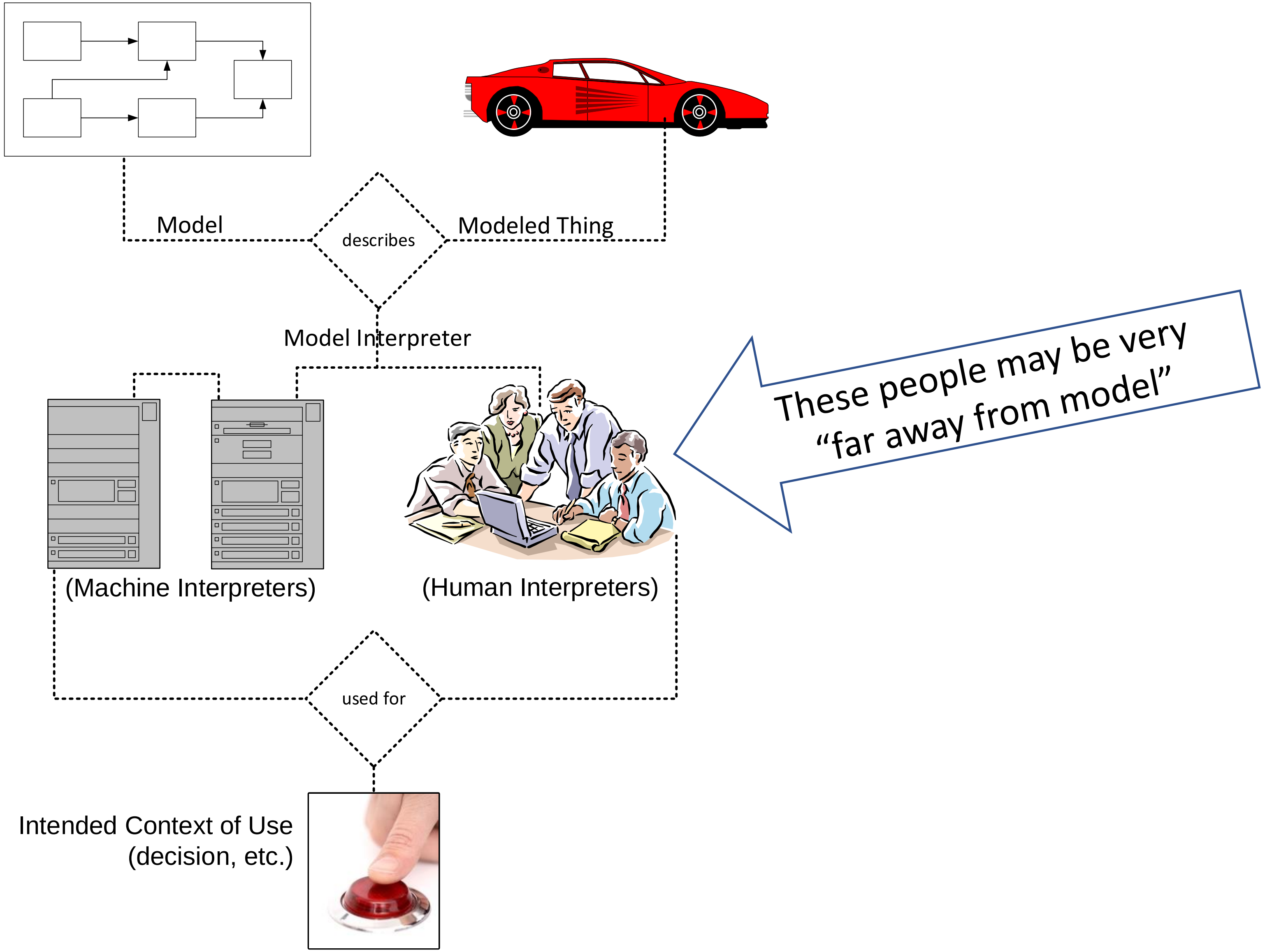
Two IFSR 2018 Topics

- Credibility of Models (Monday)
- Smallest Model of a System (Tuesday)

