Improving System Affordability during Requirements Elicitation: Bridging Theory and Practice

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Research Task / Overview

	AFFORDABILITY			
	PERCEIVED VALUE			BUDGET
	Perceived benefit	Actual benefit	Cost	
Business	Marketing	Technology push	Process improvement Labor Outsourcing Procurement strategies	Investment
System development & operation	DfE DfA Psychology-based design	Tradespace definition: Use cases, Pugh matrices, Spiral, agile, lean, Other tradit. SE / De-scope needs, Use cases, Agile, lean, Pugh matrices, Other tradit. SE; NbC: Tradespace maximization/adaptation Design&Develop.: DfR, DfA, DfE,DfS, DfF, Value-driven design / DtC, DfC, TCO, Cost reviews, DfM, Complexity control; Pareto Set: Tradespace exploration Manuf.: Certification, Quality / Process improvement, 6-sigma Ops.: Servicing / Customer service PM: Evidence-based deliverable Skunkworks / Evidence-based deliverable Skunkworks		Spiral
Context/ Environment	Awareness Lobby	Market change	Economic situation Laws and regulations	Awareness Lobby Competition

Manuf.: Manufacturing - Ops.: Operation - PM: Project Management

Goals & Objectives

PROPOSITION

(1) The **size of the solution space**, which for a given set of stakeholder needs is delimited by system requirements, relates to the probability of finding affordable solutions during tradespace exploration. Consequently it is ultimately a **limiting factor of system affordability**.

(2) Therefore, there exist models or methods to elicit and use requirements that for a given set of stakeholder needs could **facilitate the maximization of the solution space** so that the probability of finding **more affordable solutions** during tradespace exploration is also maximized.

OBJECTIVES

Understanding **HOW** current practices of **REQUIREMENTS** engineering affect system **AFFORDBILITY**

Contributing to **SYSTEMS THEORY** by linking the concepts of stakeholder **NEEDS**, system **REQUIREMENTS**, solution **SPACES**, and system **AFFORDABILITY**.

Developing **METHODS** that facilitates the **MAXIMIZATION** of the solution **SPACE** for a given set of stakeholder needs to **INCREASE** the chances of finding **AFFORDABLE** solutions

Developing a **METHOD** that facilitates the definition of a system with the **MINIMUM** necessary **REQUIREMENTS** for a given set of stakeholder needs.

Developing a **METHOD** that facilitates the **IDENTIFICATION** of **CONFLICTING** requirements during requirements elicitation

Data & Analysis

SYSTEMS THEORY

Theorem:
A requirement CANNOT EXPAND the compliant space

Theorem:
A SYSTEM requirement REDUCES the compliant space

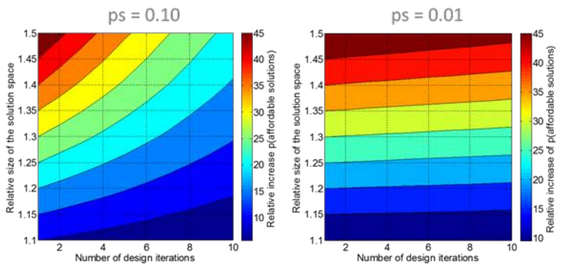
Theorem:
REMOVING two or more CONFLICTING requirements EXPANDS the compliant space.

Theorem:

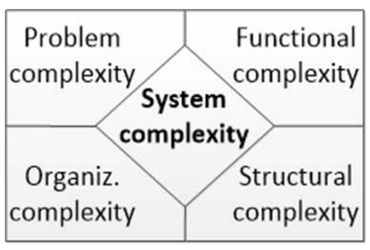
$$\uparrow \#CS_{R_i} \rightarrow \uparrow p(Z \in CS_{R_i})$$
$$\downarrow \#CS_{R_i} \rightarrow \downarrow p(Z \in CS_{R_i})$$

Theorem:

$$\uparrow \#CS_{R_i} \rightarrow \uparrow p(Z \in AVS_{SN_i})$$
$$\downarrow \#CS_{R_i} \rightarrow \downarrow p(Z \in AVS_{SN_i})$$



COMPLEXITY SCIENCE



$$C(C_1 \cdots C_n) = -\sum_{c_1} \cdots \sum_{c_n} P(c_1 \cdots c_n) \cdot log_j[P(c_1 \cdots c_n)]$$

$$C_p = K \cdot \left(\sum_{i=1}^{n} a_i \cdot r_{f_i}\right)^E \cdot \left(\prod_{j=1}^{m} {b_j}^{H_j}\right)^D$$

