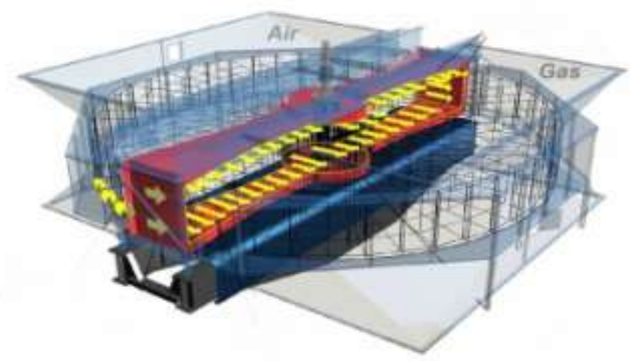

SYSTEMS ENGINEERING FOR IT AND SOFTWARE PROFESSIONALS

9th Annual IEEE/ACM Information Technology Professional Conference
The College of New Jersey
March 14, 2014

Brian Berenbach, ESEP
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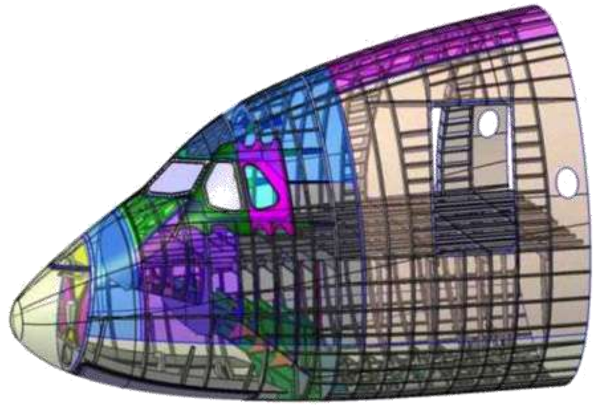

Agenda

- What is Systems Engineering?
- What is “Systems Thinking”?
- Why Do We Need Systems Engineering?
- What Exactly Do Systems Engineers Do?
- How Does It Differ From Software Engineering/IT?
- What Tools Do Systems Engineers Use?
- An Example Of Systems Thinking…
- How Can Software Professionals Transition To SE?
- Wrapup

What is Systems Engineering?

"Systems engineering is a discipline that concentrates on the design and application of the whole (system) as distinct from the parts.

It involves looking at a problem in its entirety, taking into account all the facets and all the variables and relating the social to the technical aspect".*

*Federal Aviation Administration [USA], *Systems Engineering Manual*

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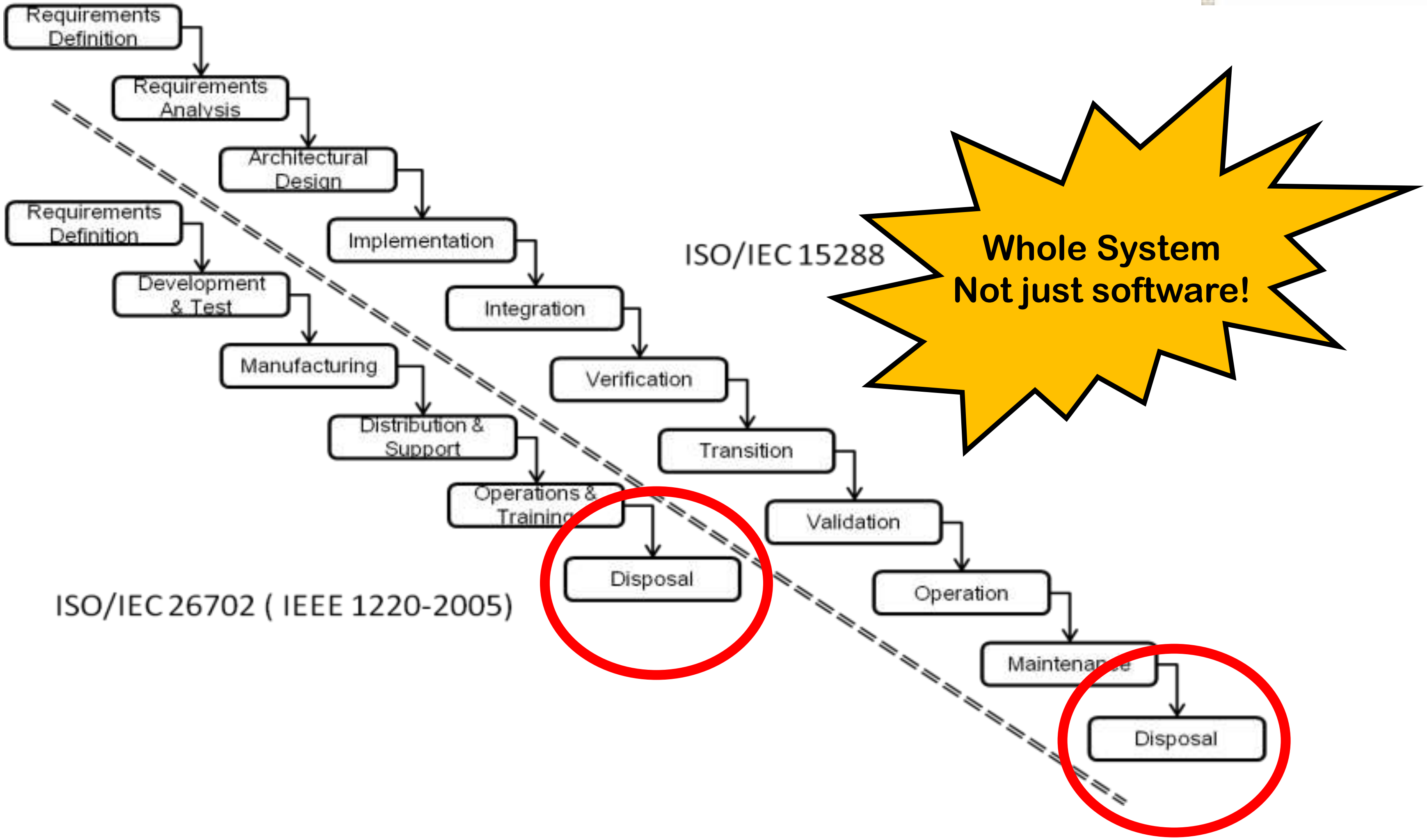
Systems Engineering Lifecycle



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Operating US Nuclear Plants

A - C	D - L	M - Q	R - W
Arkansas Nuclear 1	D.C. Cook 1	McGuire 1	River Bend 1
Arkansas Nuclear 2	D.C. Cook 2	McGui[illegible] 2	Robinson 2
Beaver Valley 1	D[illegible]-Besse	Mill[illegible] 2	Saint Lucie 1
Beaver Valley 2	Di[illegible]	[illegible] 3	Saint Lucie 2
Braidwood 1	Dia[illegible]	[illegible]	Salem 1
Braidwood 2	[illegible]	[illegible]	Salem 2
Browns Ferry [illegible]	[illegible]	[illegible]	[illegible]ok 1
Browns Ferry 2	[illegible]	[illegible]	[illegible]oyah 1
Browns [illegible]	[illegible]	[illegible]	[illegible]
Brunswick 1	[illegible]	[illegible]	[illegible]exas 1
Brunswick 2	[illegible]	[illegible]	[illegible] Texas 2
Byron [illegible]	[illegible]	[illegible]	[illegible]
Byron 2	[illegible]	[illegible]	[illegible]y 1
Callaway	[illegible]	[illegible]	[illegible]
Calvert Cliffs 1	[illegible]	[illegible]	[illegible]quehanna 1
Calvert Cliffs 2	[illegible]	[illegible]	[illegible]uehanna 2
Catawba 1	[illegible]	[illegible]	[illegible]ile Island 1
Catawba 2	[illegible]	[illegible]	Turkey Point 3
Clinton	Ho[illegible]	[illegible]	Turkey Point 4
Columbia Generating Station	In[illegible]	[illegible]	Vermont Yankee
	I[illegible]n Point	Pilg[illegible]	Vogtle 1
Comanche Peak 1	La Salle 1	Point B[illegible]ch 1	Vogtle 2
Comanche Peak 2	La Salle 2	Point Beach 2	Waterford 3
Cooper	Limerick 1	Prairie Island 1	Watts Bar 1
	Limerick 2	Prairie Island 2	Wolf Creek 1
		Quad Cities 1	
		Quad Cities 2	

Not one operating U.S. Nuclear Reactor has a decommissioning plan!

