constant:

Pt=200 W

DA=1.5 m

ISL= Yes

Total: 40 Paths

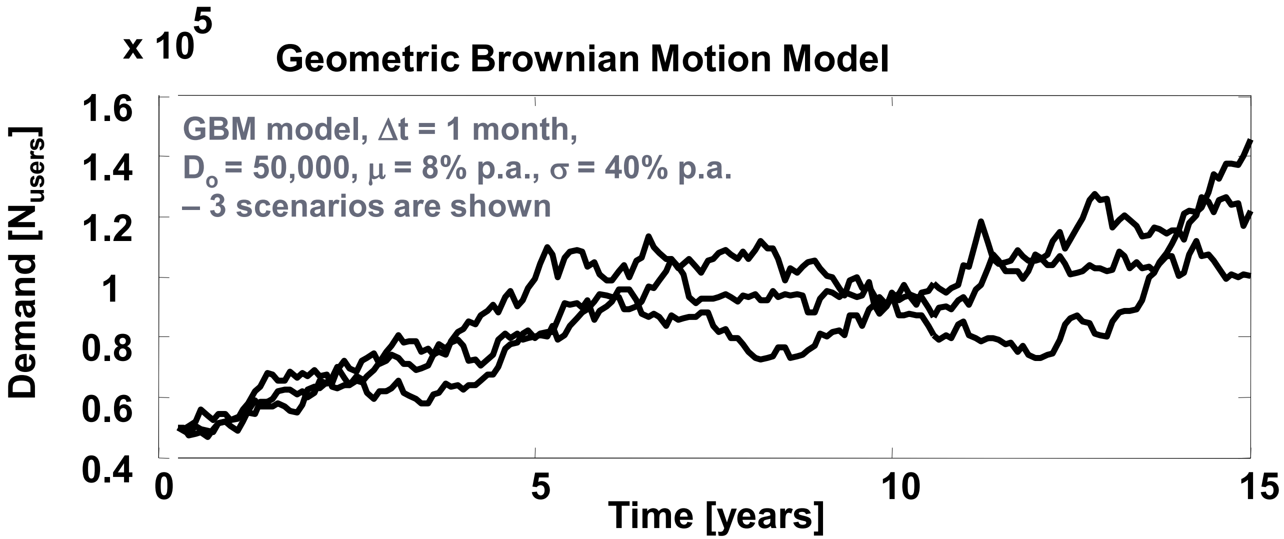
Step 3a: Model Uncertainty [GBM]

$$\frac{\Delta D}{D} = \mu \Delta t + \sigma \varepsilon \sqrt{\Delta t}$$

$$E\left[\frac{\Delta D}{D}\right] = \mu \Delta t$$

$$\mathrm{var}\left[\frac{\Delta D}{D}\right] = \sigma^2 \Delta t$$

D - demand
Δt – time period
ε- SND random variable
μ, σ - constants



- Demand can go up or down between two decision points
- Infinitely many scenarios can be generated based on this model