A. Referenced general contextual setting
B. Offered assertions for discussion (1 slide)
C. Existing conceptual frames, terms, standards
D. Conversation (the main thing)
E. Supporting references

Referenced general contextual setting



Offered assertions for discussion

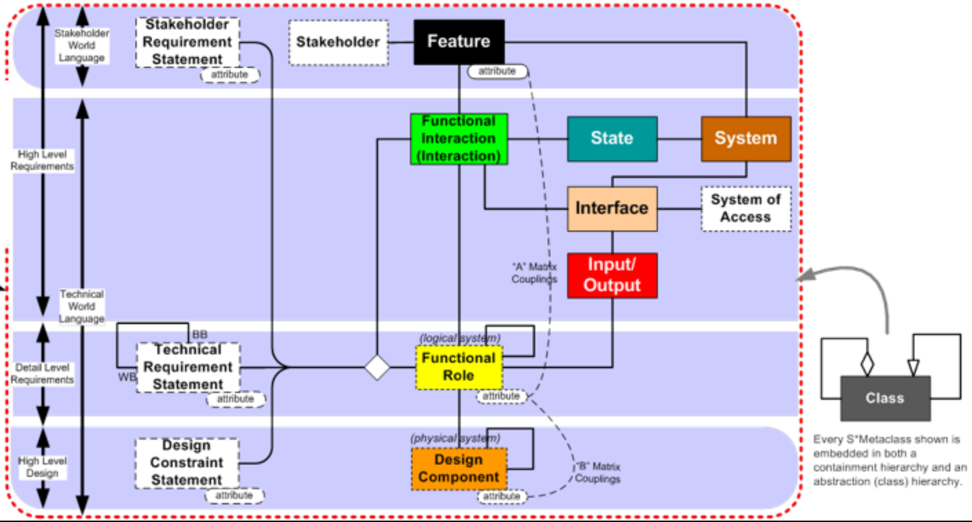
1. **Size Matters**: The size of a model is of theoretical interest because the size of a system's "minimal representation" is one definition of its complexity. A more practical engineering interest is that the size and redundancy of engineering specifications challenge the effectiveness of systems engineering processes. Humankind needs to find the simplest—but not too simple--approaches to systems engineering.
2. **Both Too Small and Too Large**: Practitioner MBSE models are often too large and too small (see 3) at once--missing key information while redundant in other aspects.
3. **System Phenomenon**: There is a misperception that "system models" are of a different nature than "discipline-specific models", arising from the peculiar history of SE compared to the other disciplines. Other engineers believe their discipline is based on "fundamental" physical laws (e.g., mechanics), and that SE is not phenomena-based. The truth is a converse: The System Phenomenon and Hamilton's Principle are the basis of all the other disciplines' "laws". In particular, this says not to omit Interactions.
4. **PBSE as Size Compression:** Model-based System Patterns, organized by Gestalt Rules, divide system descriptions into fixed and variable parts, further compressing models, and enabling PBSE. The Minimum Description Length Principle helps compress models and model space representation.
5. **Foundation of MBSE Patterns**: Smallest we have been able to find and practice over the last 30 years is the content of the S*Metamodel, therefore used as foundation of PBSE—if a different content had been found, then we would have made it the S*Metamodel.

Existing conceptual frames, terms, standards

What are S*Models?

- S*Models are MBSE system models that are based on the S*Metamodel:
  - Smallest set of modeled information required for purposes of science & engineering across life cycle of systems.
  - Independent of specific modeling language.
  - S*Metamodel maps into any contemporary modeling language, including OMG SysML®, third party COTS tools.

Summary subset of key S*Metamodel Elements



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What Is the Smallest Model of a System?

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Abstract. How we represent systems is fundamental to the history of mathematics, science, and engineering. Model-based engineering methods shift the nature of representation of systems from historical prose forms to explicit data structures more directly comparable to those of science and mathematics. However, using models does not guarantee simpler representation--indeed a typical fear voiced about models is that they may be too complex.

