CMMI® for Large-Scale, System of Systems Projects

9th Annual CMMI Technology Conference and User Group
National Defense Industrial Association (NDIA)

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Agenda

- The Problem with Large-Scale, System of Systems Projects
- Lessons from Bridge Building
- How the CMMI can be Adapted
- CMMI-based Project Modeling

"Make things as simple as possible, but not simpler."

Albert Einstein

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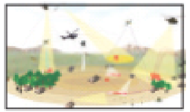
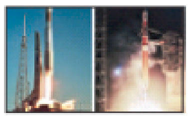
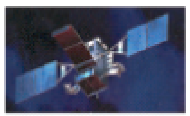
"For every complex and difficult problem, there is an answer that is simple, easy, and wrong."

H. L. Mencken

When considering systems engineering, big is not better

- There are many examples of recent failures with large-scale projects.
- The Government Accountability Office (GAO) provides authoritative statistics –

Examples of [Large-Scale] DOD Programs with Reduced Buying Power *

Program		Initial estimate	Initial quantity	Latest estimate	Latest quantity	Percent of unit cost increase
Joint Strike Fighter		$189. 8 billion	2,866 aircraft	$206.3 billion	2,458 aircraft	26.7
Future Combat Systems		$82.6 billion	15 systems	$127.5 billion	15 systems	54.4
F-22A Raptor		$81.1 billion	648 aircraft	$65.4 billion	181 aircraft	188.7
Evolved Expendable Launch Vehicle		$15.4 billion	181 vehicles	$28.0 billion	138 vehicles	137.8
Space Based Infrared System High		$4.1 billion	5 satellites	$10.2 billion	3 satellites	315.4
Expeditionary Fighting Vehicle		$8.1 billion	1,025 vehicles	$11.1 billion	1,025 vehicles	35.9

* GAO, Assessments of Selected Major Weapon Programs, March 2006, GAO-06-391

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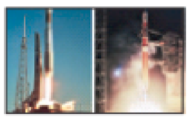
Evolved Expendable Launch Vehicle		$15.4 billion	181 vehicles	$28.0 billion	138 vehicles	137.8	
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Large-scale projects face common challenges

- The National Reconnaissance Office (NRO) found common program management flaws with large-scale projects *
  - Overzealous Advocacy
  - Immature Technology
  - Lack of Corporate Roadmaps
  - Requirements Instability
  - Ineffective Acquisition Strategy and Contractual Practices
  - Unrealistic Program Baselines
  - Inadequate Systems Engineering
  - Inexperienced Workforce and High Turnover
- "[Nearly all of the most important and costly projects] continue to cost significantly more, take longer to produce, and deliver less than was promised." **

* Best Practices for Large-Scale Federal Acquisition Programs, Steven Meier, Ph.D., PMP, (National Reconnaissance Office)
** U.S. Government Accountability Office, Assessments of Selected Weapon Programs, Mar. 2008, GAO-08-467SP

The definition of a "System of Systems" (SoS) is still being developed

- *A configuration of systems in which component systems can be added/removed during use; each provides useful services in its own right; and each is managed for those services. Yet, together they exhibit a synergistic, transcendent capability.*

  System-of-Systems Engineering for Air Force Capability Development, July 2005, U.S. Air Force United States Air Force Scientific Advisory Board

- *A set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities [DoD, 2004(1)]. Both individual systems and SoS conform to the accepted definition of a system in that each consists of parts, relationships, and a whole that is greater than the sum of the parts; however, although an SoS is a system, not all systems are SoS.*

  Systems Engineering Guide for Systems of Systems, Version 1.0 August 2008, Director, Systems and Software Engineering, Deputy Under Secretary of Defense (Acquisition and Technology), Office of the Under Secretary of Defense

- A system of systems is a "supersystem" comprised of other elements that themselves are independent complex operational systems and interact among themselves to achieve a common goal. Each element of an SoS achieves well-substantiated goals even if they are detached from the rest of the SoS.

  Mo Jamshidi, System of Systems Engineering: Innovations for the 21st Century, John Wiley & Sons, Inc., Hoboken, New Jersey, 2009

A DoD study of SoS provides useful insights

- Identified several current SoS programs –

Name	Acronym	Owner	Approach
Army Battle Command System	**ABCS**	Army	Acquisition Program
Air Operations Center	**AOC**	Air Force	Acquisition Program
Ballistic Missile Defense System	**BMDS**	Joint	Acquisition Program
USCG Command & Control Convergence	**C2 Convergence**	Coast Guard	Strategy
Common Aviation Command & Control System	**CAC2S**	Marine Corps	Acquisition Program
Distributed Common Ground Station	**DCGS-AF**	Air Force	Program Office
DoD Intelligence Information System	**DoDIIS**	Intel	DIA CIO Initiative
Future Combat Systems	**FCS**	Army	Program Office
Ground Combat Systems	**GCS**	Army	Program Executive Office PEO
Military Satellite Communications	**MILSATCOM**	Joint	AF Wing
Naval Integrated Fire Control – Counter Air	**NIFC-CA**	Navy	SE Integrator in PEO
National Security Agency	**NSA**	Intel	Agency
Naval Surface Warfare Center Dahlgren	**NSWC**	Navy	Warfare Center
Single Integrated Air Picture	**SIAP**	Joint	Acquisition Program
Space and Missile Systems Center	**SMC**	Air Force	SE Authority
Space Radar	**SR**	Joint	Acquisition Program
Theater Joint Tactical Networks	**TJTN**	Joint	PEO
Theater Medical Information Systems – Joint	**TMIP**	Joint	Acquisition Program

- Defined four types of SoS: Directed, Collaborative, Virtual, and Acknowledged.

SoS literature also shows that like large-scale projects, they face common challenges as well *

- System elements operate independently
- System elements have different life cycles
- The initial requirements are likely to be ambiguous
- Complexity is a major issue
- Management can overshadow engineering
- Fuzzy boundaries cause confusion
- SoS engineering is never finished

* INCOSE Systems Engineering Handbook, v 3.1

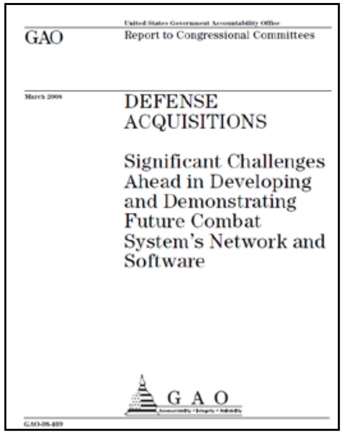
There appears to be some overlap in the challenge set for these two types of projects

Large-Scale Project Challenges (NRO)

1. **Overzealous Advocacy**
2. **Immature Technology**
3. **Lack of Corporate Roadmaps**
4. **Requirements Instability**
5. Ineffective Acquisition Strategy and Contractual Practices
6. **Unrealistic Program Baselines**
7. **Inadequate Systems Engineering**
8. Inexperienced Workforce and High Turnover

SoS Project Challenges (INCOSE)

1. System elements operate independently
2. **System elements have different life cycles**
3. **The initial requirements are likely to be ambiguous**
4. **Complexity is a major issue**
5. **Management can overshadow engineering**
6. **Fuzzy boundaries cause confusion**
7. SoS engineering is never finished


GAO

Report to Congressional Committees

DEFENSE ACQUISITIONS

Significant Challenges Ahead in Developing and Demonstrating Future Combat System's Network and Software