The Discipline of Systems Thinking

- *"<u>Synthesis</u>, or putting things together, is the key to systems thinking just as <u>analysis</u>, or taking them apart, was the key to Machine-Age thinking… the differences between Systems-Age and Machine-Age thinking derives not from the fact that one synthesizes and the other analyzes, but from the fact that systems thinking combines the two in a new way."* (Ackoff 1999)
- *Systems thinking is a discipline for seeing wholes. It is a framework for seeing <u>interrelationships</u> rather than things, for seeing <u>patterns</u> of change rather than static snapshots… Systems thinking is a discipline for seeing the 'structures' that underlie complex situations, and for discerning high and low leverage change."* (Senge 2006)
- **The combined process of <u>Synthesis</u> (putting things together) and <u>Analysis</u> (breaking things down) is enabled by <u>Inquiry</u>, *the human process of investigation via dialogue and directed discussion of outcomes*. The combination of the three constitute the discipline of Systems Thinking.**

Definitions*

Complexity

the degree to which a system or component has a design or implementation that is difficult to understand and verify

Complex System

a system composed of interconnected parts that as a whole exhibit one or more properties (behavior among the possible properties) not obvious from the properties of the individual parts.

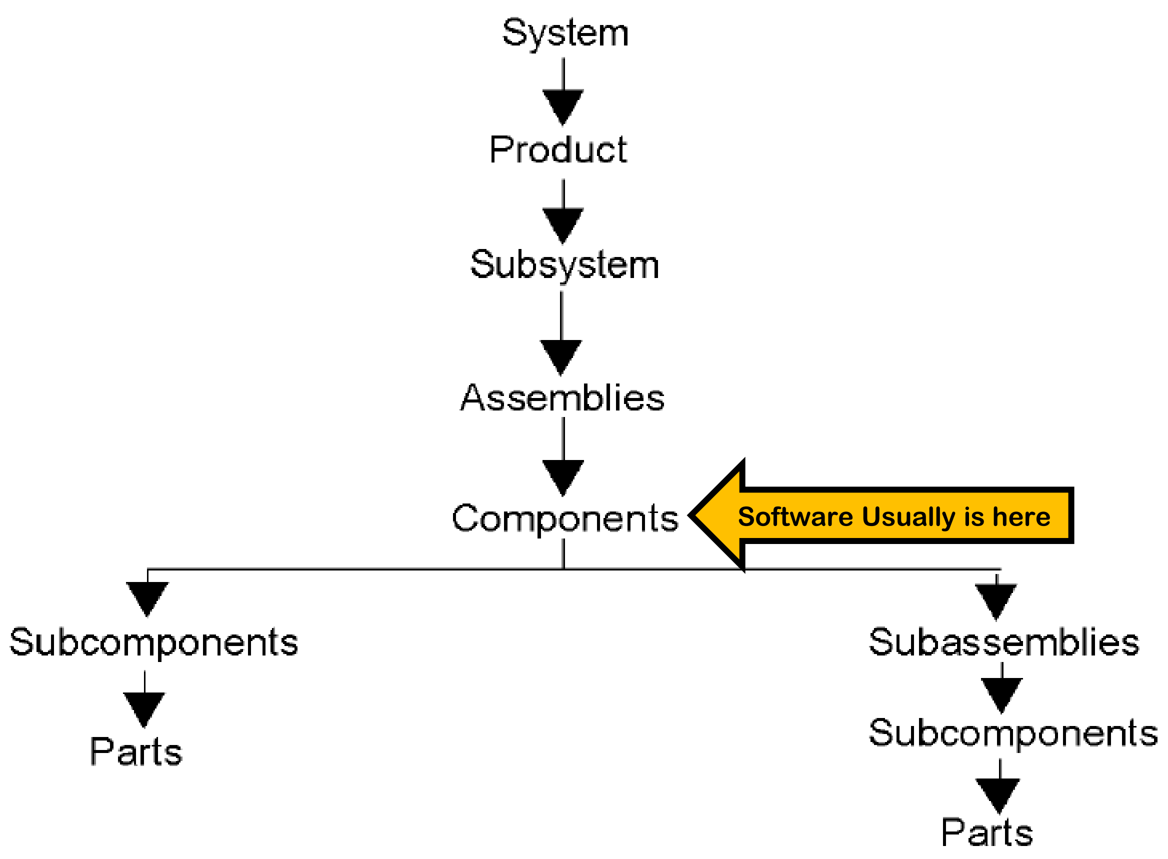
Definitions from IEEE and Cross*

System Complexity

Consider the Design of the A380 Airplane:

- It has mechanical, electrical, software (avionics) and hydraulic subsystems and components
- Initial production of the A380 was troubled by delays attributed to the 530 km (330 mi) of wiring in each aircraft. Airbus cited as underlying causes the complexity of the cabin wiring (98,000 wires and 40,000 connectors), its concurrent design and production, the high degree of customization for each airline, and failures of configuration management and change control.
- There isn't enough space for it to park at most airports
- What about 800 passengers deplaning at once? What a carousel experience!

Typical SE Decomposition*



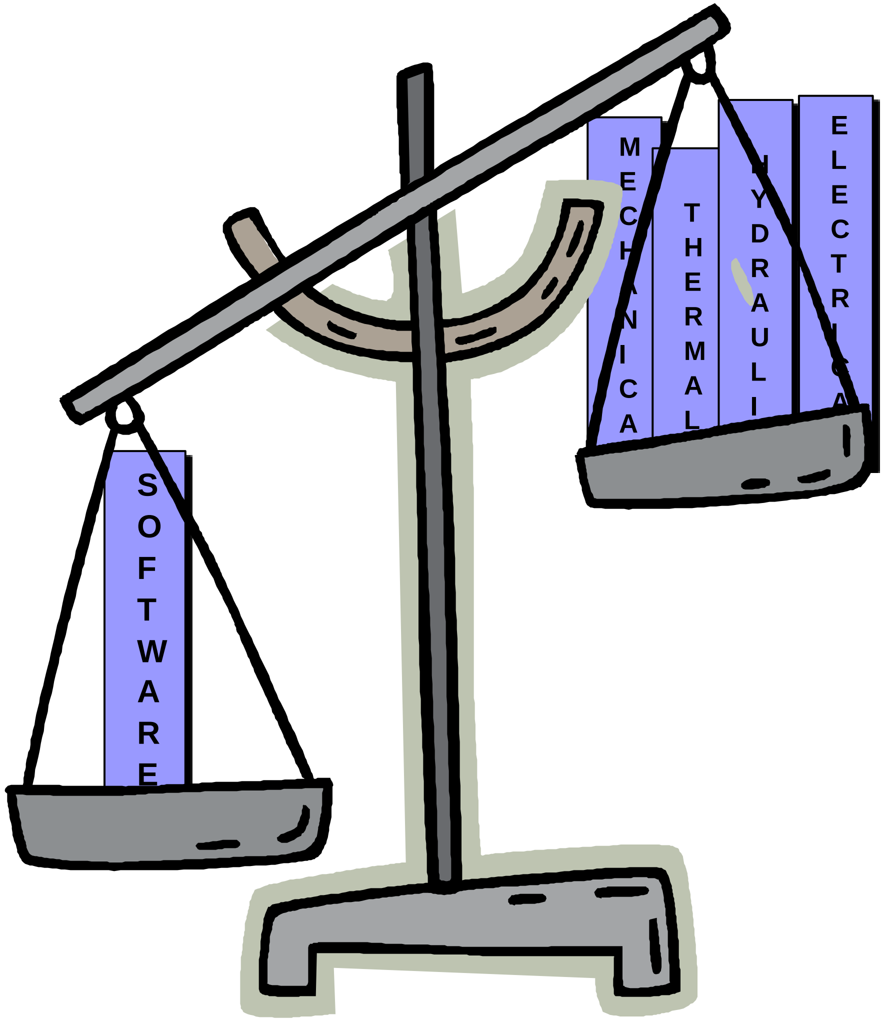
*IEEE STD1220

THE DARLINGTON FIASCO*

- "… a large staff of computer programmers was recruited and they assumed the dominant position in system design."
- "By mischance a gulf opened up right in the center of the engineering organization."
- "There were unprecedented licensing problems, and the operating license was only granted with serious reservations after the startup of the whole mega project had been delayed".