Minimality of system representations is of both theoretical and practical interest. The mathematical and scientific interest is that the size of a system's "minimal representation" is one definition of its complexity. The practical engineering interest is that the size and redundancy of engineering specifications challenge the effectiveness of systems engineering processes. INCOSE thought leaders have asked how systems work can be made 10:1 simpler to attract a 10:1 larger global community of practitioners. And so, we ask: What is the smallest model of a system?

Introduction and Background: Size Matters!

Representation Size, Purpose, Traditions. This paper discusses possible (and potentially least) upper bounds on the sizes of effective representations of systems, *for the purposes of systems engineering*. Compared to traditional systems engineering approaches, it draws more directly on scientific traditions for representing behavior as physical interaction. Systems engineering is still young, and its connections to supporting sciences is still evolving rapidly.

Language and Compression. This subject may appear to be related to the language used to describe systems, and an interesting thread in the mathematical study of description length is whether minimality is in a sense independent of language (Chaitin, Grunwald, Li and Vitany). In any case, systems modeling languages such as SysML® and its predecessors provide valuable assets for the movement to model-based methods (SysML Partners). Our subject here is not the machinery of these specific modeling languages, but the systems ideas that minimal models must address. When used for system families (product lines, ensembles), the representation described here is subject to significant compression by the use of patterns. This turns out to provide powerful insights about approaches to major practical reductions in the size of SE descriptions and processes, and about ongoing future evolution of domain languages over time. These dynamics also suggest that such patterns can be understood as emergent when the interaction rules of the systems engineering process are properly arranged.

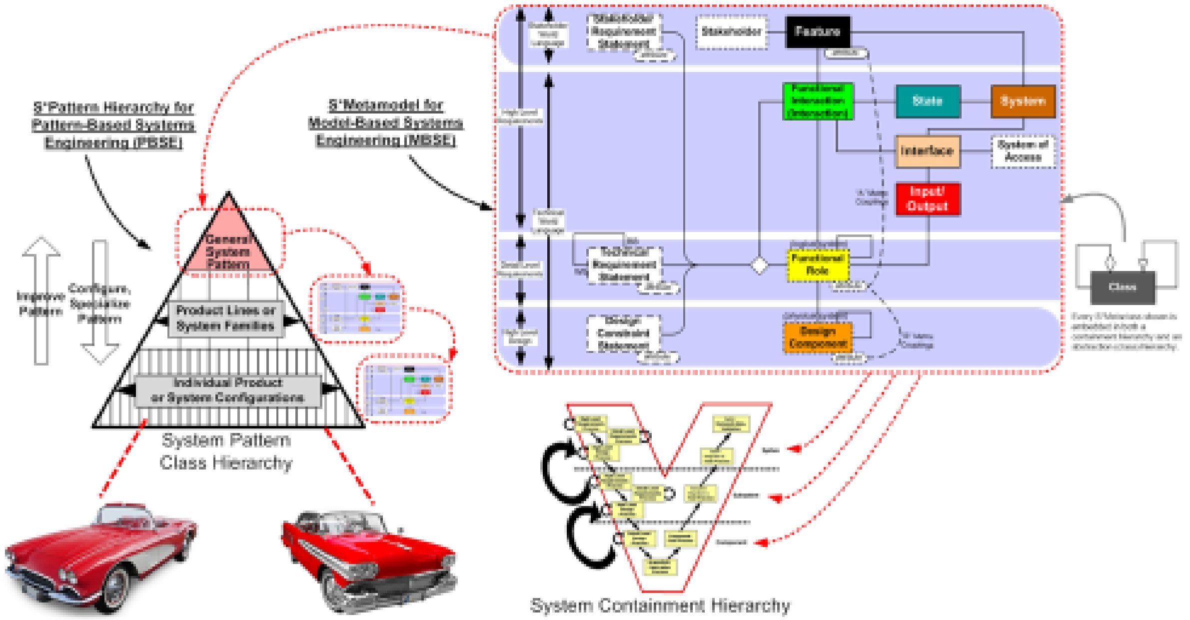
Practical representation challenges of traditional systems engineering. Traditional system documentation of concept of operations (CONOPS), system requirements, design specifications, failure mode and effects analysis (FMEA), test plans, operations and maintenance procedures, and other task-specific system representations over the life cycle of a system can exceed thousands of pages. This does not encourage the engagement of a 10:1

Existing conceptual frames, terms, standards

Smallest Model

What are S*Patterns?