Calibration factor; Size of requirement set; Conflicting requirements

H10 ≥ 2 phases of matter

LR Opposing directions laws of society

H1-H5-H7 Opposing directions laws of physics

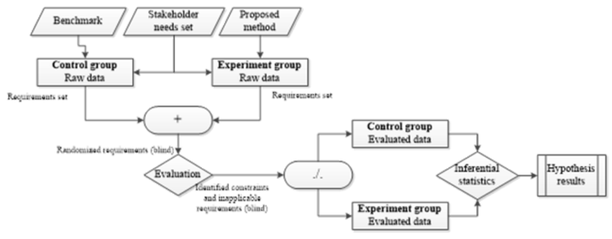
H8 Competing for resources

LR Logical contradictions

REQUIREMENTS CATEGORIZATION

Value level	Functions (Do)	Performance (Being)	Resources (Have)	Interaction (Interact)
Break-event	Req. 1 Req. 2 Req. 3	Req. 4	Req. 5 Req. 6	Req. 7
Goal	Req. 8	Req. 9		
Wish		Req. 10	Req. 11 Req. 12	

Functional requirements (*Do*)
What the system does in essence, which includes what it accepts and what it delivers
Performance requirements (*Being*):
How well the system does it, which includes performance related to functions the system performs or characteristics of the system on its own, such as –ilities
Resource requirements (*Have*):
What the system uses to transform what it accepts in what it delivers
Interaction requirements (*Interact*):
Where the system does it, which includes any type of operation during its life-cycle.



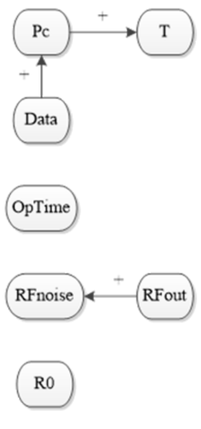
NULL HYPOTHESES

FIRST H0 Both groups elicit the same amount of constraints.	SECOND H0 Both groups elicit the same amount of inapplicable reqs.	THIRD H0 Both groups elicit the same amount of net requirements.
p = 0.001 ✓	0.025 ✓	0.804 ✓
C vs T	C vs T	C vs T
mean = 27% vs 4% ✓	16% vs 5% ✓	25 vs 29 ✓
median = 26% vs 5% ✓	18%nvs 1% ✓	24 vs 25 ✓
0.000 ✓	Statistical power > 97%	
C vs T		
27% vs 2% ✓		
26% vs 0% ✓		

MOE	Problem statement	Self-perception on req quality	Experience in systems engineering
1.H0	0.220	0.038	-0.055
2.H0	0.459*	-0.166	-0.129
3.H0	-0.408	0.579**	0.570**

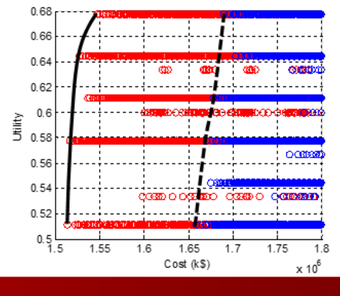
TENSION MATRIX & ELEMENTAL DECOMPOSITION
Reducing conflicting requirements

Reqs.		Resources			Phases of matter				Elemental decomposition: Laws of physics			Laws of society			Logical
		r7	r8	r9	S	L	G	V	T	P	v	L1	L2	L3	
F	r1	X												↑	Methods in chapter 2
	r2		X							↑			↓		
	r3		X												
P	r4								↓						
	r5	X								↑		↓	↑		
	r6			X							↑				
R	r7														
	r8								↓						
	r9														
I	r10				X										
	r11						X		↓					↓	
	r12					X									