GAO

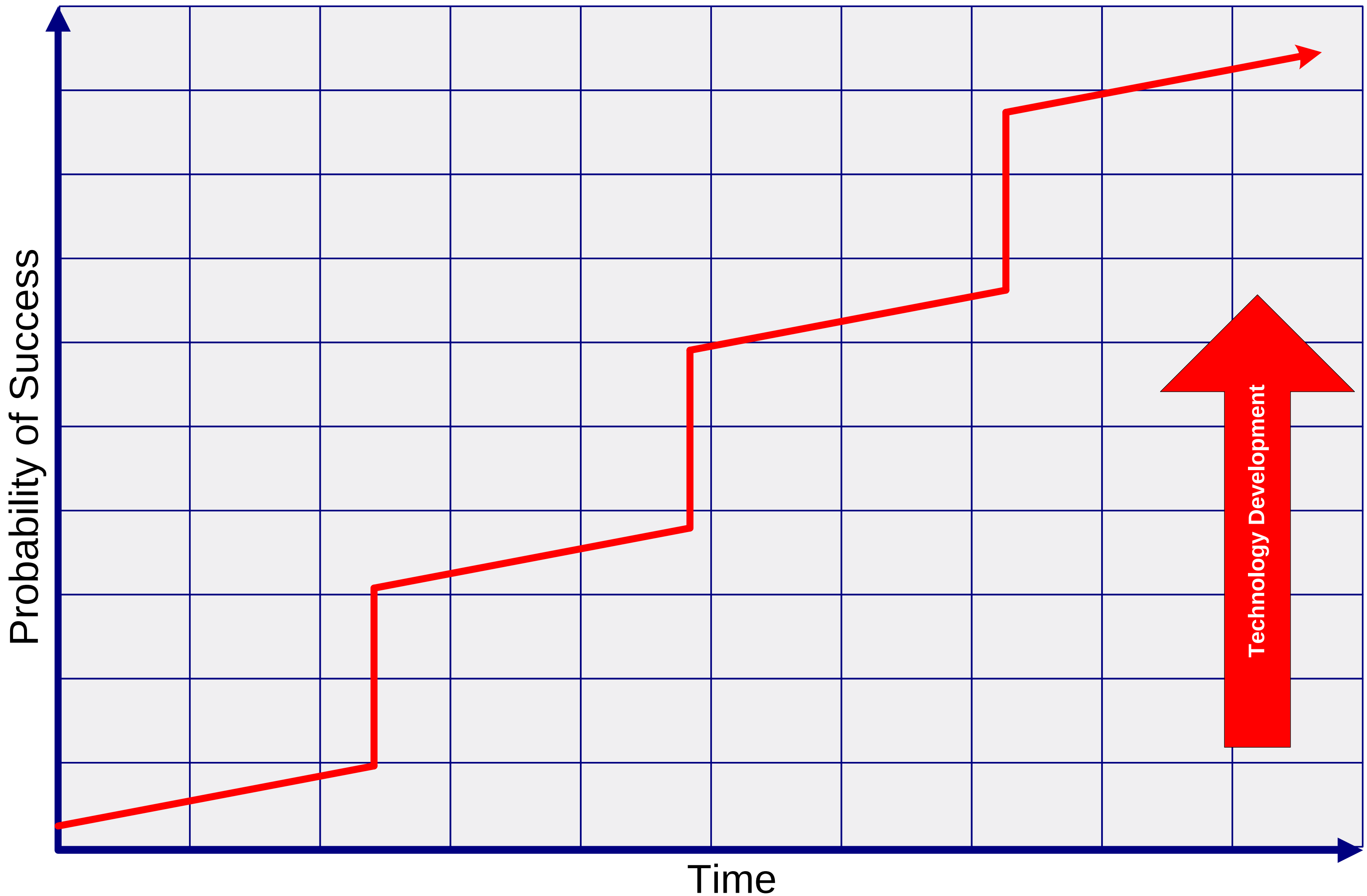
Software Practices Have Been Adopted, but Implementation Has Been Hampered by Evolving Requirements

The Army and LSI have adopted a number of disciplined software practices, but their effective implementation at the software developer level has been hampered by evolving system-level requirements. In accordance with CMMI[13] and under the advisory of the Software Engineering Institute, the Army and LSI have adopted software practices that are known to be successful in fostering quality software development, such as disciplined processes, structured management review processes, and an "evolutionary" development process. In our analysis of five FCS software developers, we found that requirements management was the cause of most problems, indicating that a key practice for managing and developing requirements has not been effectively implemented for the five software packages reviewed.

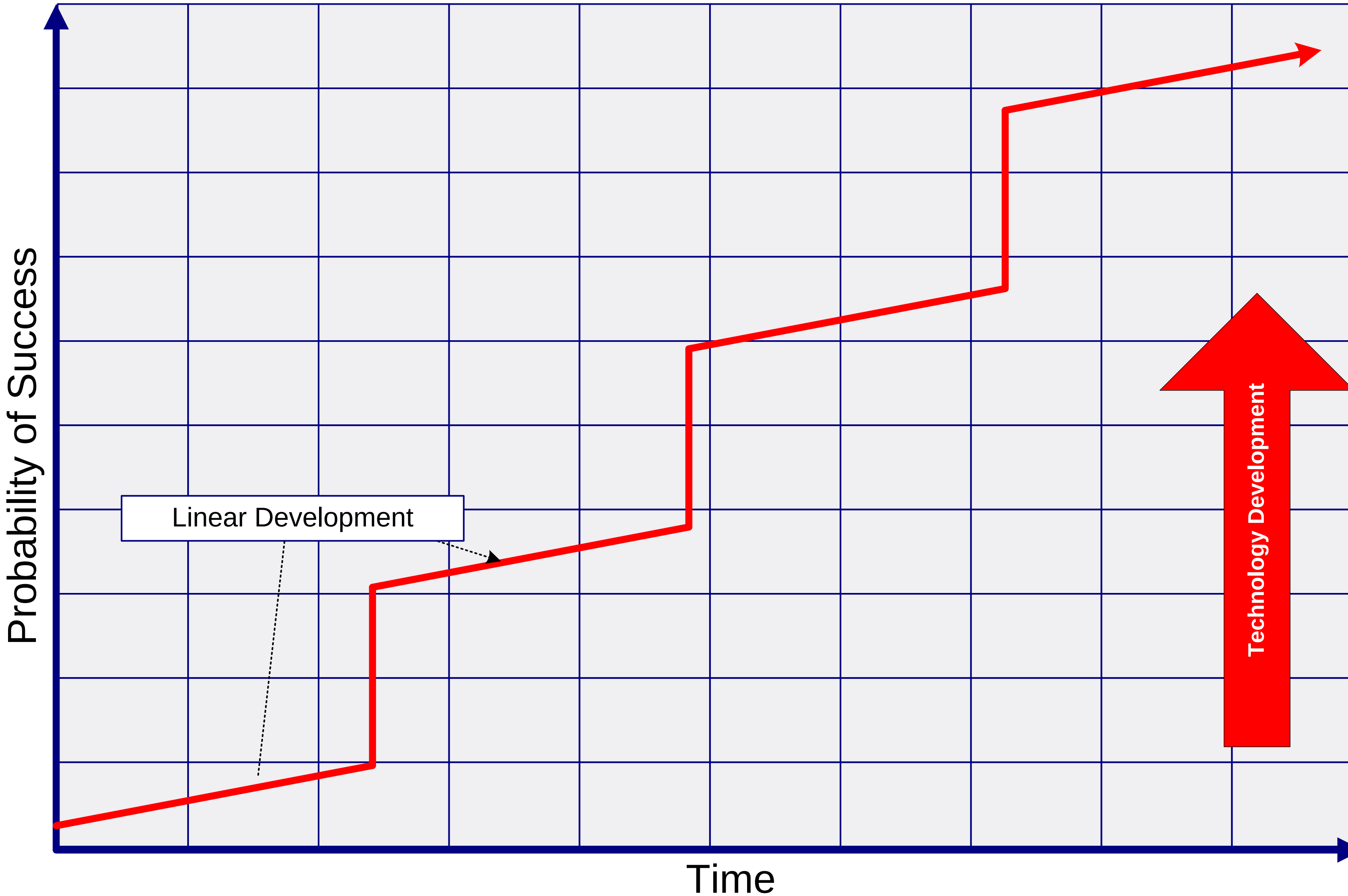
"It is tradition in this untraditional software field for everyone to do things his own way. We are still in the prehistoric age."