- S*Patterns are configurable, re-usable S*Models of families of systems:
  - Architectural Frameworks, Product Lines, Platforms, etc.
  - A form of model compression.
  - Using the elements of the S*Metamodel.



Lawnmower Product Line: Configurations Table									
		Units	Walk-Behind	Walk-Behind	Walk-Behind	Riding	Riding	Riding Mower	Autonomous
			Push Mower	Mower	Self-Propelled	Rider	Tractor	Tractor	Autonomous
			Push Mower	Self-Propelled	Wide Cut	Rider	Lawn	Garden	Auto Mower
	Model Number		M3	M5	M11	M17	M19	M23	M100
	Market Segment		Sm Resident	Med Resident	Med Resident	Lg Resident	Lg Resident	Home Garden	High End Suburban
Power	Engine Manufacturer		B&S	B&S	Tecumseh	Tecumseh	Kohler	Kohler	Elektroset
	Horsepower	HP	5	6.5	13	16	18.5	22	0.5
Production	Cutting Width	Inches	17	19	36	36	42	48	16
	Maximum Mowing Speed	MPH	3	3	4	8	10	12	2.5
	Maximum Mowing Productivity	Acres/Hr			1.6				
	Turning Radius	Inches	0	0	0	0	126	165	0
	Fuel Tank Capacity	Hours	1.5	1.7	2.5	2.8	3.2	3.5	2
	Towing Feature						x	x	
	Electric Starter Feature				x	x	x	x	
	Basic Mowing Feature Group		x	x	x	x	x	x	x
Mower	No. of Anti-Scalping Rollers		0	0	1	2	4	6	0
	Cutting Height Minimum	Inches	1	1.5	1.5	1.5	1	1.5	1.2
	Cutting Height Maximum	Inches	4	5	5	6	8	10	3.8
	Operator Riding Feature					x	x	x	
	Grass Bagging Feature		Optional	Optional	Optional	Optional	Optional	Optional	
	Mulching Feature		Standard	Factory Installed	Dealer Installed				
	Aerator Feature					Optional	Optional	Optional	
	Autonomous Mowing Feature								x
	Dethatching Feature					Optional	Optional	Optional	
Physical	Wheel Base	Inches	18	20	22	40	48	52	16
	Overall Length	Inches	18	20	23	58	56	68	28.3
	Overall Height	Inches	40	42	42	30	32	36	10.3
	Width	Inches	18	20	22	40	48	52	23.6
	Weight	Pounds	120	160	300	680	705	1020	15.6
	Self-Propelled Mowing Feature			x	x	x	x	x	x
	Automatic TransmFeature							x	
Financials	Retail Price	Dollars	360	460	1800	3300	6100	9990	1799
	Manufacturer Cost	Dollars	120	140	550	950	1800	3500	310
Maintenance	Warranty	Months	12	12	18	24	24	24	12
	Product Service Life	Hours	500	500	600	1100	1350	1500	300
	Time Between Service	Hours	100	100	150	200	200	250	100
Safety	Spark Arrest Feature		x	x	x	x	x	x	