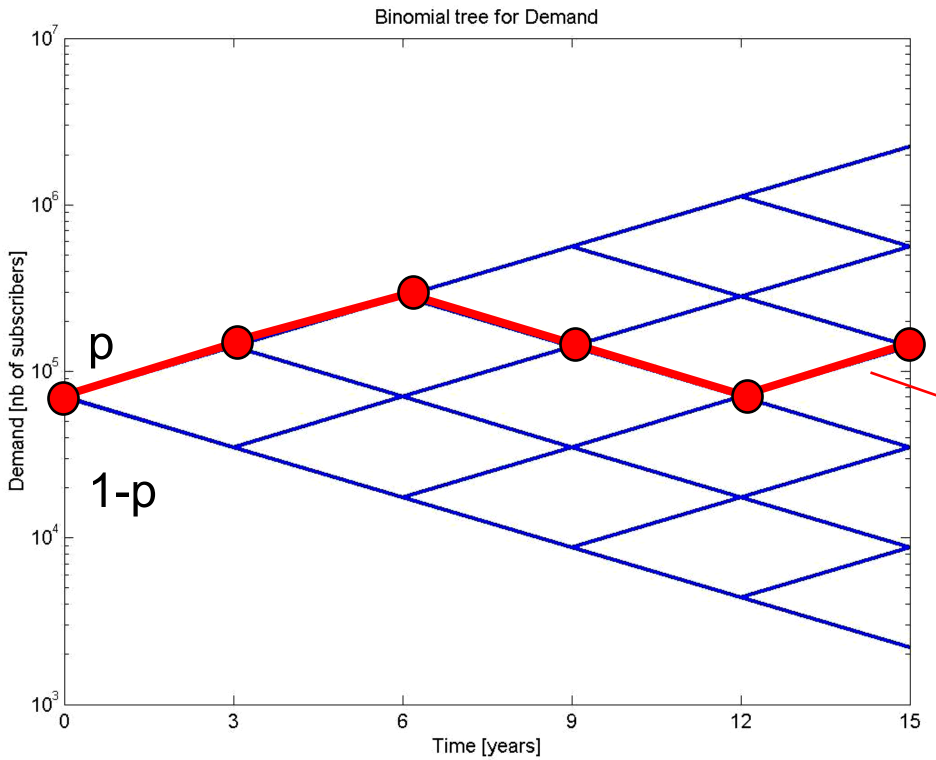
Step 3b: Binomial Lattice Model

$$u = e^{\sigma\sqrt{\Delta t}}$$

$$d = 1/u$$

$$p = \frac{e^{u\Delta t} - d}{u - d}$$

Discretized Random Walk



Total

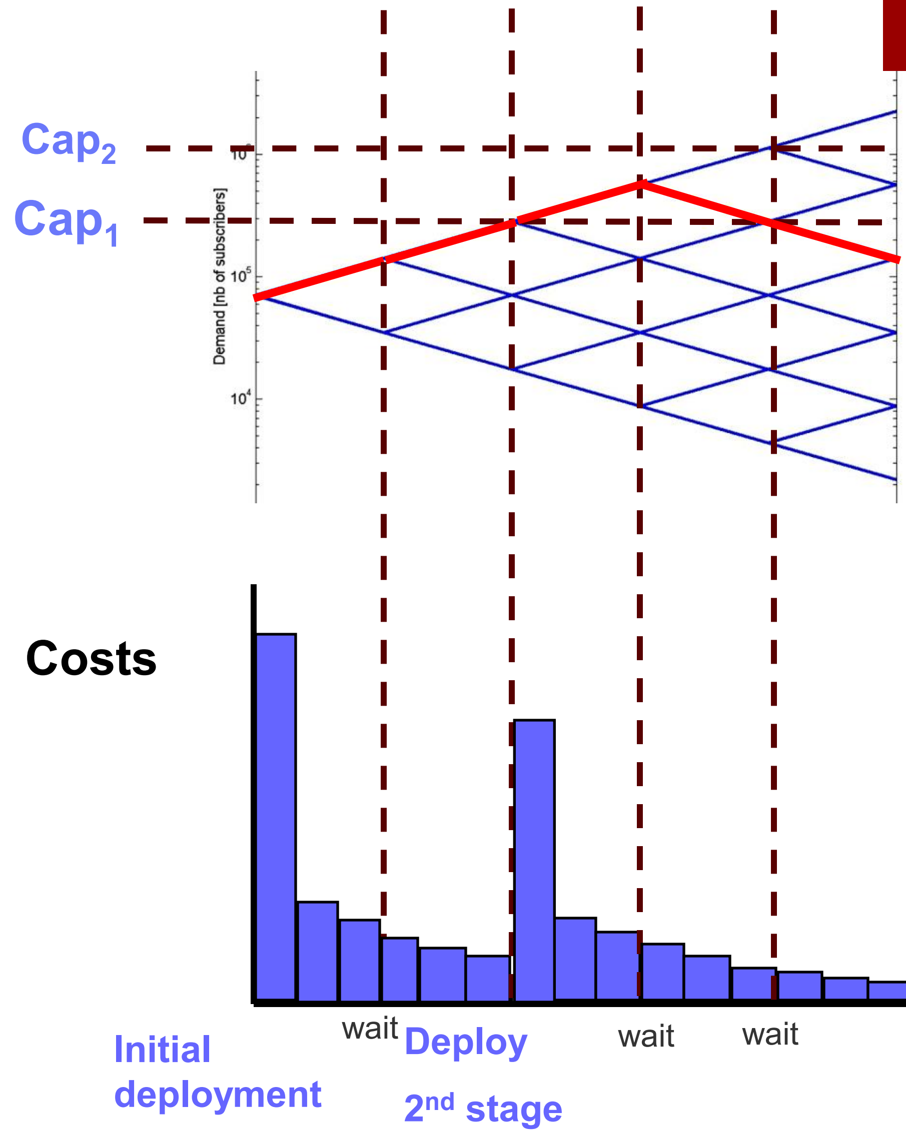
2^5=32 scenarios

Sample scenario

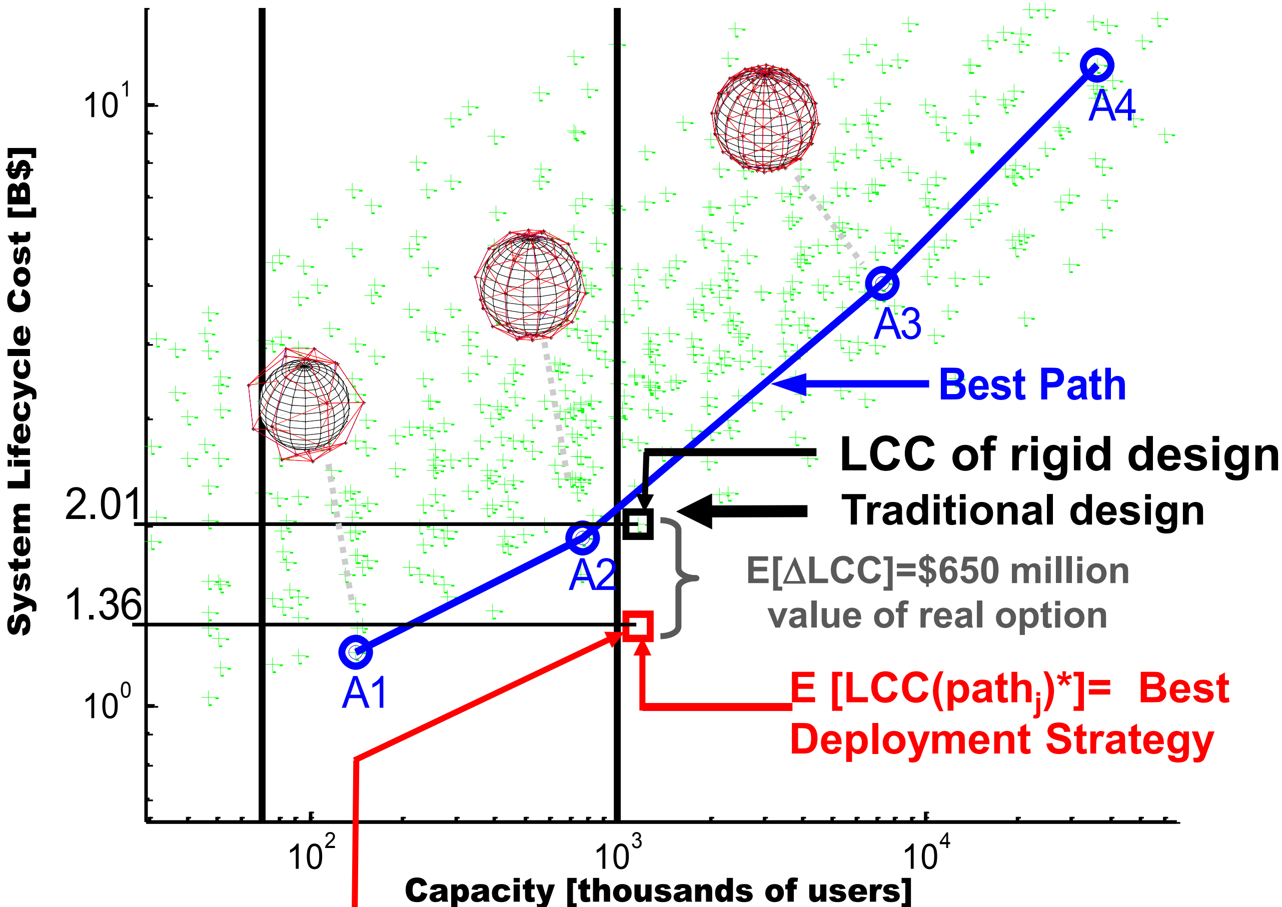
$$P(i) = p^k (1 - p)^{n-k}$$

Step 4: Calculate cost of paths

- We compute the costs of a path with respect to each demand scenario
- We then look at the weighted average of every allowable path for cost over all scenarios
- Decision rule: We always adapt to demand when demand exceeds capacity
- The costs are discounted: the present value of LCC is considered



Step 5: Identify optimal path



$$E\left[LCC(path_j)\right] = \sum_{i=1}^{n} p_i LCC\left(scenario^i_{path_j}\right)$$

- For a given targeted capacity, we compare our solution to the traditional approach
- Our approach allows large savings (30% on average)

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Learning Objectives Revisited

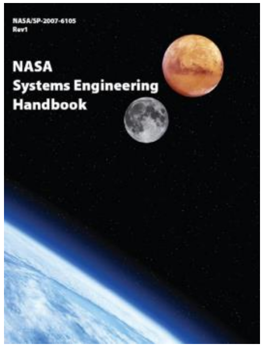
Participants in this class will be able to …

- SE1: Describe the most important **Systems Engineering standards and best practices** as well as newly emerging approaches[1]
- SE2: Structure the **key steps in the systems engineering process** starting with stakeholder analysis and ending with transitioning systems to operations