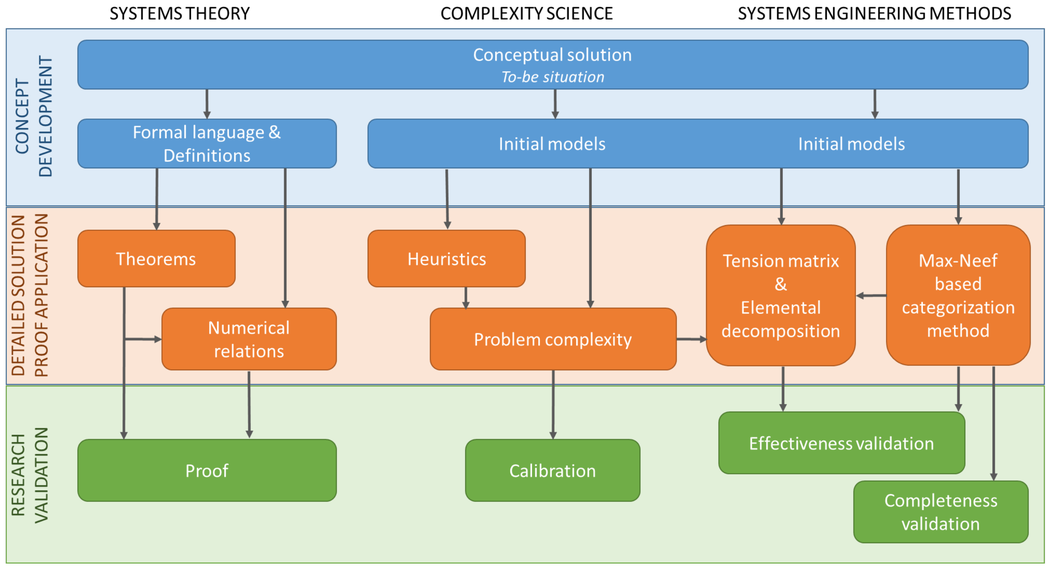


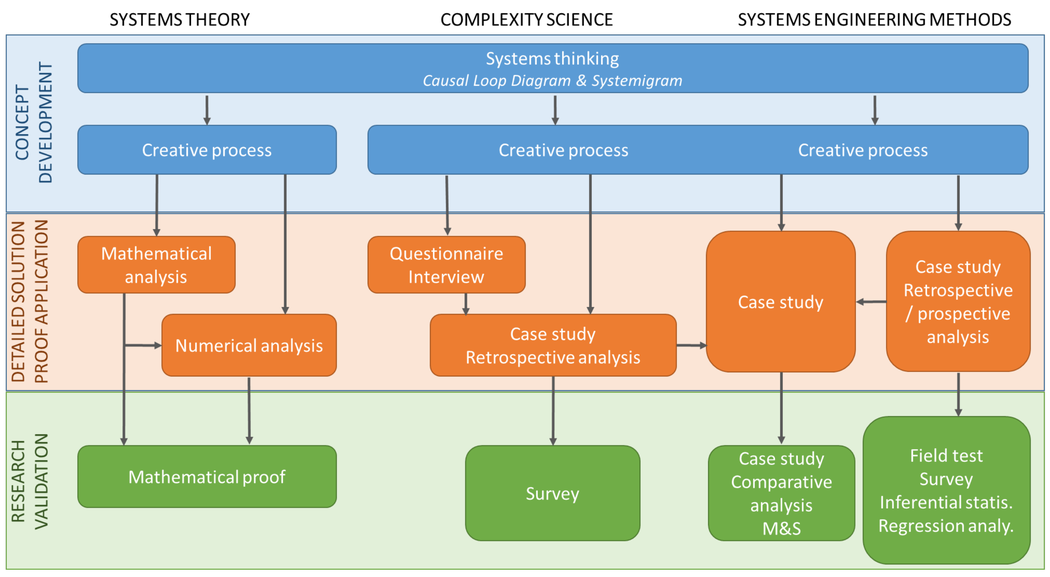
Heuristics
Targeted modeling
Elemental decomposition

Comparative analysis:
Benchmark Vs. Tension Matrix



Methodology





Future Research

SYSTEMS THEORY

Include CONTINUOUS levels of satisfaction and compliance

Incorporate ERRORS and TIME in the mathematical constructs

Investigate sensitivity of UNIFORMITY distribution of solutions.

Investigate the effects of LEARNING and ANCHORING

SYSTEMS ENGINEERING METHODS

Increase DIVERSITY of the experiments

Integrate with SYSTEMS THEORY

Expand to NON-TEXTUAL requirements

Develop GENERIC models of elemental decomposition

COMPLEXITY SCIENCE

Perform an ABSOLUTE quantitative calibration of the problem complexity analytical formulation based on existing project data.

Formally INTEGRATE problem complexity with other complexity metrics.

Contacts/References

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The contents of this poster have been extracted from A. Salado, "Measuring and Influencing Problem Complexity and its Impact on System Affordability during Requirements Elicitation for Complex Engineered Systems," *Doctoral Dissertation*, Stevens Institute of Technology, 2014.
A full list of references is provided in this document.