Complexity Measurement Results

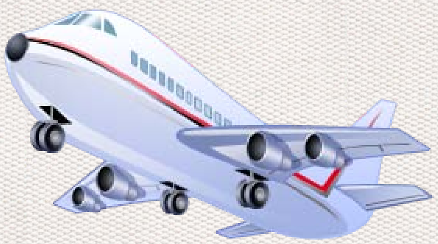
2012

Sarah Sheard

Third Millennium Systems

MOTIVATION

Systems Have Evolved



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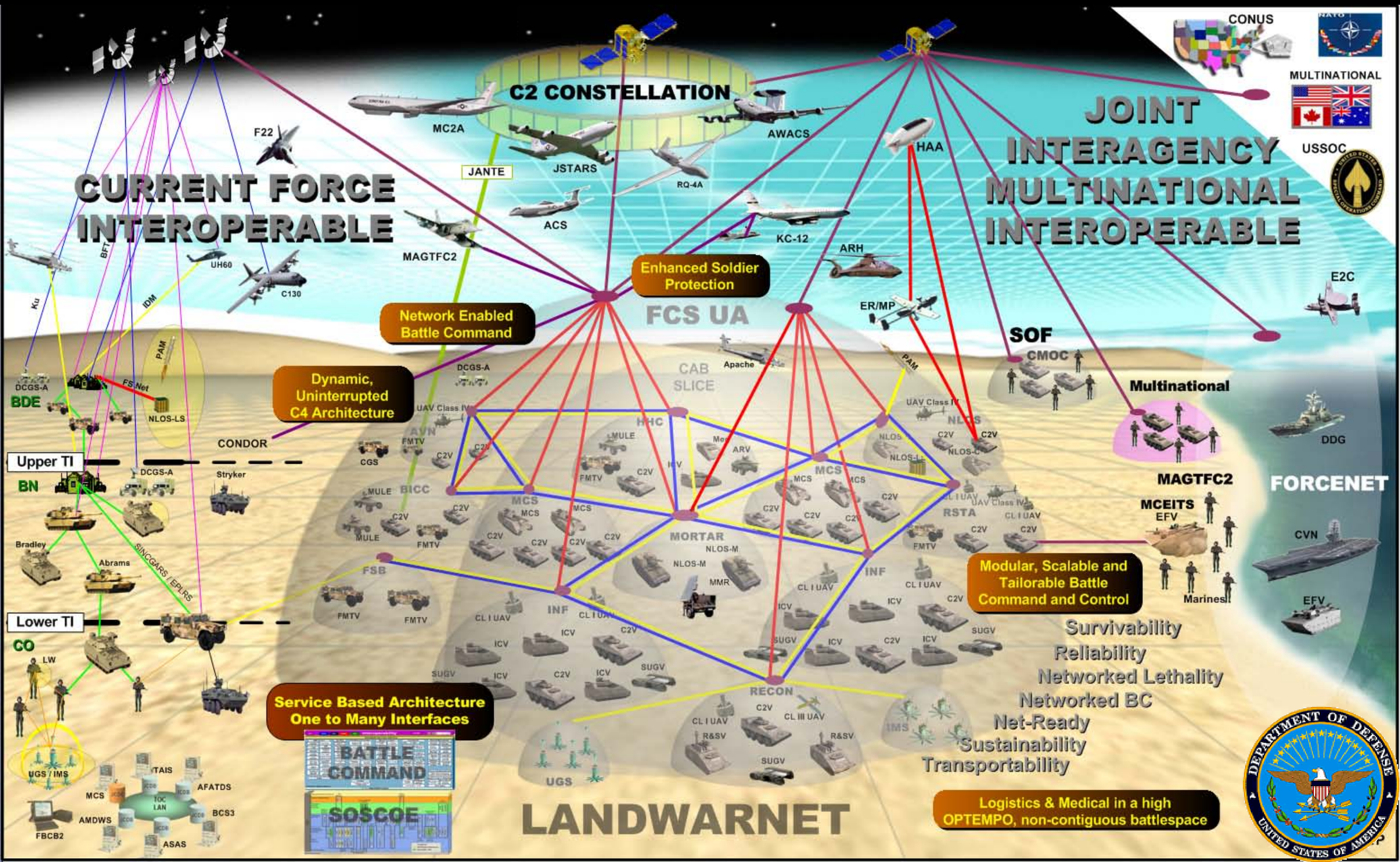
Army SOS perception