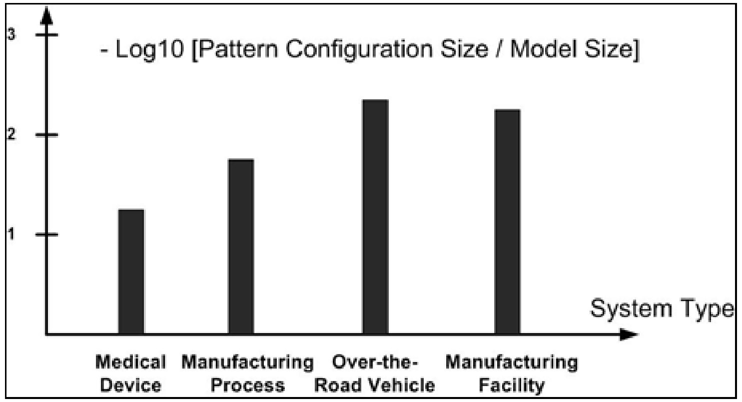


Figure 12: Pattern Compression

Existing conceptual frames, terms, standards

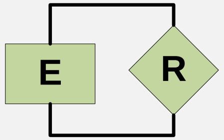
Smallest Model

Emergence of Patterns from Patterns: S*Pattern Class Hierarchy

More General

Definition of **Relational Modeling Paradigm**

Entity-Relationship Paradigm

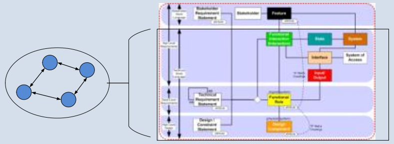


E=Entity
R= Relationship

Structured or unstructured semantic web

Minimal System S*Metamodel: Definition of (Elementary) System, Material Cause

S*Metamodel Core



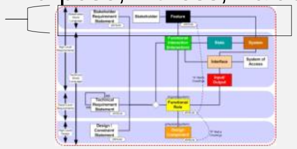
Core S*Metamodel

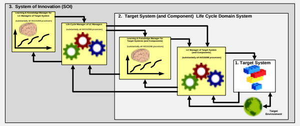
Smallest model of a system, for engineering or science

Emergence & Definition of **System of Innovation**, Fitness, Value, Purpose, Stakeholders, Agility, Final Cause, Formal Cause, Efficient Cause, Intelligence, Management, Science, Living Systems

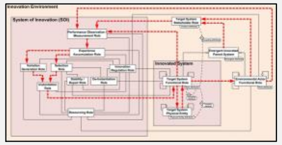
EI Pattern, SOI Pattern, Fitness, Value

S*Purpose, Fitness, Value

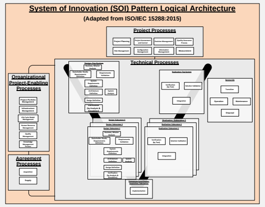




Agile Sys Life Cycle Pattern



System of Innovation Pattern



ISO 15288 System Life Cycle Mgmt Pattern

Emergence & Definition of **Domain Specific Systems**

Domain Specific Pattern

- **Terrestrial Vehicle Domain Pattern**
- **Manufacturing System Pattern**
- **Product Service System Pattern**
- **Space Tourism Pattern**
- **Electrical Power Domain Pattern**
- **Aircraft Flight Control Pattern**
- **Medical Device Pattern**
- **Distribution System Pattern**
- **Socio-Technical Pattern**
- **Critical Infrastructure Domain Pattern**

More Specific

Existing conceptual frames, terms, standards

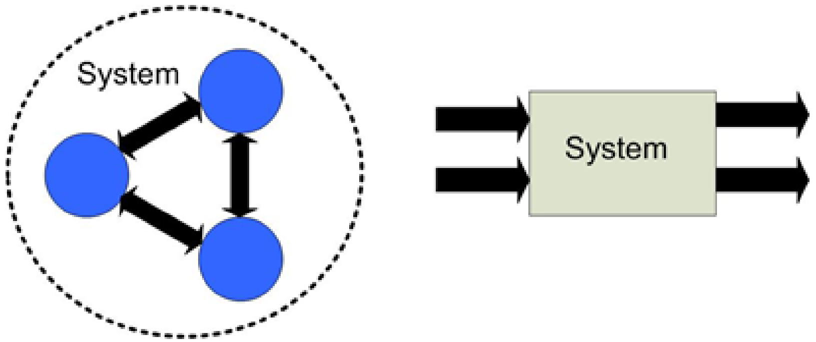
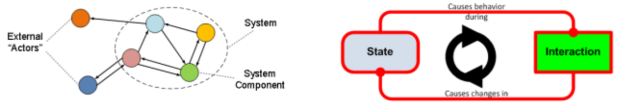


Figure 6: Two Different Starting Points:
Systems As Interacting Components versus A SIPOC Perspective

The System Phenomenon

- In the perspective described here, by system we mean a collection of interacting components:



- Where interaction involves the exchange of energy, force, mass, or information, . . .
- Through which one component impacts the state of another component, . . .
- And in which the state of a component impacts its behavior in future interactions.