Robert N. Britcher

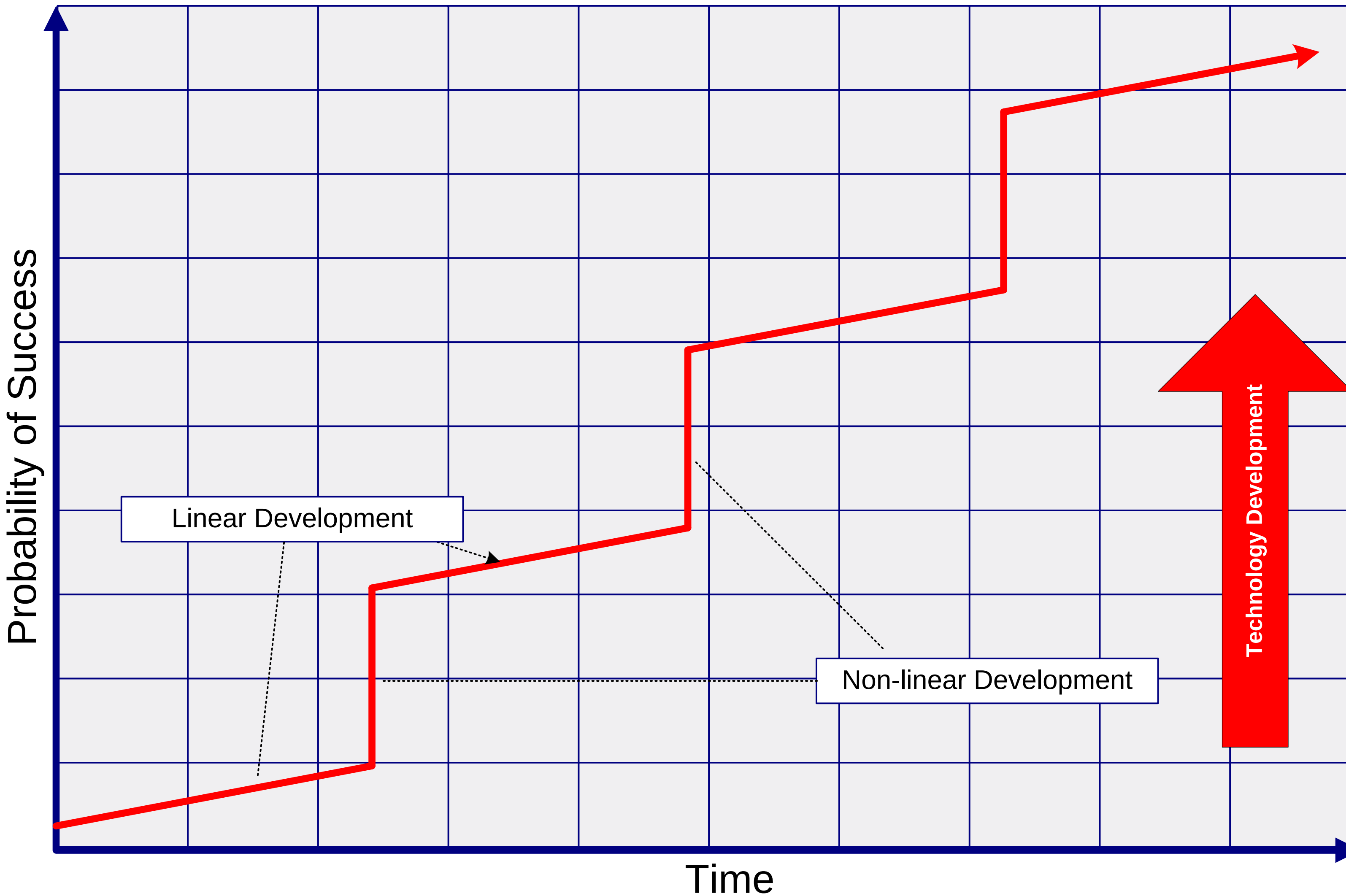
We know that projects use technology and technology changes over time…



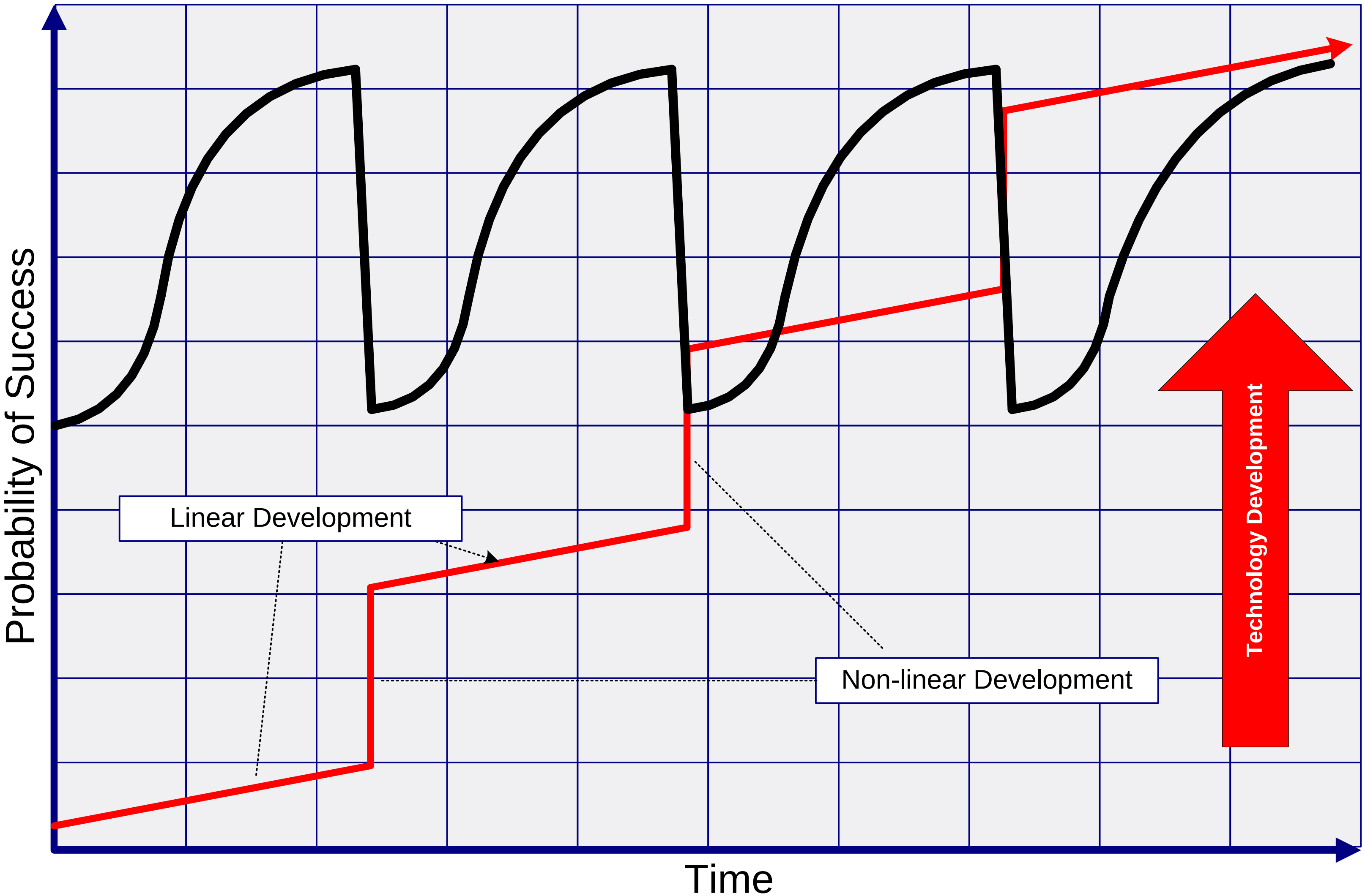
Normally the progression of technical capabilities is predictable and widely understood…