*Excerpted from a proprietary AECL Research Report (May,1994)

Potential Management Issue without SE

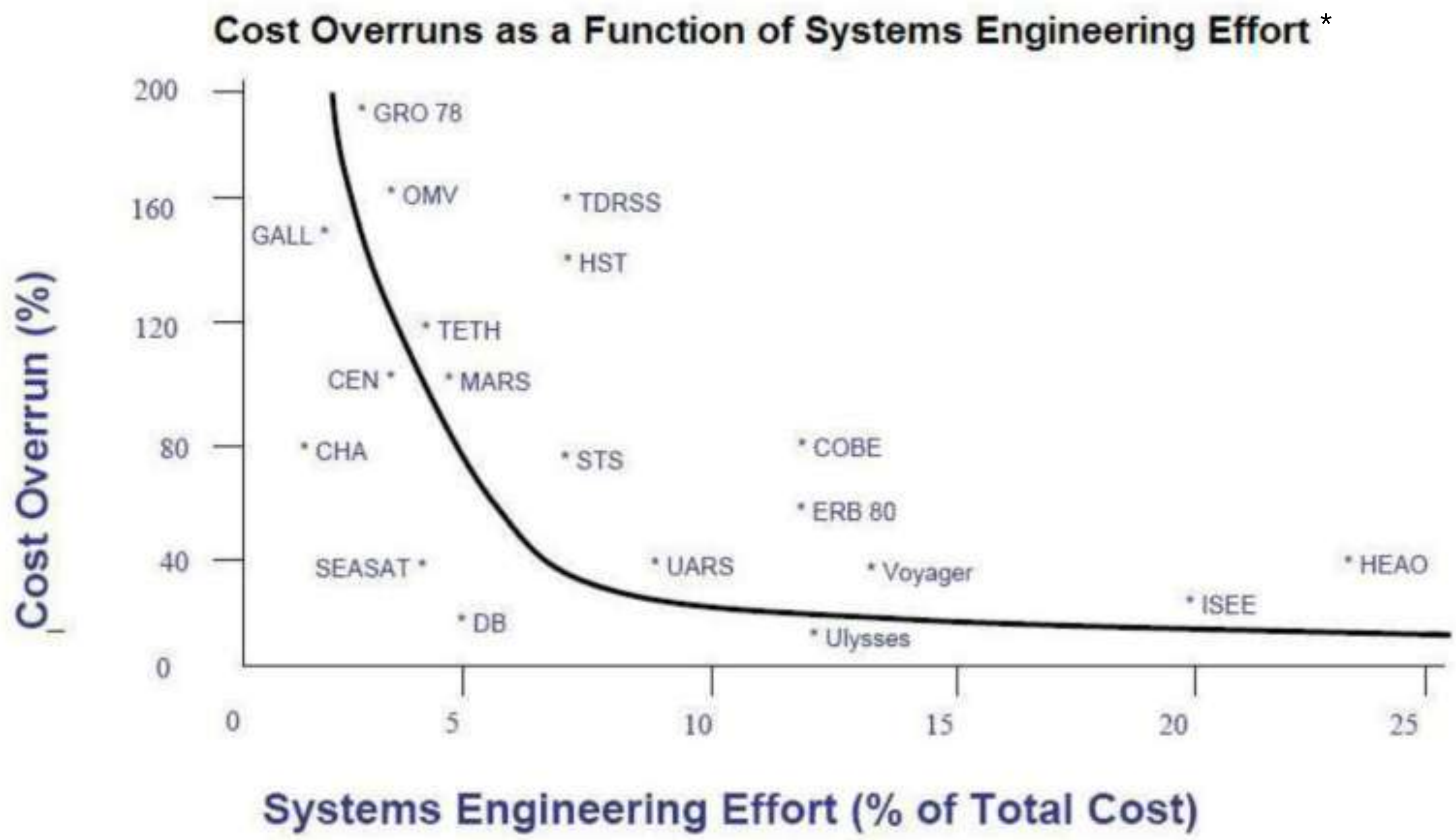


Integration of Engineering Efforts

MECHANICAL	THERMAL	HYDRAULIC	ELECTRICAL	CHEMICAL	SOFTWARE

Systems Engineering

Does SE Help?

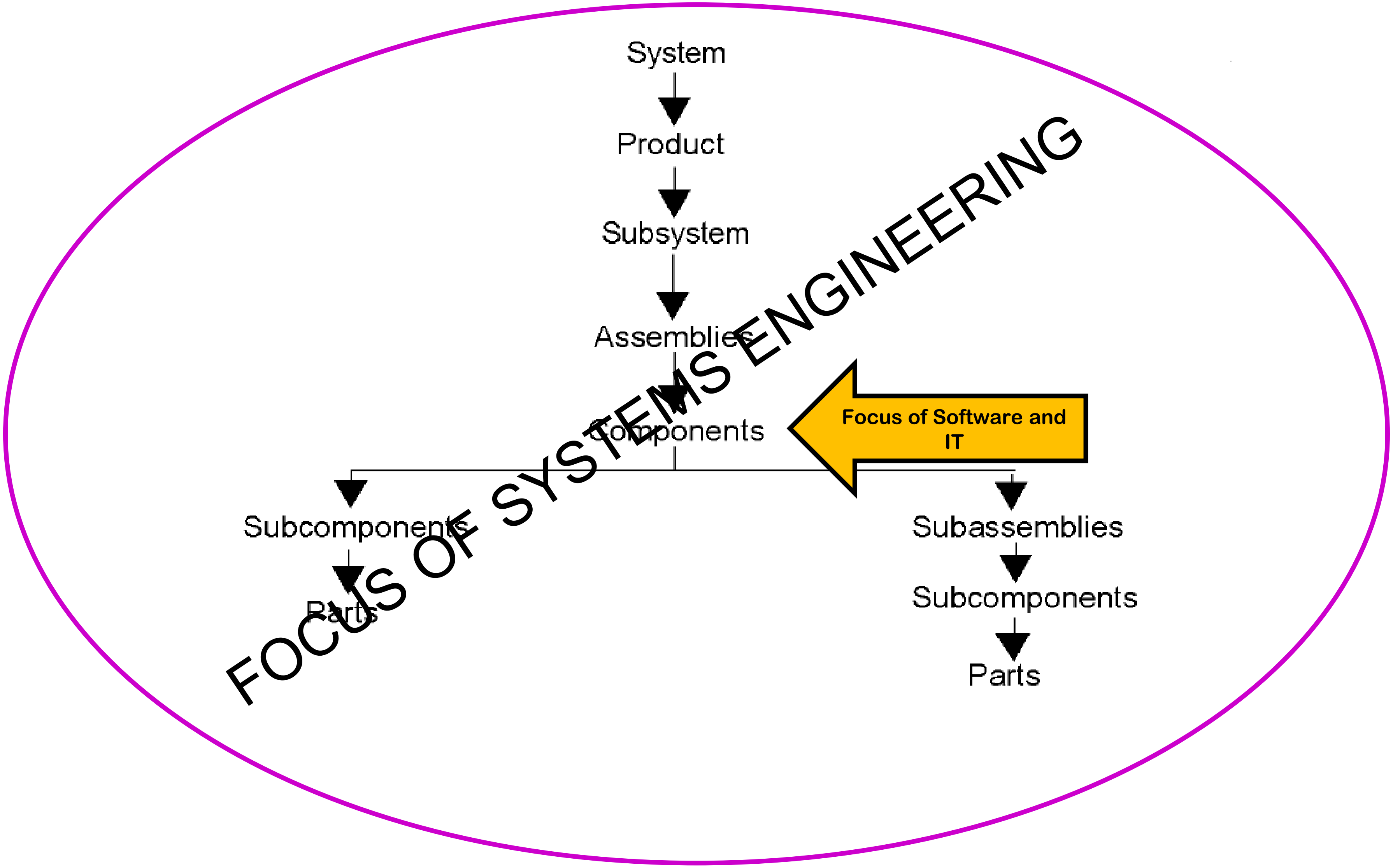


Cost Overruns as a Function of Systems Engineering Effort *
Cost Overrun (%)
200
160
120
80
40
0
0
5
10
15
20
25
Systems Engineering Effort (% of Total Cost)
* GRO 78
* OMV
* TDRSS
GALL *
* HST
* TETH
CEN *
* MARS
* CHA
* STS
* COBE
* ERB 80
SEASAT *
* UARS
* Voyager
* HEAO
* ISEE
* DB
* Ulysses

What do systems engineers do?

- Help define a conceptual vision
- Elicitation of requirements
- Analysis and vetting of requirements
- Translation of Requirements to Design
- Design Maturation
- Multidisciplinary Team Management
- Manage Technical Complexity and Details

So How Does Systems Eng. Differ from Software Eng.?