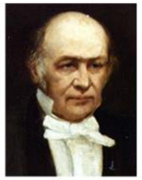
The System Phenomenon

- Phenomena of the hard sciences are in each case instances of the following "System Phenomenon":
  - *behavior emergent from the interaction of behaviors (phenomena themselves) a level of decomposition lower.*
- In each such case, the emergent interaction-based behavior of the larger system is a *stationary path of the action integral*:

$$S = \int_{t_1}^{t_2} L(x, \dot{x}, t)\, dt$$

(Hamilton's Principle)

- Reduced to simplest forms, the resulting equations of motion (or if not solvable, empirically observed paths) provide "physical laws" subject to scientific verification.



William Rowan Hamilton

2018 Annual INCOSE international workshop
Jacksonville, FL, USA
January 20 - 23, 2018

Emmy Noether

System Patterns:
The System Phenomenon, Hamilton's Principle, and Noether's Theorem as a Basis for System Science

IW2018 System Science Working Group Meeting, 01.23.2018
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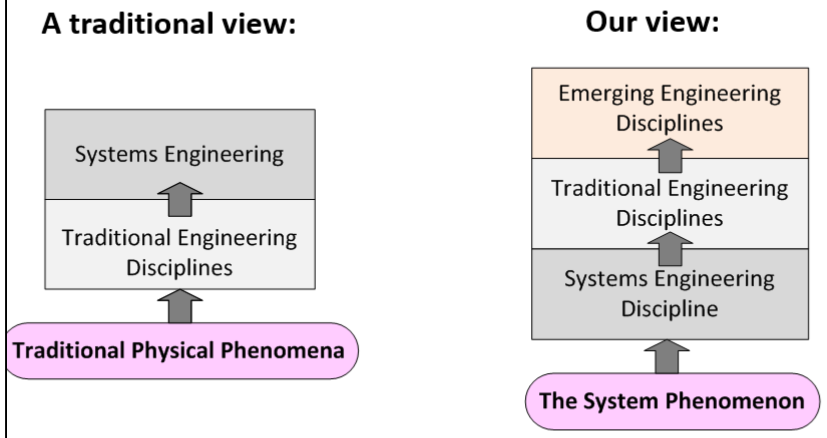

Edinburgh, Scotland, UK, July 18-21, 2016

Got Phenomena? Science-Based Disciplines for Emerging Systems Challenges

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Abstract. Engineering disciplines (ME, EE, CE, ChE) sometimes argue their fields have "real physical phenomena", "hard science" based laws, and first principles, claiming Systems Engineering lacks equivalent phenomenological foundation. We argue the opposite, and how replanting systems engineering in MBSE/PBSE supports emergence of new hard sciences and phenomena-based domain disciplines.

Supporting this perspective is the System Phenomenon, wellspring of engineering opportunities and challenges. Governed by Hamilton's Principle, it is a traditional path for derivation of equations of motion or physical laws of so-called "fundamental" physical phenomena of mechanics, electromagnetics, chemistry, and thermodynamics.