- SE3: Analyze the **important role of humans** as beneficiaries, designers, operators and maintainers of aerospace and other systems
- SE4: Characterize the **limitations of the way that current systems engineering is** practiced in terms of dealing with complexity, lifecycle uncertainty and other factors
- SE5**: Apply some of the fundamental methods and tools** of systems engineering to a 'simple' cyber-electro-mechanical system as a stepping stone to more complex and real world projects

[1] Our main "textbook" for the class will be the NASA Systems Engineering Handbook, NASA/TP-2007-6105, Rev 1. All participants will receive a copy of the handbook.

Note: This class is not an explicit preparation for CSEP Certification

SE1: Standards and Handbooks



- Systems Engineering Standards

1. **NASA Systems Engineering Handbook,** NASA/SP-2007-6105, Rev 1, Dec 2007
2. **INCOSE Systems Engineering Handbook**, A Guide for System Lifecycle Processes and Activities, INCOSE-TP-2003-002-03, version 3, International Council on Systems Engineering (INCOSE), June 2006 – version 4 was just issued in July 2015
3. **ISO/IEC 15288:2008(E), IEEE Std 15288-2008**, Second edition, 2008-02-01 Systems and software engineering — System life cycle processes, Ingénierie des systèmes et du logiciel — Processus du cycle de vie du système – May 2015 edition
4. **ECSS-E-10A** – European Systems Engineering Standard, http://www.ecss.nl/