Sample Work Breakdown Structure*

Project Phases

D	Design
P	Procurement / Manufacture
I	Installation / Construction
C	Testing / Commissioning
W	Warranty

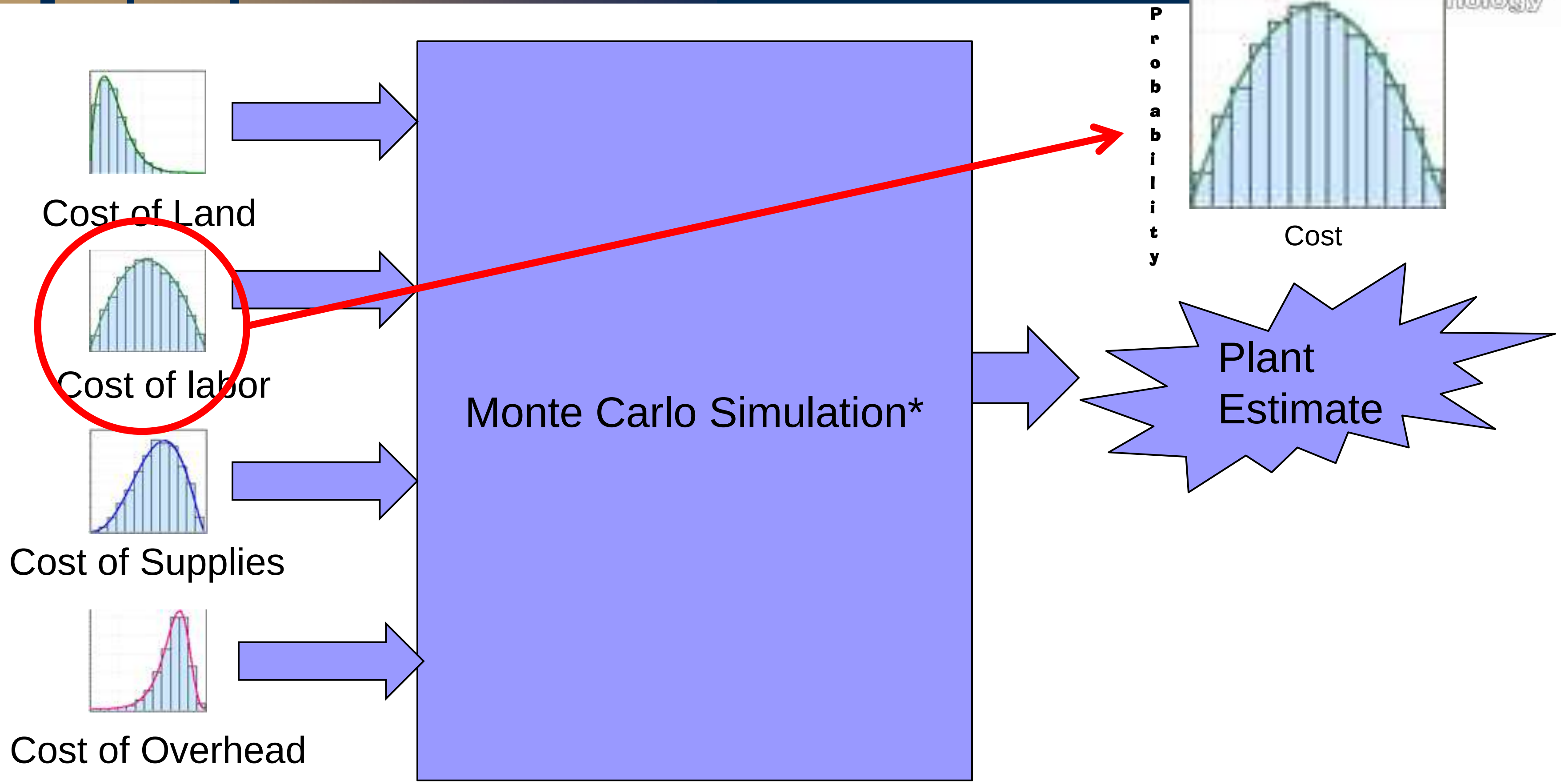
TYPICAL WORK DONE BY SYSTEMS ENGINEERING MANAGER

*Color represents responsible team or subcontractor

SE TYPICAL TOOLBOX

- Cost Estimation
- Requirements Elicitation - ConOps
- Modeling & Simulation – MonteCarlo Methods
- System Design – SysML, PDR, CDR
- Management of Complexity
- Management of Disparate Teams & Skills

Cost & Risk Estimation



*Monte Carlo methods are used for simulating systems with many coupled degrees of freedom

Concept of Operations (ConOps)

- The ConOps objective is to communicate with the end user of the system during the early specification stages to assure the operational needs are clearly understood and incorporated into the design decision database for later inclusion in the system and segment specifications

Willow Island Fertilizer Plant

Ammonium Nitrate Manufacturing

Concept of Operations

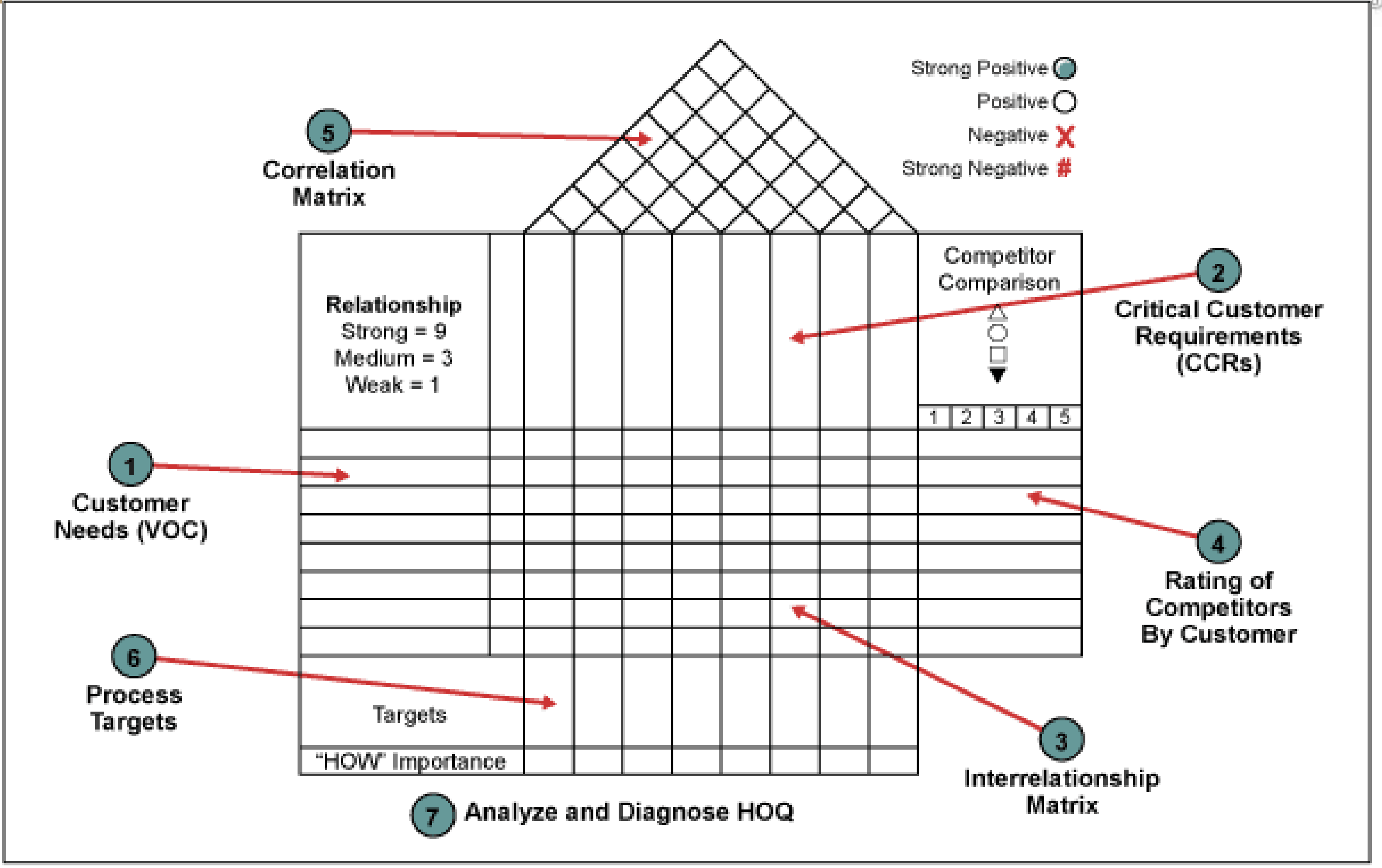
Version 1.0 Joe Smith

Pugh Matrices

- Comparative Analysis of Different options

(Feature)	Concept 1	Concept 2	Concept 3	Concept 4
Comparison to Other Brand (feature set)	3	4	1	2
Ease of Use/Workflow	3	4	5	3
Innovation (perception)	3	4	1	2
Time to Market	2	3	3	2
Reliability	2	2	3	5
Seviceability	5	1	2	3
Downward Compatibility	2	4	5	3
>$100K cost per unit	5	3	5	5
$200K or lower sale price per unit	4	2	5	2
Small Footprint	3	4	5	3
Expandable	3	4	5	4