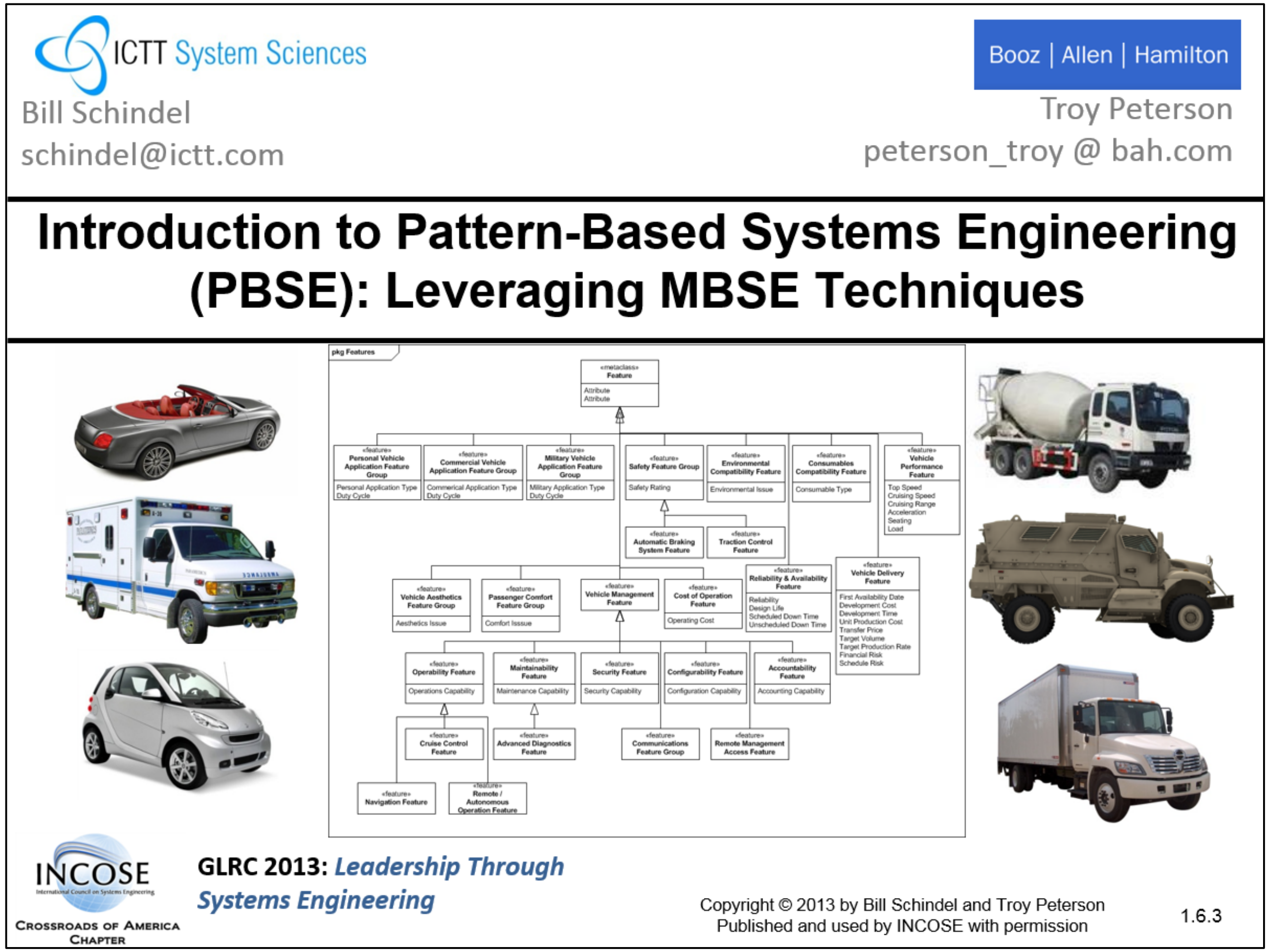
We argue that laws and phenomena of traditional disciplines are less fundamental than the System Phenomenon from which they spring. This is a practical reminder of emerging higher disciplines, with phenomena, first principles, and physical laws. Contemporary examples include ground vehicles, aircraft, marine vessels, and biochemical networks; ahead are health care, distribution networks, market systems, ecologies, and the IoT.