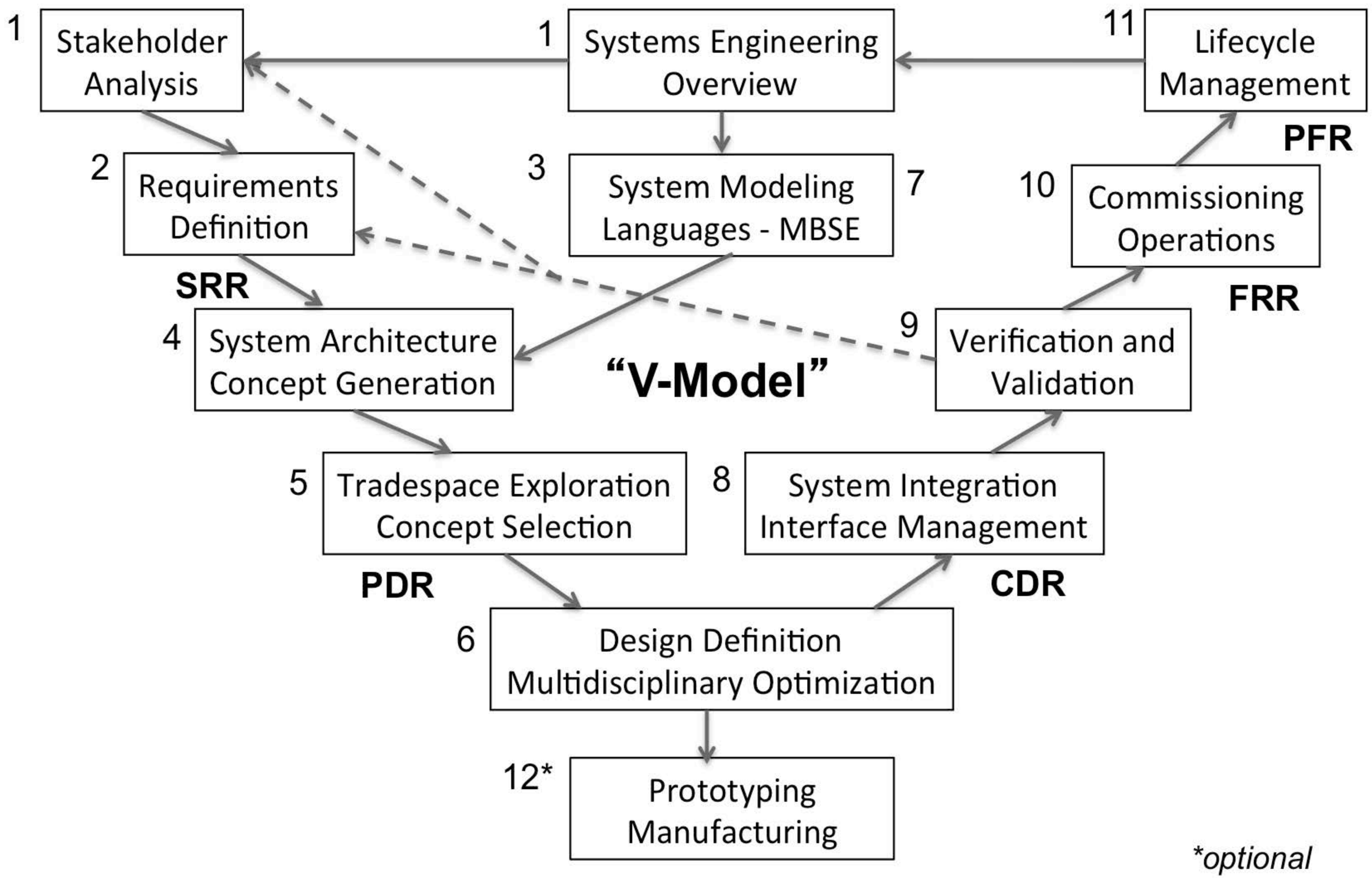
- Selected Conference and Journal Articles (in “Readings” folder)
  - Explore beyond traditional SE
  - Somewhat MIT-centric

What is your opinion about these standards now, at the end of the class?

See the question in supplement files.