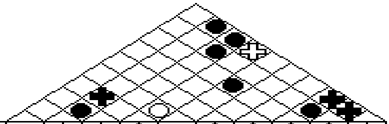
House of Quality



Sample HOQ

Auxiliary Power Unit Product Planning Matrix

Interactions:
- ✚ Strong Negative
- ✜ Moderate Negative
- ● Strong Positive
- ○ Moderate Negative

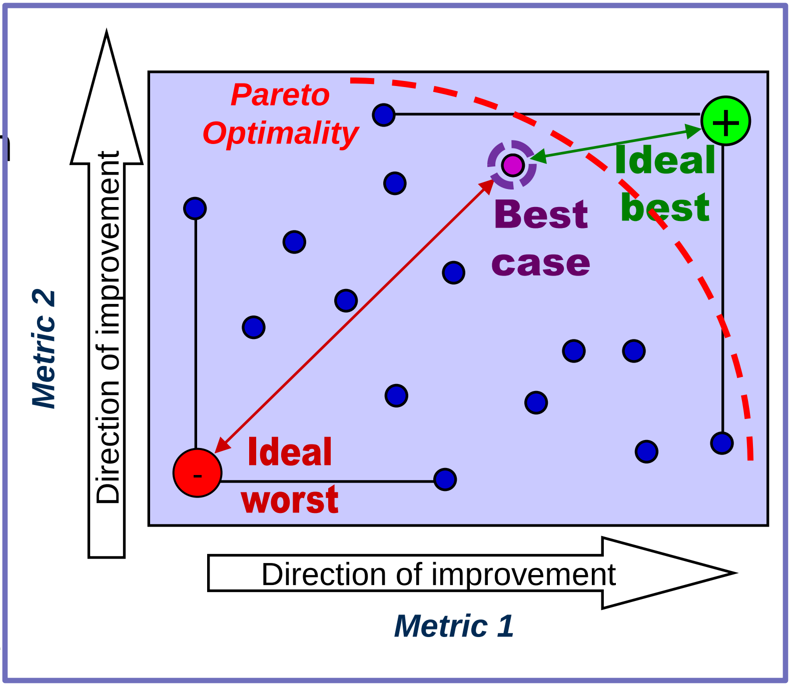


			Bleed air ducting location	Maximum APU weight	Low turbine wheel weight	High equivalent shaft horsepower	Controlled turbine inlet temp.	Bleed air	Electrical power output	Turbine assy tri-hub containment	Strong containment ring	Lightweight containment ring	Competitive Evaluation (1-Low, 5-High)
	Goal		○	↓	↓	↑	○	↑	↑	↑	↑	↓	
	Area		Physical			Operation				Contain			
	Customer Needs	**Priority**											1 3 5
Interface	Fit with customer envelop/interface	3	5								3		3: W; 4: T
Interface	Support oil-cooled generator	5		3									3: T; 4: W
Interface	Low weight	4	3	5	3					3		5	2: T; 4: W
Oper.	Provide bleed air	4	3			5	5	5					2: T; 3: W
Oper.	Provide electrical power	3				5			5				2: W; 3: T
Oper.	Operate safely	5			3		3			5	5		3: WT
	Reliable	5					5			3			3: WT
Technical Evaluation		5											
		4			W		T			T		W	
		3	W	WT	T	W	W	WT	WT	W	WT		
		2				T						T	
		1	T										
Target Value / Specification Value			Interface point A	160 lbs.	6 lbs.	350 hp	1850 degrees F	75 lbs/min.	75 KVA	2.5 lbs at power	3 lbs. at power	< 6 lbs.	
Technical Difficulty (1-Low, 5-High)			1	4	3	5	3	3	3	4	2	4	
Importance Rating			39	35	27	35	60	20	15	52	34	20	

W - We
T - They

Multi-Attribute Decision Making

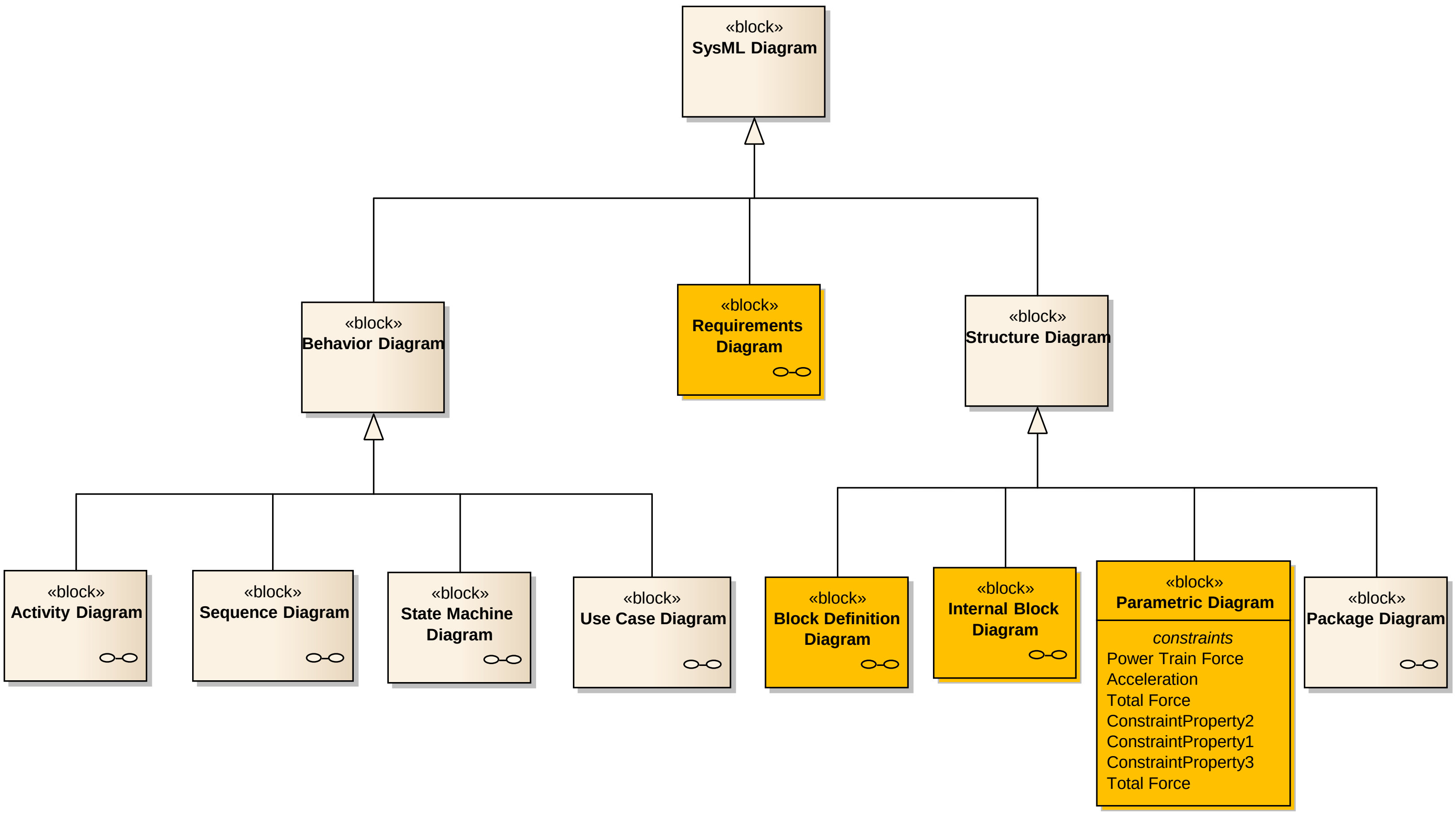
- We do not necessarily want a design which is optimized for a single metric
- Want solutions that are good in multiple dimensions; *Pareto* optimality
- One method is the Technique for Ordered Preference by Similarity to the Ideal Solution (TOPSIS)
  - Select from a range of alternative solutions
  - Uses a weighted series of criteria to identify the best and worst of each criteria and combines them into the theoretical best and worst points
  - Actual ranking is performed based on maximizing the normalized distance from the theoretical worst and minimizing the distance from the theoretical best