1. Introduction

As a formal body of knowledge and practice, Systems Engineering is much younger than the more established engineering disciplines, such as Civil, Mechanical, Chemical, and Electrical Engineering. Comparing their underlying scientific foundations to some equivalent in Systems Engineering sometimes arises as a dispute, concerning whose profession is "real" engineering based on (or at least later explained by) hard science, with tangible physical phenomena, and accompanied by physical laws and first principles. This paper argues for a different perspective altogether (Figure 1), and the reader exploring this paper is warned to avoid the trap of the seemingly familiar in parsing the message.

Existing conceptual frames, terms, standards

Smallest Model



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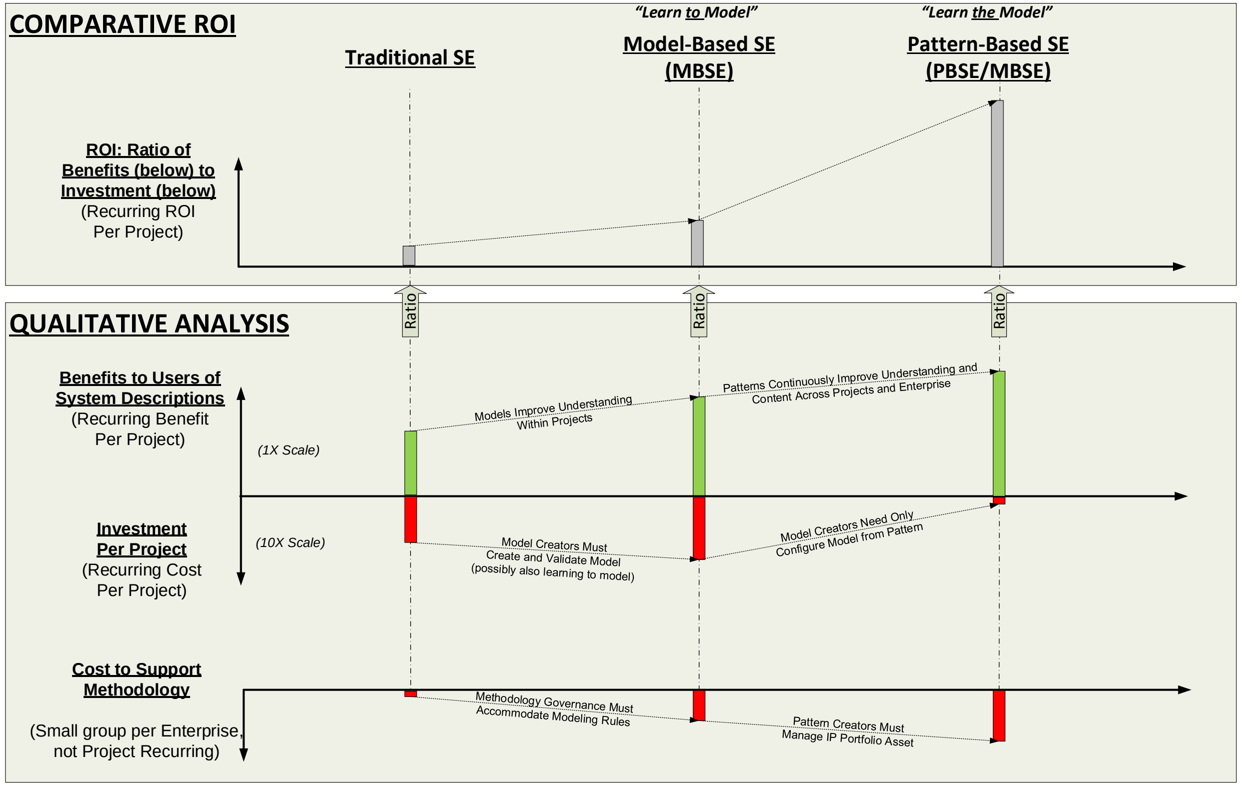
Introduction to Pattern-Based Systems Engineering (PBSE): Leveraging MBSE Techniques

INCOSE
Crossroads of America Chapter

GLRC 2013: *Leadership Through Systems Engineering*

1.6.3



References (stored on conversation site)

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