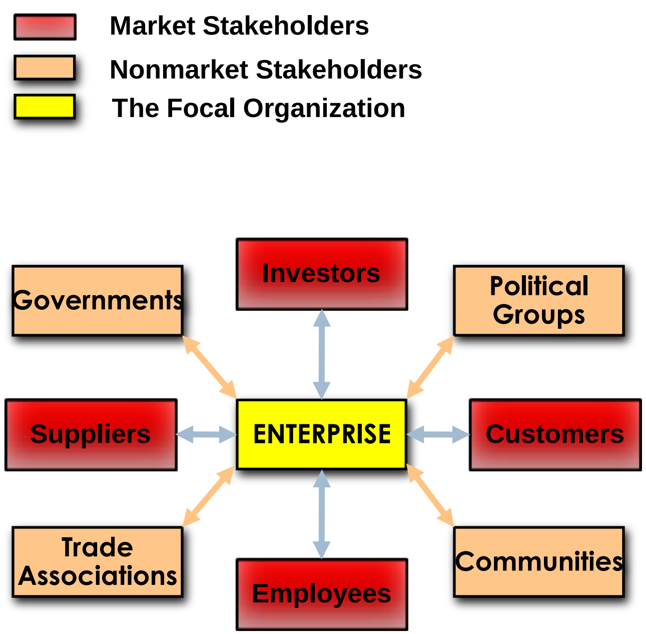
SE2: Structure Key Steps: "V"-Model

16.842/ENG-421 Fundamentals of Systems Engineering

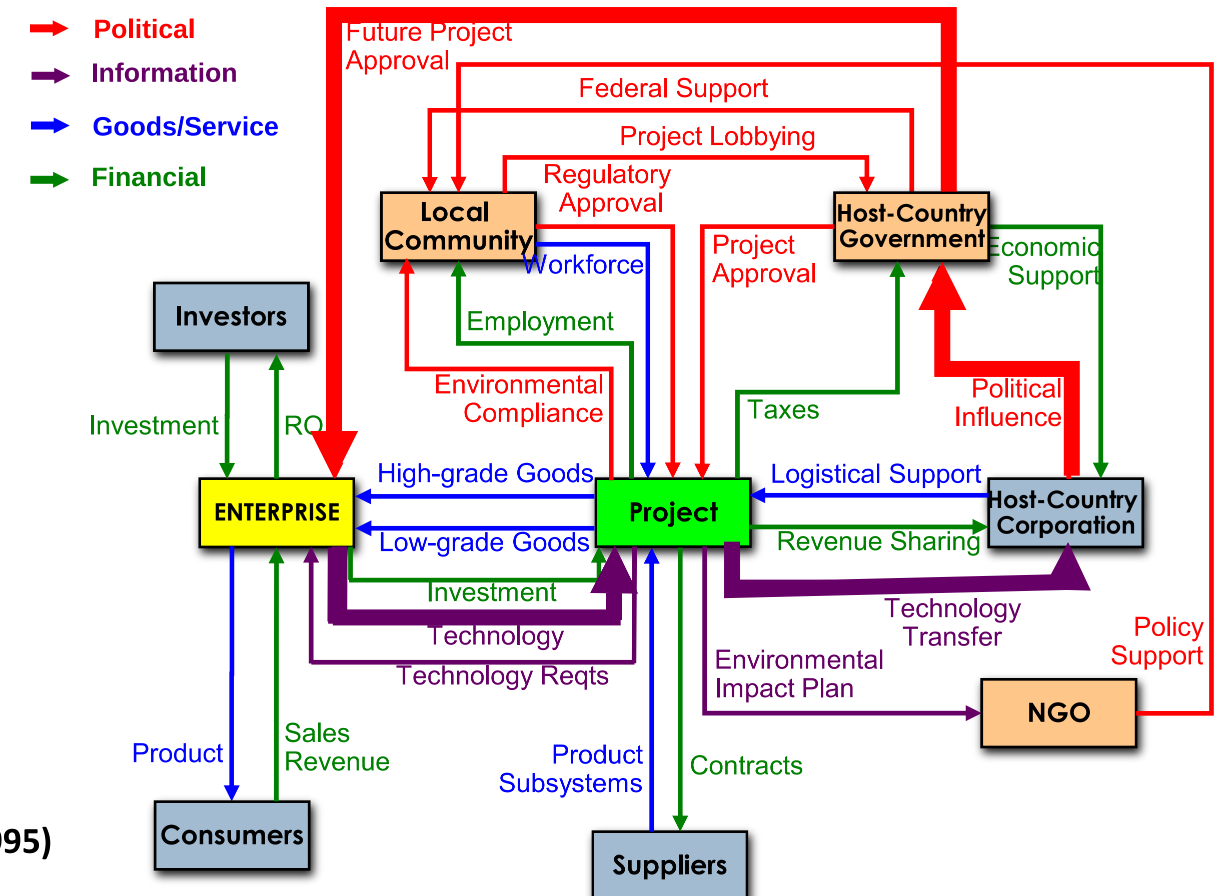


Numbers indicate the session # in this class

SE4: Stakeholders and Value Network



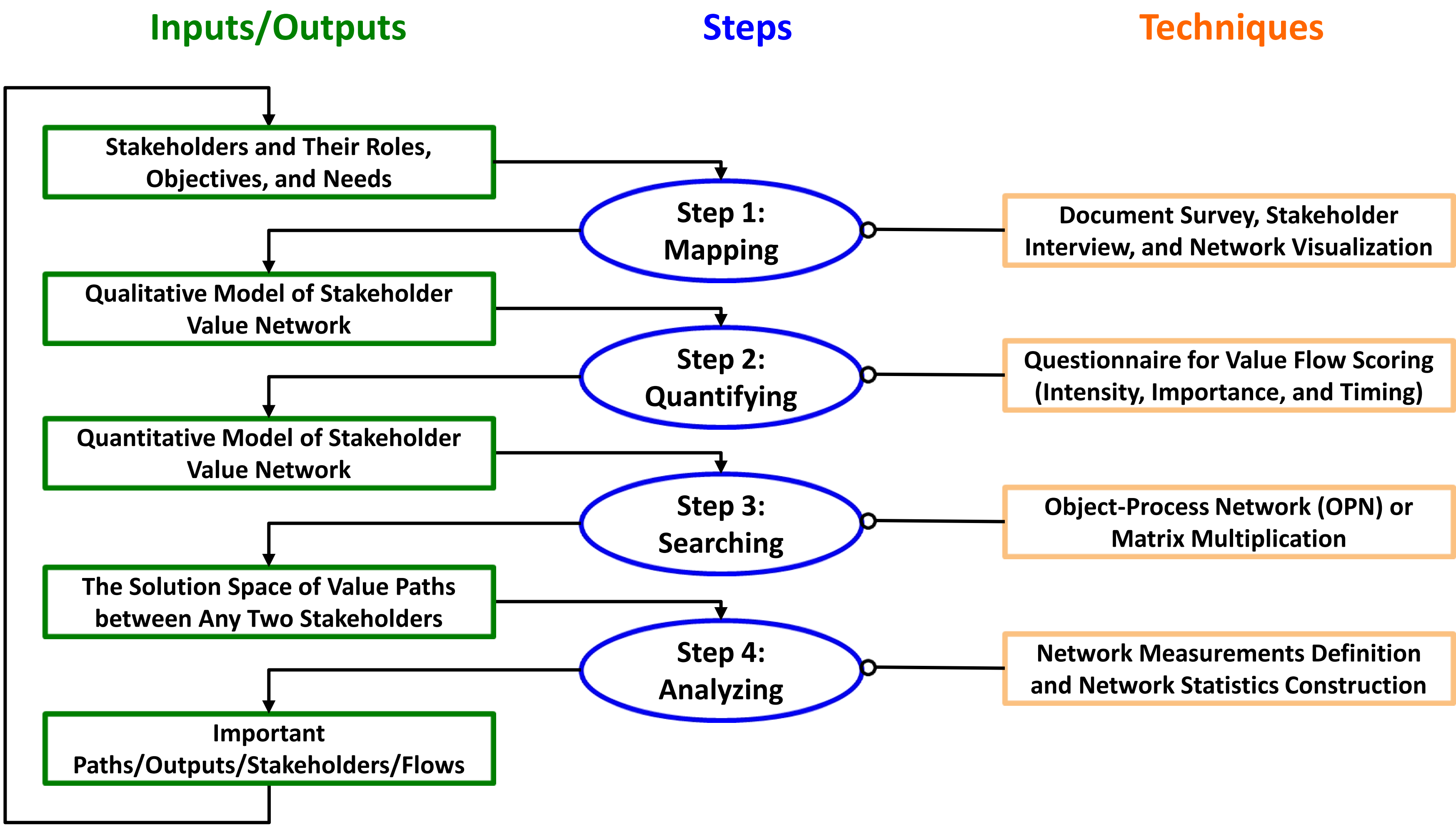
"Hub-and-Spoke" Stakeholder Model
(Adapted from Donaldson and Preston, 1995)