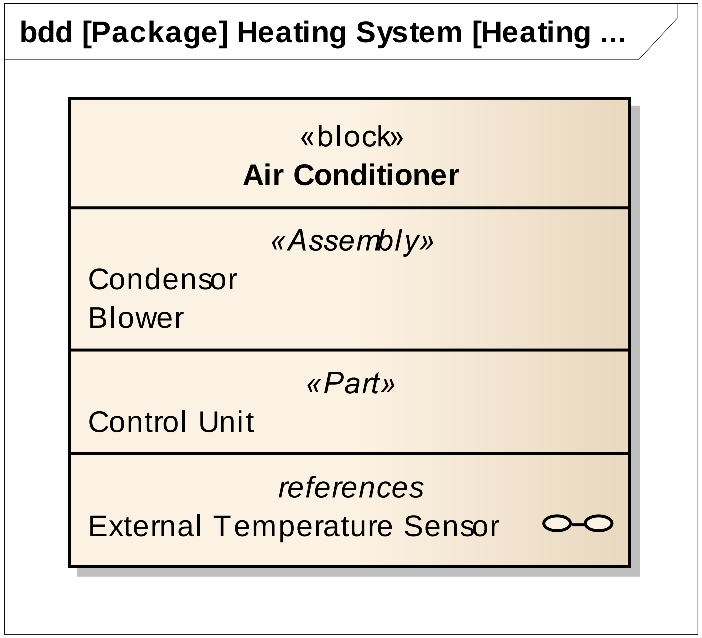
Design/Product Complexity

- Need a language to “glue” domain specific concerns together
- Need to see the “big picture”
  - Hazards & Threats
  - Requirements
    - Functional (functionality/features)
    - Non-functional
      - Environmental
      - Regulatory
  - Architecture
  - Design
  - Testing

SysML Diagram Types



Blocks are the building units of a system

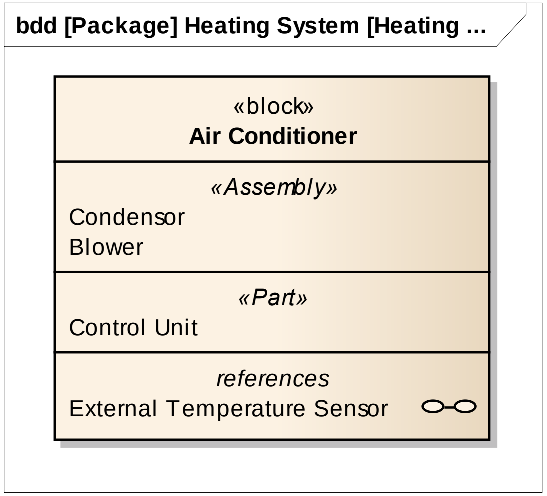


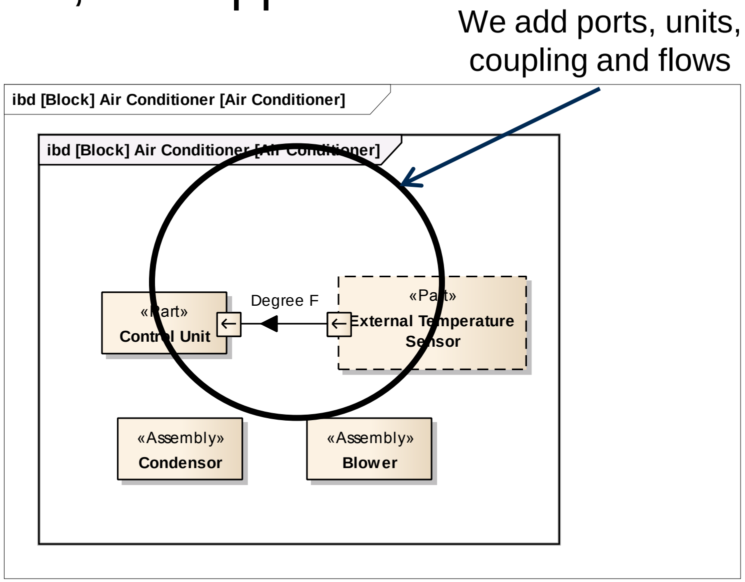
Block Properties

- A Property is a Structural Part of a Block

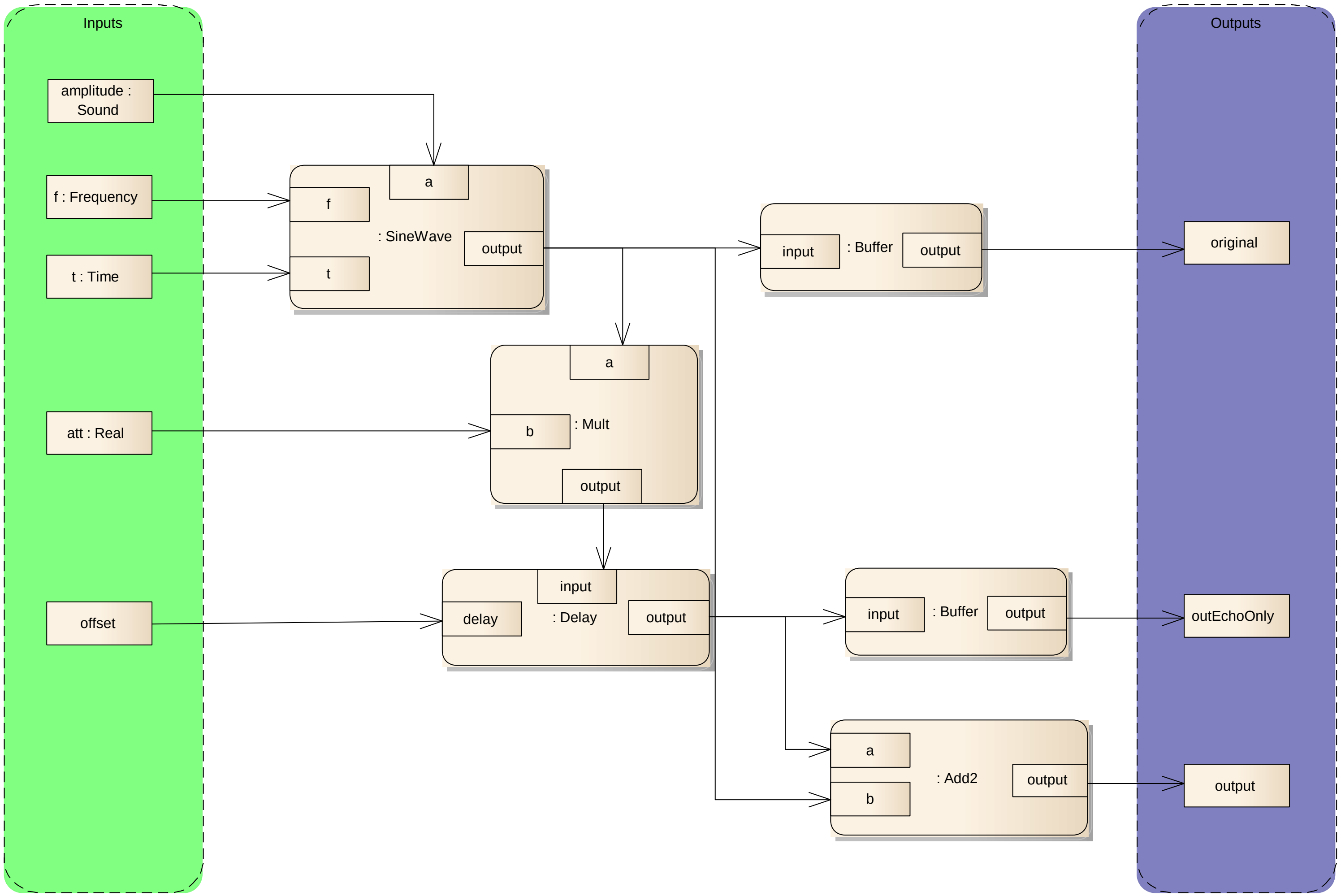
  e.g. if an air conditioner is a block, then compressor, blower, etc. would be parts of the block.

  - Properties of a block are shown on an internal block diagram, and should appear automatically in one or more block partitions
  - The partitions can, however, be suppressed.





SysML Parametric Modeling Example



Preliminary Design Review

"The preliminary design review is planned to verify and validate the set of system requirements, the design artifacts, and justification elements at the end of the first engineering loop (also known as the "design-to" gate)."

- INCOSE SeBOK

Willow Island Fertilizer Plant

Ammonium Nitrate Manufacturing

Preliminary Design Review

Version 1.0 Seok-Won Lee

Critical Design Review

"The critical design review is planned to verify and validate the set of system requirements, the design artifacts, and justification elements at the end of the last engineering loop (the "build-to" and "code-to" designs are released after this review)."