But, technical advancement is not always linear, planned, predicted, controlled, understood, or acknowledged…



Those project managers that attempt to build with new technology bare the greatest risk



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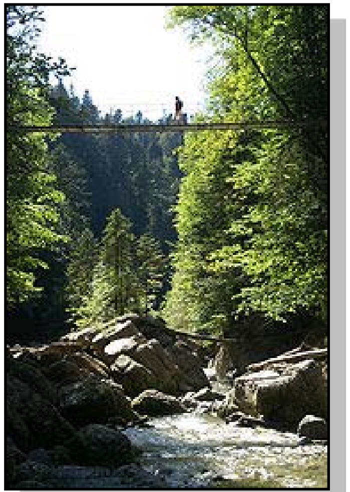
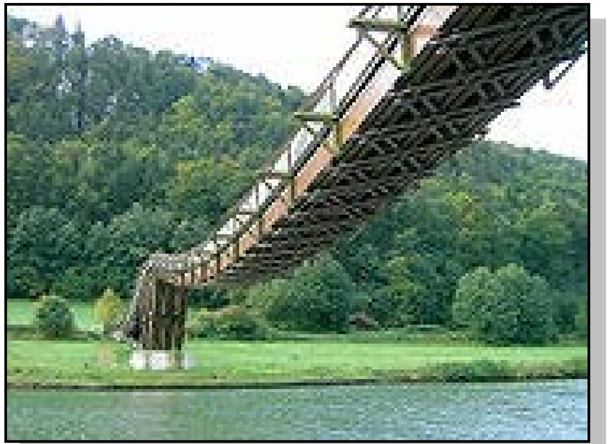
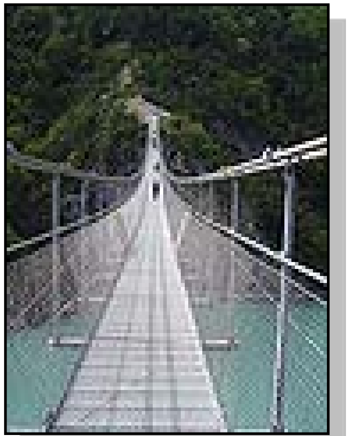
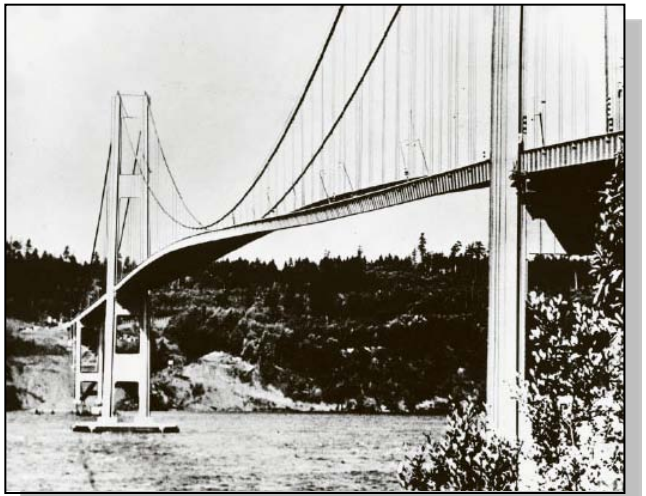
Perhaps the progression of bridge building through the ages might provide useful insights

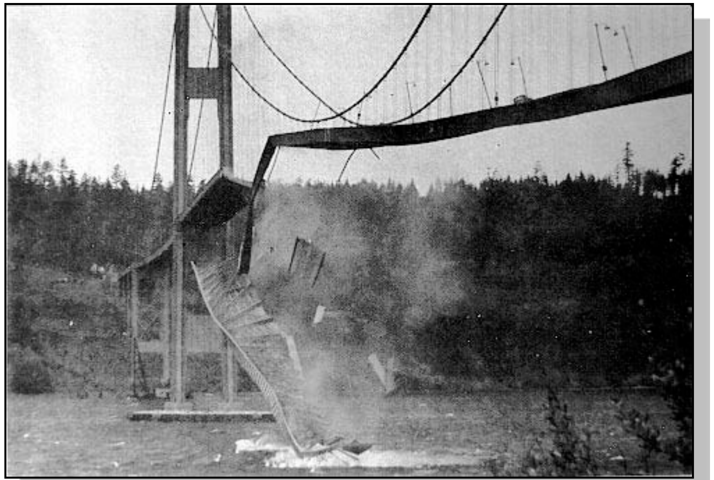




New technical capabilities such as steel and calculus created opportunities and threats