Stakeholder Value Network
(Feng, Cameron, and Crawley, 2008)

Figure 3 in Wen Feng; Edward F. Crawley; Olivier de Weck; Rene Keller;Bob Robinson. : Dependency structure matrix modelling forstakeholder value networks". Proceedings of the 12thInternational DSM Conference, Cambridge, UK, 22.-23.07. 3-16.DSM 2010.

SE4: Stakeholder Value Network (SVN) Methodology



Feng W., Crawley E.F., de Weck O.L., Keller R., Robinson R., "Dependency Structure Matrix Modeling for Stakeholder Value Networks", 12th International Dependency and Structure Modeling Conference, DSM'10, Cambridge, UK, 22-23 July 2010

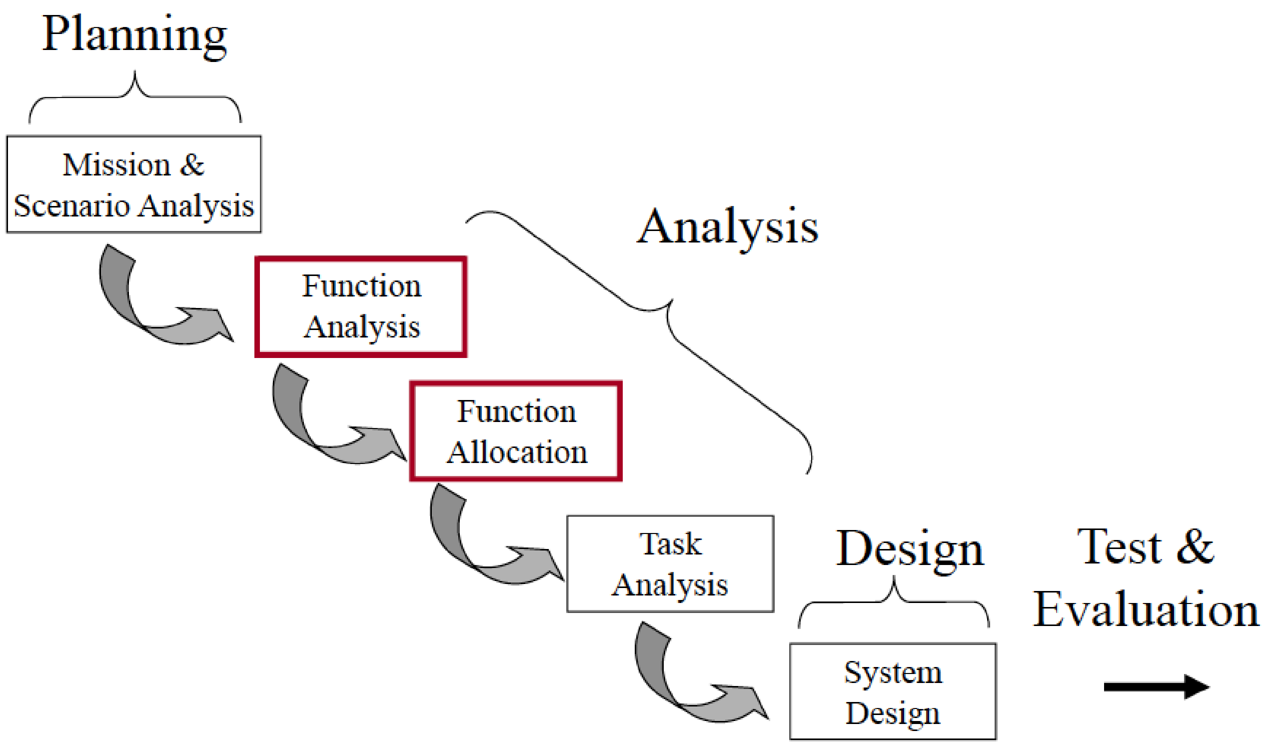
SE3: Role of individuals in SE: **Human Factors**

- How to design systems so that humans can use them effectively and safely (interfaces, procedures …)
- Often ignored until too late
- Result of classical SE (without human factors):

Important Human Factors Questions
How to best display status information?
Human tasks during operations?
Level of automation?
Training requirements for operators?

Russian Nuclear Power Plant Control Room (Source: Prof. M. Cummings)