-INCOSE SeBOK

Willow Island Fertilizer Plant

Ammonium Nitrate Manufacturing

Critical Design Review

Version 1.0

Kyung-Sook Shin

PM &SEM Tension

Systems Engineering Manager

Project Manager

AN APPLICATION OF SYSTEMS THINKING

The Bhopal Disaster

“In the early hours of Monday, Dec. 3, 1984, a toxic cloud of methyl isocyanate (MIC) gas enveloped the hundreds of shanties and huts surrounding a pesticide plant in Bhopal, India. Later, as the deadly cloud slowly drifted in the cool night air through streets in surrounding sections, sleeping residents awoke, coughing, choking, and rubbing painfully stinging eyes. By the time the gas cleared at dawn, many were dead or injured. Four months after the tragedy, the Indian government reported to its Parliament that 1,430 people had died. In 1991 the official Indian government panel charged with tabulating deaths and injuries updated the count to more than 3,800 dead and approximately 11,000 with disabilities.”

The Bhopal Disaster

- In the early hours of Monday, Dec. 3, 1984, a toxic cloud of methyl isocyanate
(MIC) gas enveloped the hundreds of shanties and huts surro … g a
pestici … rifted in the
cool n … dents
awoke … the time
the ga … after the
traged … 0 people
had d … tabulating
death … d
appro …

Estimates of the number of people killed in the first few days by the plume from the UCC plant actually run as high as 10,000, with 15,000 to 20,000 premature deaths reportedly occurring in the subsequent two decades.

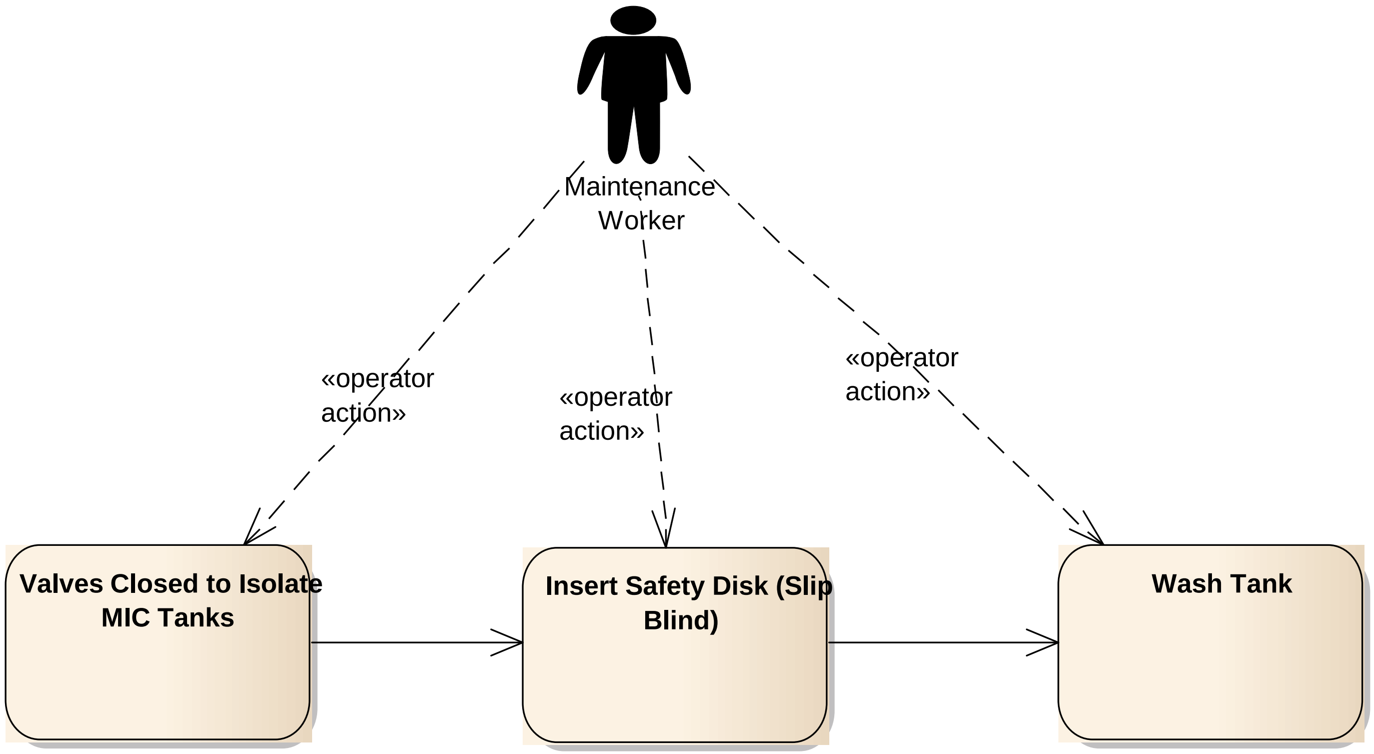
- Althou … disgruntled
plant … yanate,
addec … ilt up heat
and p … ound into a
lethal … hat escaped into the cool night air.

Operator Error?

"Although it was not known at the time, the gas was formed when a **disgruntled plant employee, apparently bent on spoiling a batch of methyl isocyanate, added water to a storage tank**. The water caused a reaction that built up heat and pressure in the tank, quickly transforming the chemical compound into a lethal gas that escaped into the cool night air."

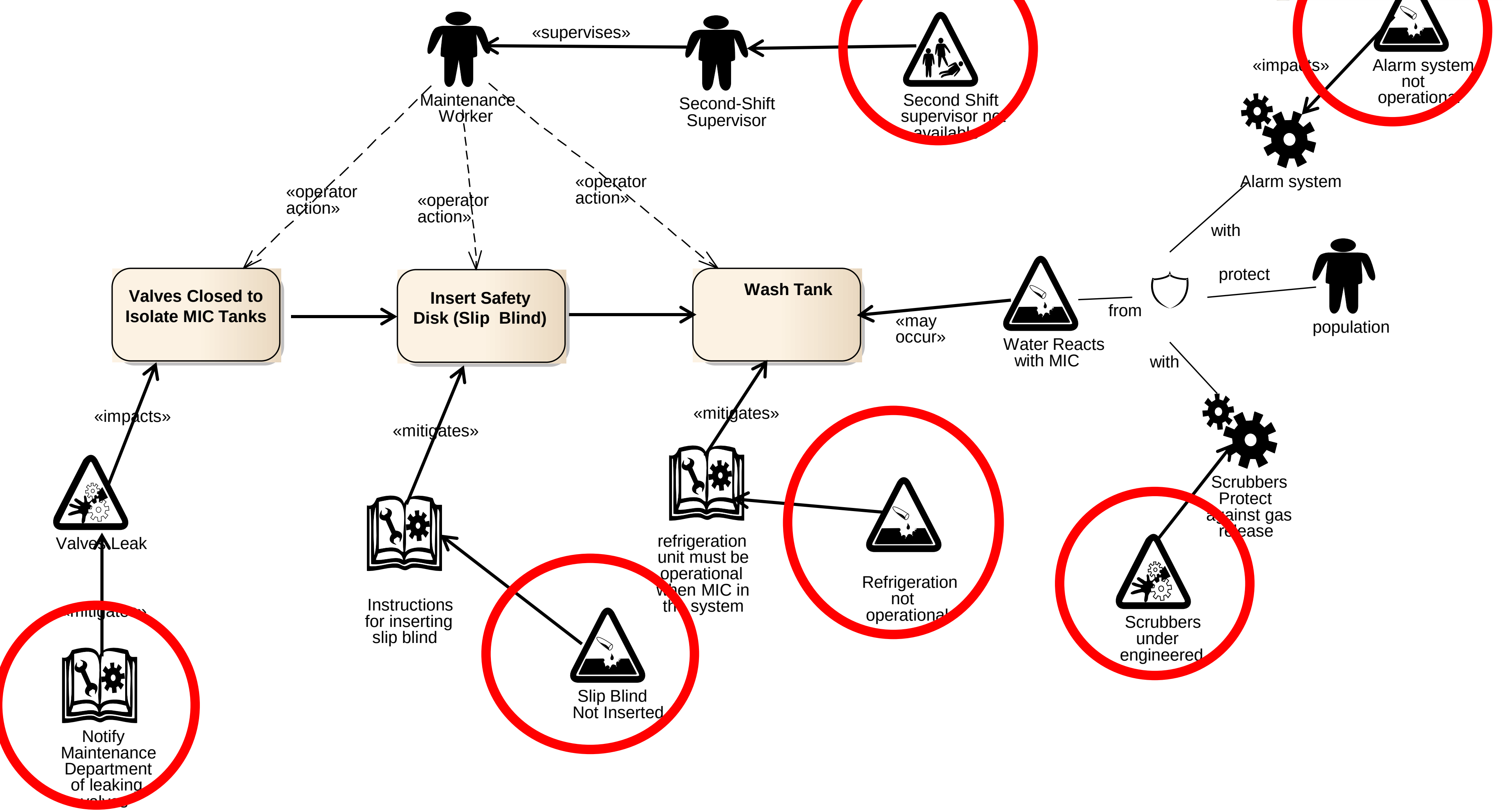
– Union Carbide Spokesman

Actually, No!