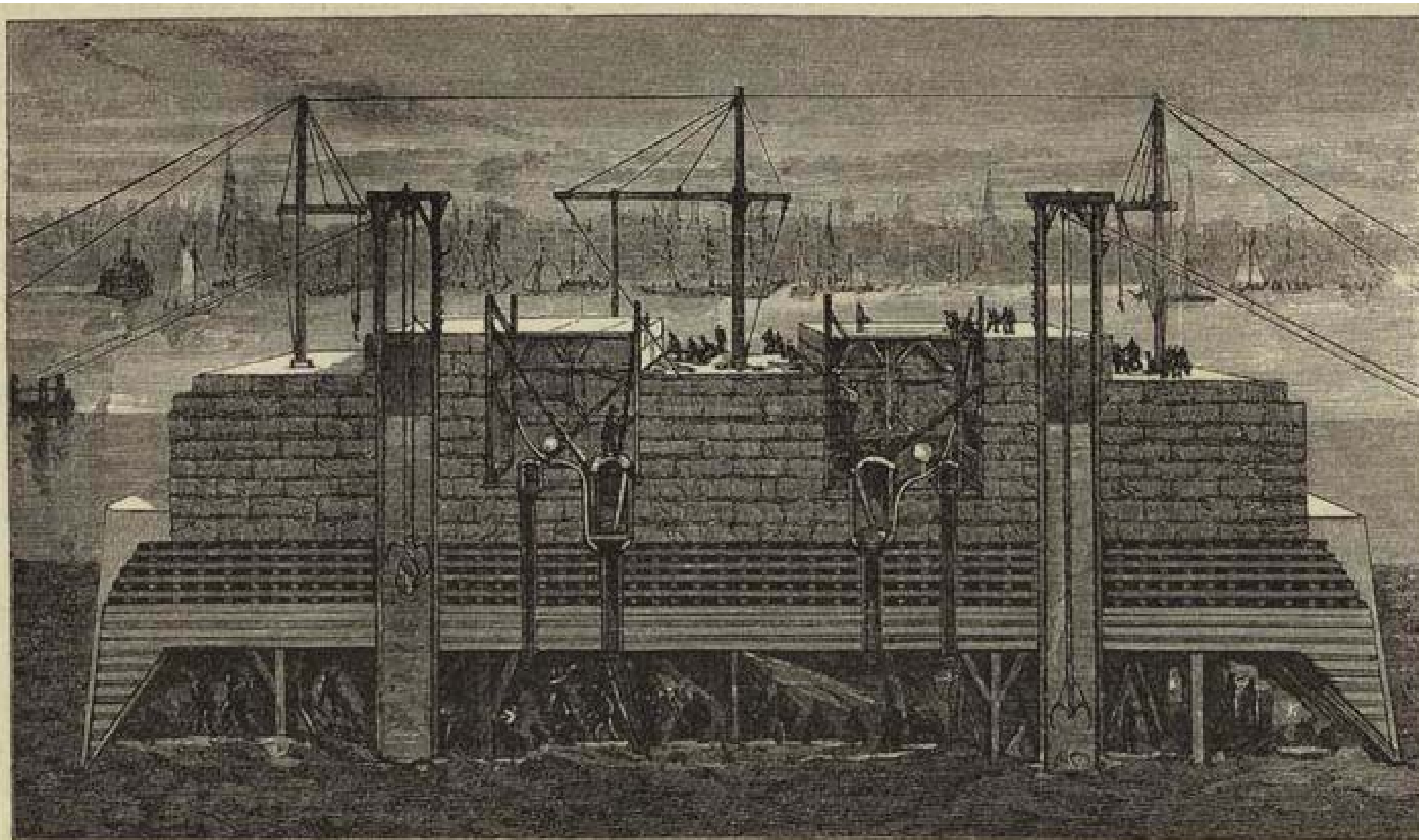




The Brooklyn Bridge Project exhibited many of the challenges we see with Large Scale, SoS projects today

- Project Duration: 14 years
  - Construction began: January 3, 1870
  - Opening date: May 24, 1883
- Length: 5,989 feet
  - Longest in the world by 50%
  - Remained the longest for 20 years
- Cost: $16,000,000 ($270M today)
- Builders: John Roebling, then Washington & Emily Roebling

The bridge was a very dangerous project, especially for the project manager



THE CAISSON.

HM May 1883 Building Brooklyn Bridge

There were several key enablers of success for the Brooklyn Bridge Project

- Project management
  - "Owned" the design and implementation
  - Excellent succession planning
  - Leadership
- Technical leadership
  - Detailed designs developed prior to construction
  - Understood the risks
- Engineering management
  - Used the best practices of that time
  - Highly respected

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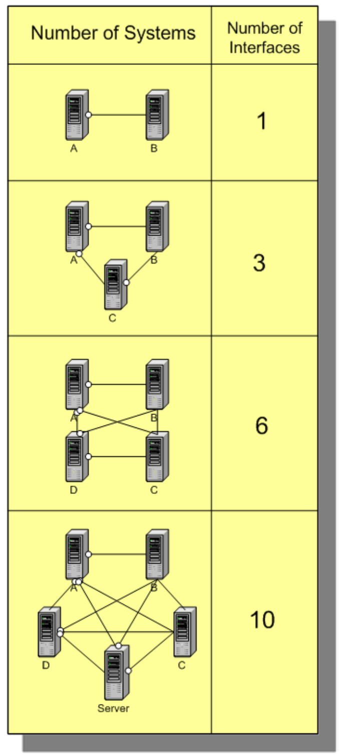
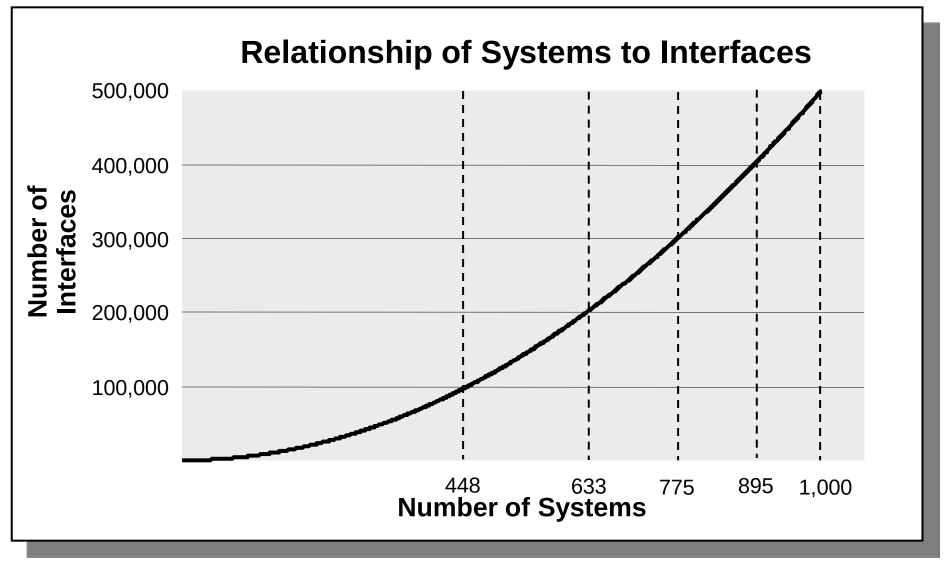
Interface management, as part of Product Integration (PI), becomes more difficult with each added system

- A critical aspect of product integration is the management of internal and external interfaces of the products and product components to ensure compatibility among the interfaces. Attention should be paid to interface management throughout the project. *

- Large-scale SoS projects have difficulty managing interfaces because –
  - Size/scale
  - Unpredictable
  - Uncontrollable
  - Poorly understood

- If it is difficult to manage a big project when the external environment is stable, it is infinitely more difficult to do so when it is changing.