A simplified Human Systems Engineering (HSE) Process

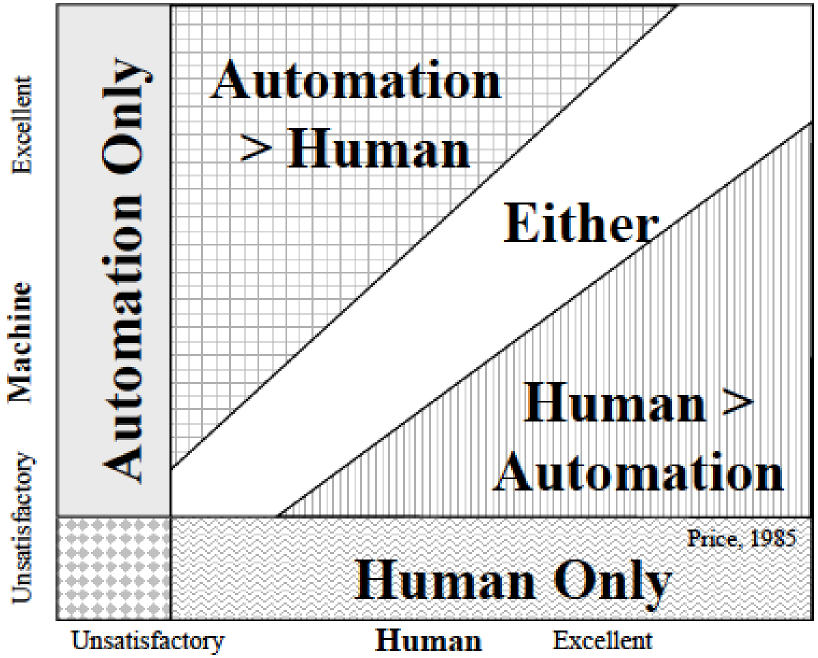


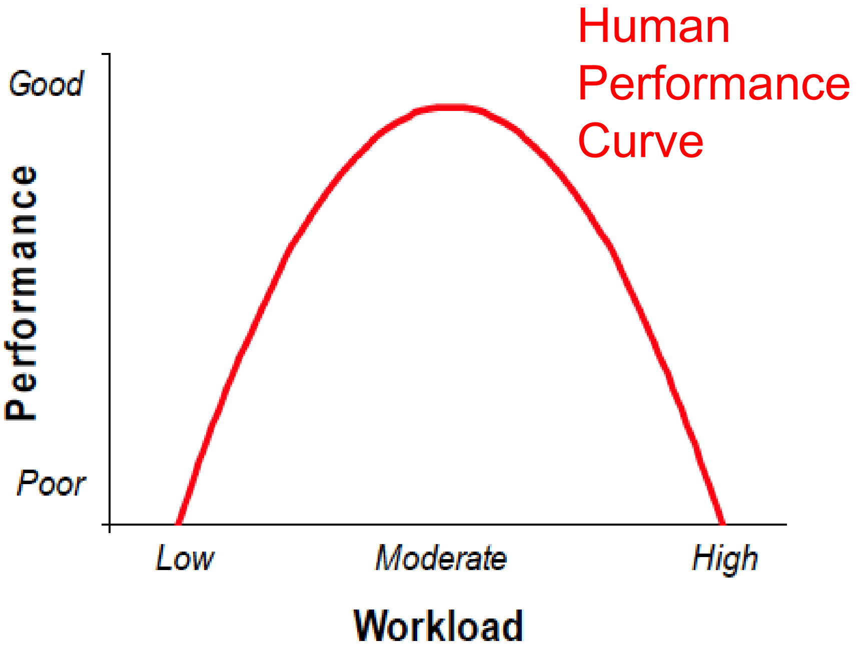
Courtesy of Mary Cummings. Used with permission.

- Credit: Prof. Missy Cummings
  - More info at MIT: 16.470J Statistical Methods in Experimental Design
  - Now taught by DR. Carr

Function Allocation is crucial

- Growing system complexity and mission requirements mean that mutually exclusive role allocation between humans and automation will not be sufficient
- Humans and automation both have strengths & limitations
  - Brittleness vs. attention inefficiencies





SE4: System Complexity

Magic Number 7 +/-2 [Miller 1956]

http://www.musanim.com/miller1956/

Limitations of human mind at Levels 3+

How many levels in drawing tree?

$$\#levels = \left\lceil \frac{\log(\#\,parts)}{\log(7)} \right\rceil$$

		~ #parts	#levels	
Screwdriver	(B&D)	3	1	simple
Roller Blades	(Bauer)	30	2	
Inkjet Printer	(HP)	300	3	
Copy Machine	(Xerox)	2,000	4	
Automobile	(GM)	10,000	5	
Airliner	(Boeing)	100,000	6	complex

Source: Ulrich, K.T., Eppinger S.D. , Product Design and Development Second Edition, McGraw Hill, 2nd edition, 2000, Exhibit 1-3

SPAC

NEWS OPINION

Get th

Component Is[...] Months

by Peter B. de Selding — Octo[...]