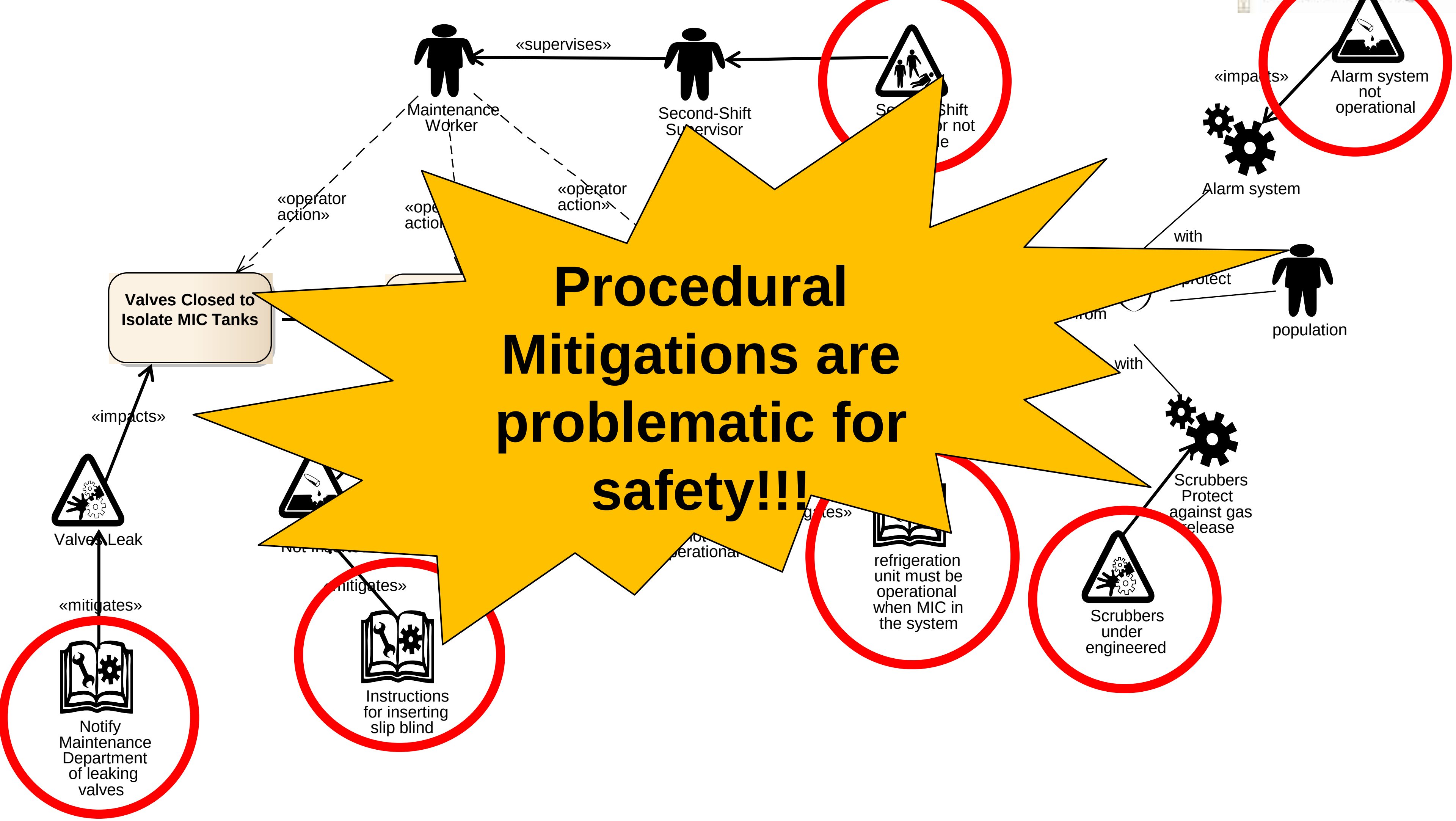


Maintenance Worker
«operator action»
«operator action»
«operator action»
Valves Closed to Isolate MIC Tanks
Insert Safety Disk (Slip Blind)
Wash Tank

Holistic [System] View



Holistic [System] View



Transitioning to Systems Engineering

- **Academic Certification Program**
- **M.S/PhD in Systems Engineering**
- **INCOSE* Certification**

***International Council on Systems Engineering**

Sample Certification programs

STEVENS
INSTITUTE of TECHNOLOGY
THE INNOVATION UNIVERSITY®

School of Systems & Enterprises

Systems Engineering and Architecting

The topics covered and material presented in this certificate provides an interdisciplinary approach based on an "entire view" of missions and operational environments and combines the capabilities of platforms, systems, operators, and support to fashion solutions that meet customer needs.

- SYS 625 Fundamentals of Systems Engineering
- SYS 650 System Architecture and Design
- EM 612 Project Management of Complex Systems
- SYS 605 Systems Integration

Systems Engineering Management

- EM 612 Project Management of Complex Systems
- SYS 625 Fundamentals of Systems Engineering
- SYS 660 Decision and Risk Analysis
- EM 680 Designing and Managing the Development Enterprise

Professional or Academic Masters Degree

- **The Professional Master in Applied Systems Engineering (PMASE)**
  - Targeted to working professionals,
    >5-10 years experience
  - Two Year Program via Cohort Delivery Model*
  - Balance between theory and practice
- **Academic Masters Degree**
  - Traditional M.Sc. for anyone with a B.Sc. in science or engineering

*A cohort is a group of students that are taking the same classes on the same schedule in pursuit of the same goal. PMASE's hybrid format enables students to participate through interaction and instruction via the latest distance learning technology, pre-recorded learning modules available on-demand online, ive instruction and activities in Atlanta during campus visits.

*Distance Learning, Webinar, Campus visits

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The base ASEP, CSEP, and ESEP credentials cover the breadth of systems engineering at increasing levels of leadership, accomplishments, and experience.

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INCOSE ESEP

Senior Level

INCOSE CSEP

Foundation Level

INCOSE ASEP

Entry Level

Extensions

Extensions cover a specific domain or subset of systems engineering in more detail. A base SEP credential must first be earned.

INCOSE ACQ™

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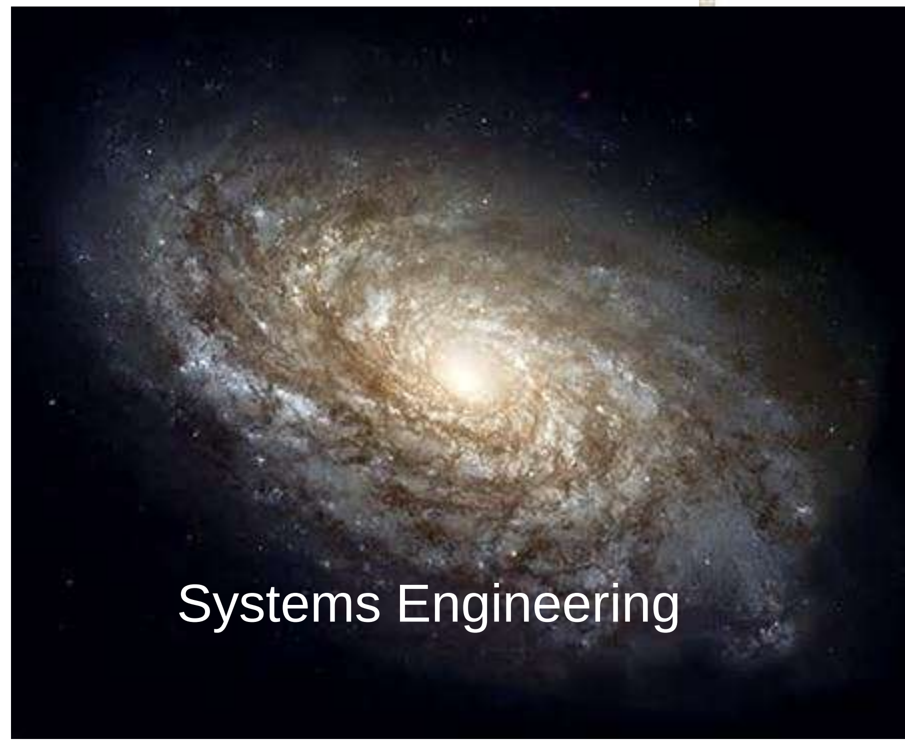
Onward and Upward




That's all Folks!