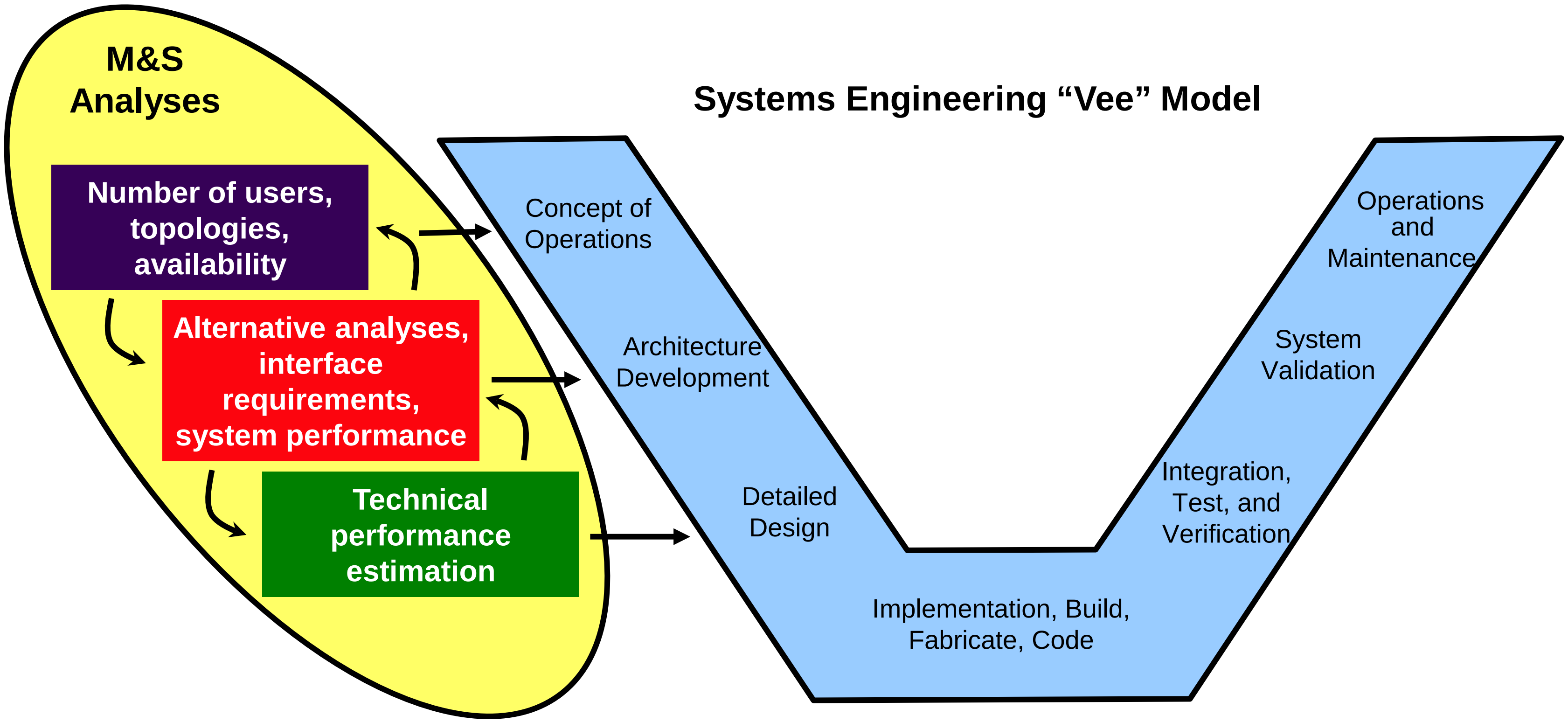




* CMMI for Development, Version 1.2, (Product Integration Process Area)

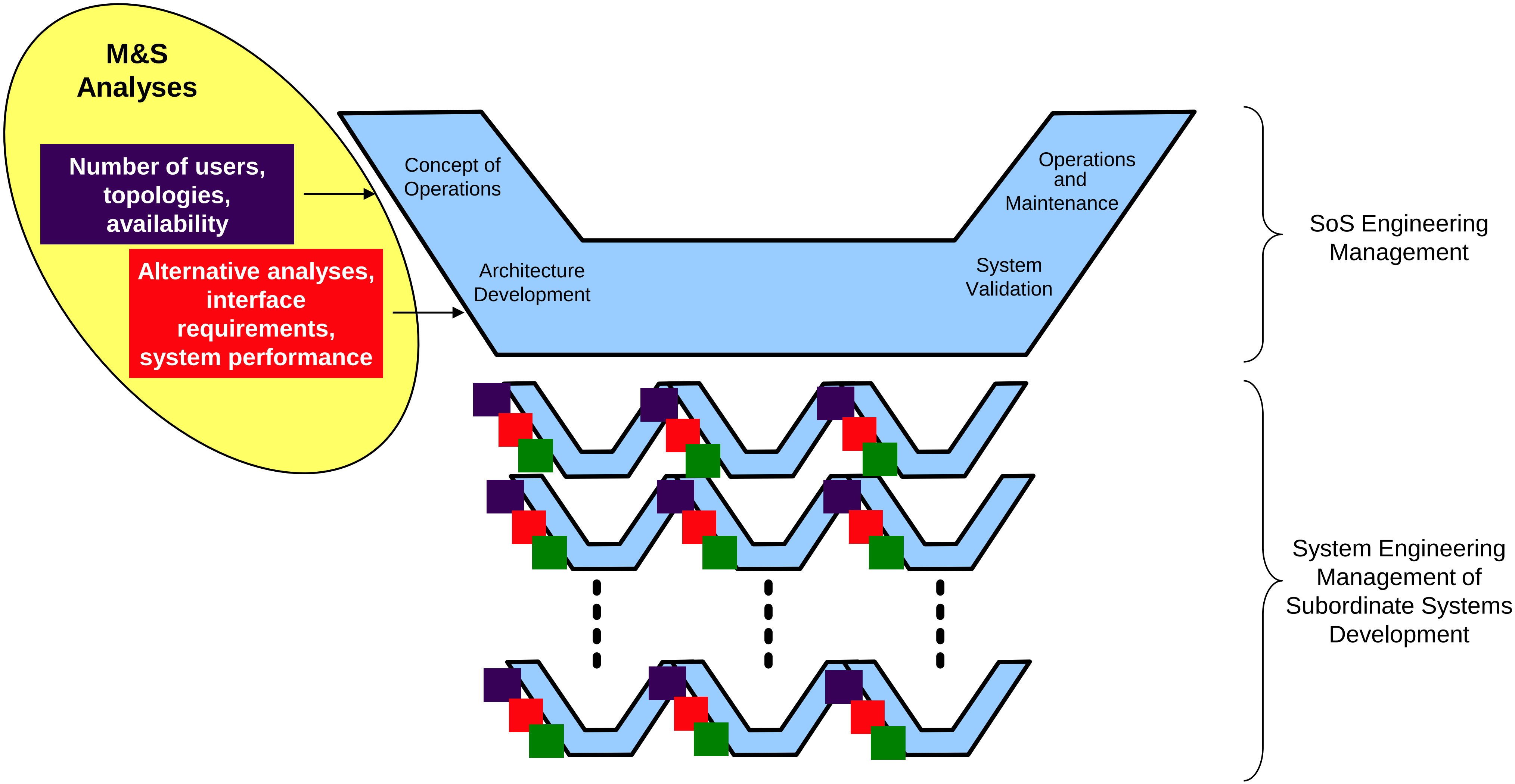
Modeling and Simulation (M&S) is a primary method used for Decision Analysis and Resolution (DAR) in the overall SE process *

- M&S can reduce risk throughout the SE process, especially during the early phases of the project.