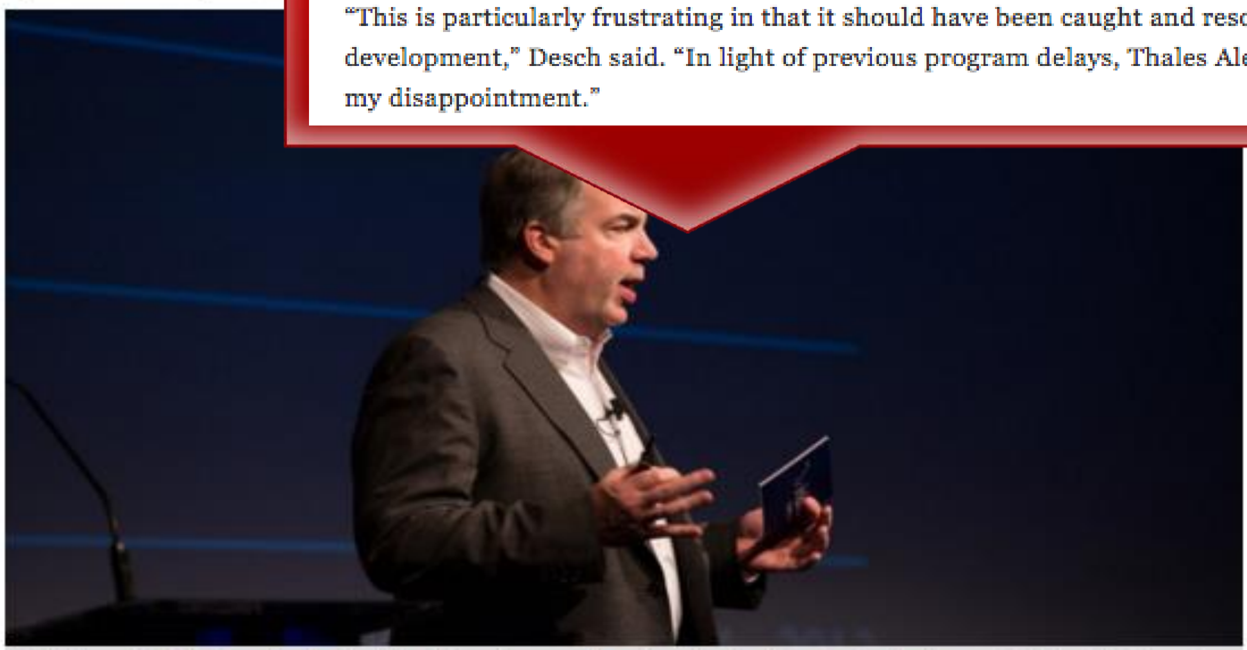
In a conference call with investors, Iridium Chief Executive Matthew J. Desch made no attempt to hide his exasperation at the latest delay, especially because it was caused by a component that had posed issues for prime contractor Thales Alenia Space previously.

The component, built by ViaSat Inc. of Carlsbad, California, is an extension of a Ka-band transmit/receive module. This hardware already had been associated with production delays on Iridium Next.

"Thales now appears to have found an issue during post-assembly testing of this same T/R module," Desch said. The defect "could create performance problems in the Ka-band downlink to our Earth stations."

Thales Alenia Space of France and Italy will now change the circuitry in the module and then reinstall it onto the first two satellites to launch on Dnepr.

"This is particularly frustrating in that it should have been caught and resolved much earlier in development," Desch said. "In light of previous program delays, Thales Alenia knows — quite clearly — my disappointment."



"This is particularly frustrating in that it should have been caught and resolved much earlier in development," Iridium Chief Executive Matthew J. Desch said. "In light of previous program delays, Thales Alenia knows — quite clearly — my disappointment." Credit: Iridium

-Mars Plans Lack Details

Today

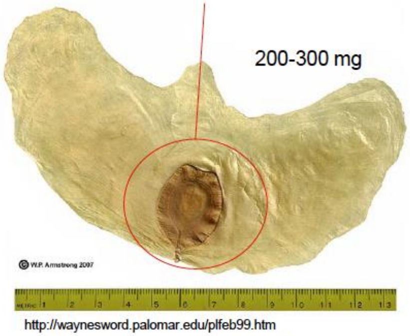
Most Read

1. Blue Origin may have New Shepard, but SpaceX has Karlie Kloss

SE5: Application to a case case

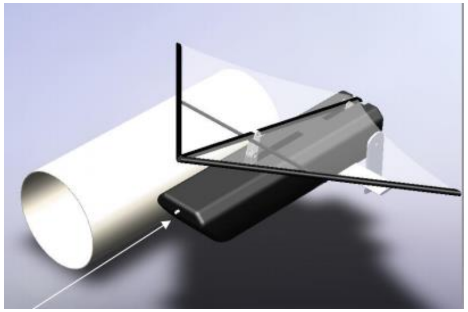
- Cansat 2016 Competition served as our “safe” case study
  - Clear rules, 47 requirements as a starter, cyber-physical complexity somewhere between levels 2 and 3, real stakeholders etc…
- **Comments about PDR**
  - All teams successfully passed PDR
    - Couple of RIDs issued, e.g. over-mass budget 500 grams, need to work out aerodynamics of advanced glider concepts etc…
  - Excellent application of SE concepts, some went beyond expectations
  - Importance of concept generation* and selection was very clear
  - Application Deadline was November 30, 2015

EPFL Team 4
SKALE
Bio-Inspired Design
alsomitra macrocarpa



Alsomitra shape → Roll and yaw stabilization

MIT Team 7
Glidestar
Rogallo Wing



* Joint use of structured and unstructured creativity techniques: e.g. brainstorming -> morph

Outline for Today

- Definition of Lifecycle Management
- Lifecycle Properties, i.e. the "Illities"
- A Case Study
  - Reconfiguration of Communications Satellite Constellations
- Summary of Key Concepts taught in this class
- Career / Study Recommendations regarding SE

Career / Study Recommendations for SE

- **Academic**
  - This class 16.842 / ENG-421 was just a "door opener" to systems engineering
  - Take classes that go deeper into individual topics, e.g. MBSE, System Safety, Multidisciplinary System Optimization (16.888/ESD.77 Spring 2016) etc…
  - Self-Study: SE Journal, IEEE Journals, etc…
  - Professional Degrees in Systems Engineering, e.g. MIT SDM (average age 33)
- **Professional**
  - Get experience on actual projects, e.g. MIT REXIS, EPFL CleanSpace One, Octanis 1, Solar Impulse etc.…
  - Start your own company / venture → It's a Systems Challenge
- INCOSE
  - Join as a student or professional member if interested
  - Certification as ASEP or CSEP ("Certified Systems Engineering Professional")
- Keep in Touch !

Thank you !

Students at MIT and EPFL
TAs: Ioana and Lise-Loup
MIT and EPFL Technical Staff
Prof. Volker Gass

Next Week: Voluntary Seminar on the Future of SE and Manufacturing