* CMMI for Development, Version 1.2, (DAR Process Area)

High quality M&S becomes much more difficult when developing a large-scale, SoS



CMMI capability levels can be adapted to help manage greater complexity

General Structure of the Capability Levels for each Process Area

Performed	Managed	Defined	Quantitatively Managed	Optimized
Specific Practice 1 Specific Practice n Generic Practice 1 Generic Practice n	Generic Practice 2 Generic Practice n	Generic Practice 3 Generic Practice n	Generic Practice 4 Generic Practice n	Generic Practice 5 Generic Practice n

- Parse the capability levels –
  - People: *what specific staff need to be in place to achieve the planned performance?*
  - Process: *what are the specific process results that will indicate success?*
  - Tools: *what specific tools will be needed to perform the process?*
  - Documentation: *what specific document should be produced?*
- Apply the capability level at both the system (project) level and SoS level (program, enterprise)

For each process area, the capability levels can be refined such that organization-specific metrics can be identified

	1. Performed		2. Managed		3. Defined		4. Quantitatively Managed		5. Optimized	
People	Specific Practice 1 Specific Practice n	System	Generic Practice 2 Generic Practice n	System	Generic Practice 3 Generic Practice n	System	Generic Practice 4 Generic Practice n	System	Generic Practice 5 Generic Practice n	System
	Generic Practice 1 Generic Practice n	SoS		SoS		SoS		SoS		SoS
Process	Specific Practice 1 Specific Practice n	System	Generic Practice 2 Generic Practice n	System	Generic Practice 3 Generic Practice n	System	Generic Practice 4 Generic Practice n	System	Generic Practice 5 Generic Practice n	System
	Generic Practice 1 Generic Practice n	SoS		SoS		SoS		SoS		SoS
Tools	Specific Practice 1 Specific Practice n	System	Generic Practice 2 Generic Practice n	System	Generic Practice 3 Generic Practice n	System	Generic Practice 4 Generic Practice n	System	Generic Practice 5 Generic Practice n	System
	Generic Practice 1 Generic Practice n	SoS		SoS		SoS		SoS		SoS
Documentation	Specific Practice 1 Specific Practice n	System	Generic Practice 2 Generic Practice n	System	Generic Practice 3 Generic Practice n	System	Generic Practice 4 Generic Practice n	System	Generic Practice 5 Generic Practice n	System
	Generic Practice 1 Generic Practice n	SoS		SoS		SoS		SoS		SoS

Example 1 – Product Integration, Level 1, *Documentation Requirements*

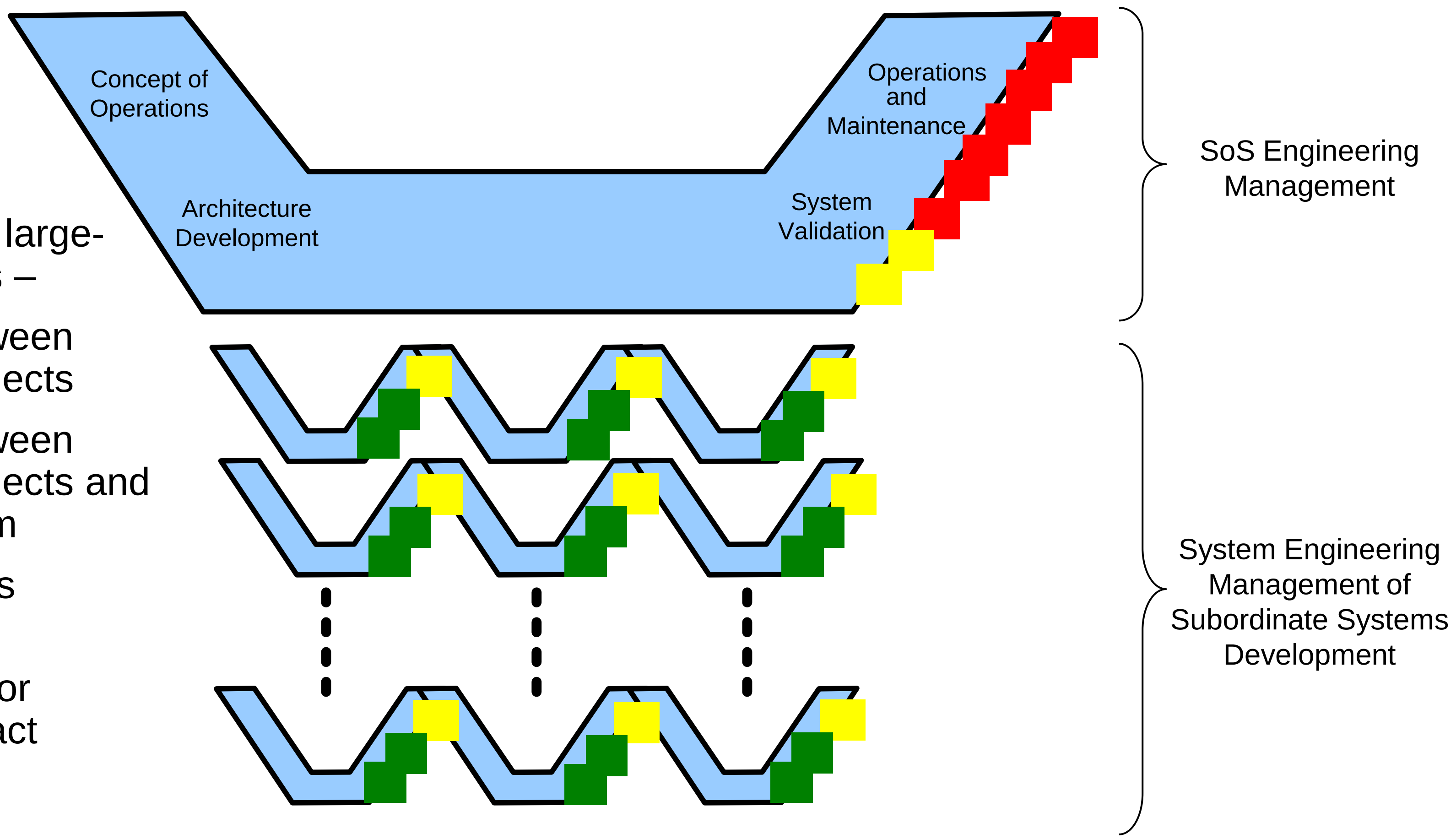
- Integration Plan
- Integration Procedures
- Integration Criteria

Example 2 – Product Integration, Level 5, *People Requirements*

- PI staff understand and contribute to process optimization activities
- Appropriately skilled and trained staff are assigned to monitor PI, support root cause analyses, and implement PI process improvements.

Product Integration (PI) processes might be more quickly assessed and problem areas targeted for improvement

- PI challenges with large-scale SoS projects –
  - Disconnect between subordinate projects
  - Disconnect between subordinate projects and the SoS program
  - Disjoint business practices
  - Diverse vendor or integrator contract requirements



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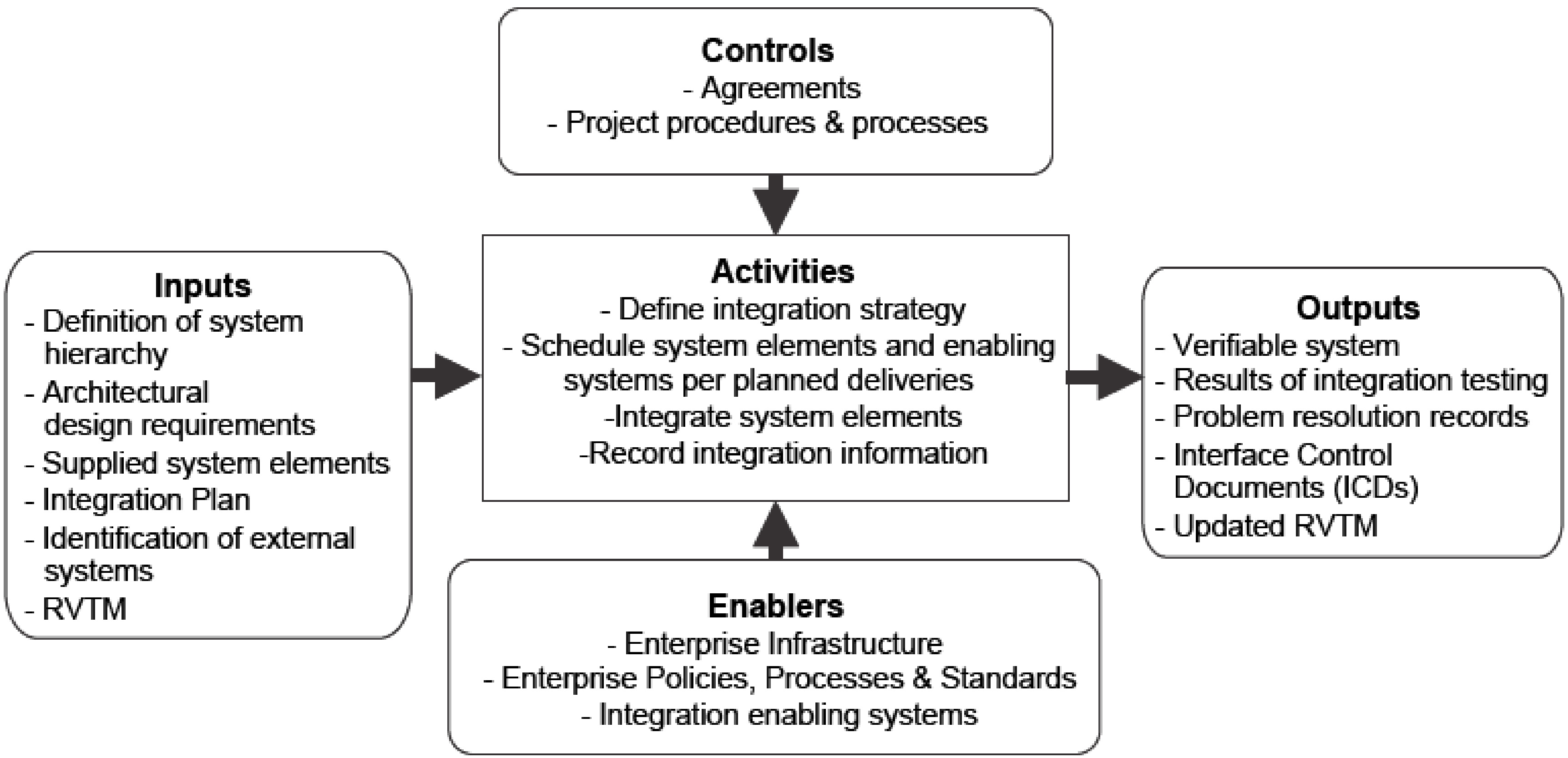
Business Process Management (BPM) technology might be used to better plan and manage large-scale, SoS projects

- Common BPM capabilities allow for –
  - Modeling a process, typically in a graphical format
  - Integrating a variety of processes, external applications, and databases with the defined process
  - Managing step-by-step process execution across multiple personnel roles
  - Creating exception handling and alternative processes
  - Monitoring the health and fulfillment cycle of the process
  - Assigning roles to personnel either by user direction within the process or based on current workload queues
  - Collecting metrics on process execution
  - Simulating the execution of the defined process based on either empirical results or user-provided parameters

As an example, we can use the PI process

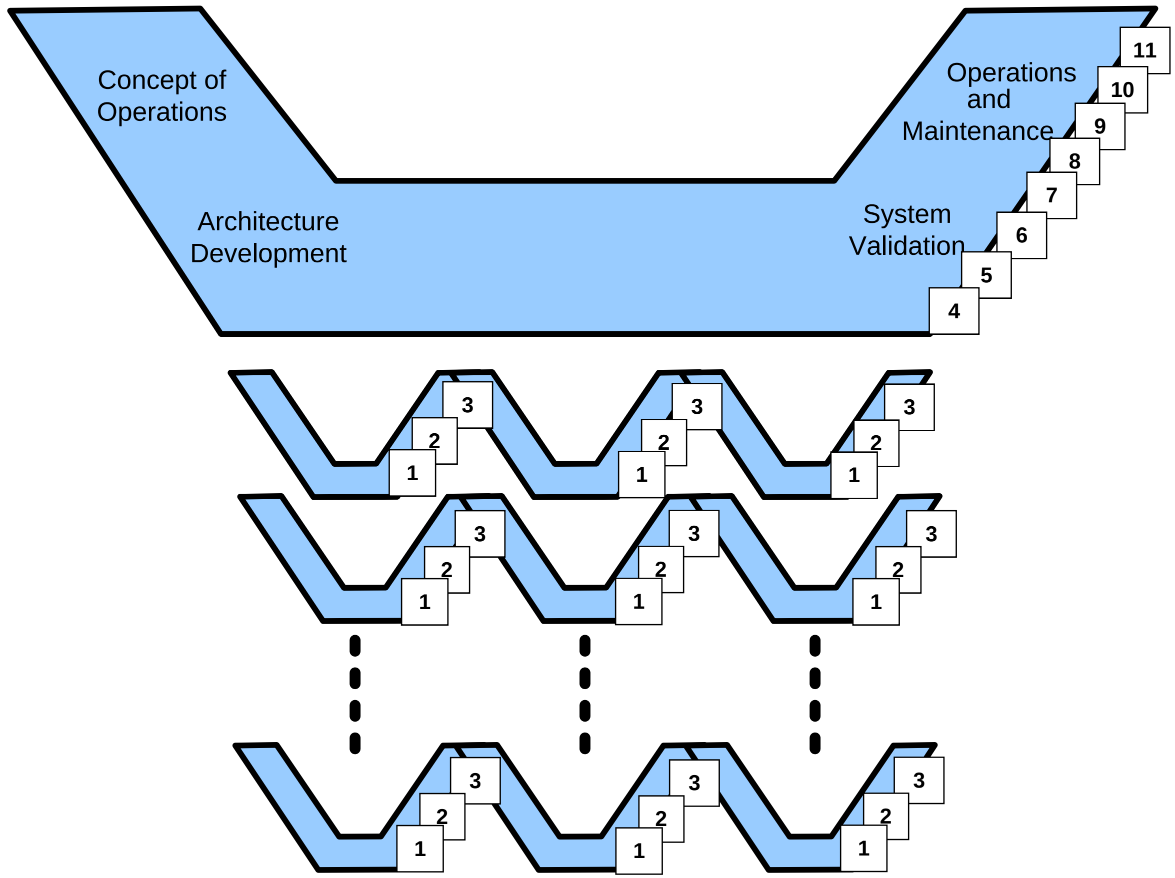
Context Diagram for the Integration Process *



* INCOSE Systems Engineering Handbook, v.3.1

Since integration processes must occur at each level of the SoS hierarchy, they can be modeled to support project planning

- Level of Effort (LOE)
- Documentation
- Review cycles
- Staffing requirements to Quantitatively Manager and/or Optimize
- Tool and database requirements
- Organizational issues and communications flow



In summary…

- Large-Scale, SoS projects are challenged on many fronts.
- Project Managers are not equipped to make excellent decisions.
- One key issue is that standard processes tend to break down.
- Large-Scale, SoS projects are much more complicated and therefore the planning (i.e., project modeling) and management (i.e., monitoring, assessments, control, improvement) of engineering processes must also be more sophisticated.
- The CMMI community can help with this problem by adapting proven methodologies so that they can be readily applied to these larger projects.

I am happy to take your questions and look forward to hearing your thoughts!