Complexity Characteristics

Balance ● Growth ● Connections

Technical Characteristics/ System Characteristics/ Objective Complexity

- Many pieces
- Emergent
- Nonlinear
- Chaotic
- Adaptive
- Tightly coupled
- Self-Organized
- Decentralized
- Political
- Open
- Multi-Scale

Many pieces
Em
Nonlinear
Chaotic
Adaptive
Tightly coupled
Self-Organized
Decentralized
Politica
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Multi-Scale

Cognitive Characteristics/ Subjective Complexity

- Uncertain
- Difficult to understand
- Unclear cause and effect
- Unpredictable
- Uncontrollable
- Unstable
- Unrepairable, unmaintainable
- Takes too long to build
- Costly

Uncertain
nderstand
and effect
predictable
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Unstable
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ng to build
Costly

Third Millennium Systems

Assessing the Impact of Complexity Attributes on System Development Project Outcomes

Ph. D. Dissertation of Sarah Sheard

Doctoral Advisory Committee

Dr. Ali Mostashari, School of Systems and Enterprises, Chairman

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Dr. Arthur Pyster, School of Systems and Enterprises

Dr. Brian Sauser, School of Systems and Enterprises

Dr. Tal Ben-Zvi, Howe School of Technology Management

Goal: Use Complexity Measurement on SE Projects

- Determine which measures of complexity might matter to program outcomes
- How can we tell if measures matter?
  - Methodology

But first:

- How measure complexity?
  - Types
- What things could be complex?
  - Entities

6 Types of Complexity

Balance ● Growth ● Connections

From science literature

- Structural: Size, Connectivity, Inhomogeneity (SS,SC,SI)
- Dynamic: Short-term (Operational); Long-term (Evolution) (DS, DL)
- Socio-Political (SP)

- Organizational instability
- Organizational structure
- Stakeholder
- Test & Operations
- Management philosophy

- Combinatorial (Size)
- Requirements
- Performance
- Skills gap
- Technical feasibility
- Technology maturity
- Intrinsic, Uncertainty, Other

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Many Entities

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Complexity Types and Entities

Balance ● Growth ● Connections

Type \ Entity:	Project	System	Environment	Cognitive
SS	Project is constructed of many tasks and teams	System is constructed of many elements	Environment includes by many elements in many structures	Mind is taxed by many elements and many problems
SC	Project outcomes emerge from connected tasks and teams	System behavior emerges from connected elements	Environmental behavior results from interacting elements	Mind has difficulty predicting emergence from many interactions
SI	Project has diverse and inhomogeneous tasks and teams	System structure has diversity and inhomogeneity	Environmental structures are diverse and inhomogeneous	Mental models are simpler without diversity and inhomogeneity
DS	Project behavior can change rapidly	System behavior can change rapidly	Environmental behavior can change rapidly	Mind has difficulty predicting nonlinear and rapid change
DL	Project and its behavior can evolve significantly over time	System and its behavior can evolve significantly over time	Environment and its behavior evolve significantly over time	Human mind has difficulty envisioning evolution to different forms
SP	Project is greatly influenced by socio-political factors	System may have socio-political factors	Environment is heavily influenced by socio-political factors	Engineers frequently are not strong in sociopolitical areas

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Typical questions

15. At the system level, how many sub-systems were there? (count the major pieces into which the system was divided, whether they were called subsystems, elements, components, or other terms)
(1) 1 (2) 2-3 (3) 4-6 (4) 7-10 (5) >10

25. "If one task slipped, this would cause problems with another task." Do you agree with this statement?
(1) SA (2) A (3) N (4) D (5) SD

38. Where did your project fit, on a scale of Traditional, Transitional, or Messy Frontier in the following eight attributes?
a ESEP1 Mission environment:
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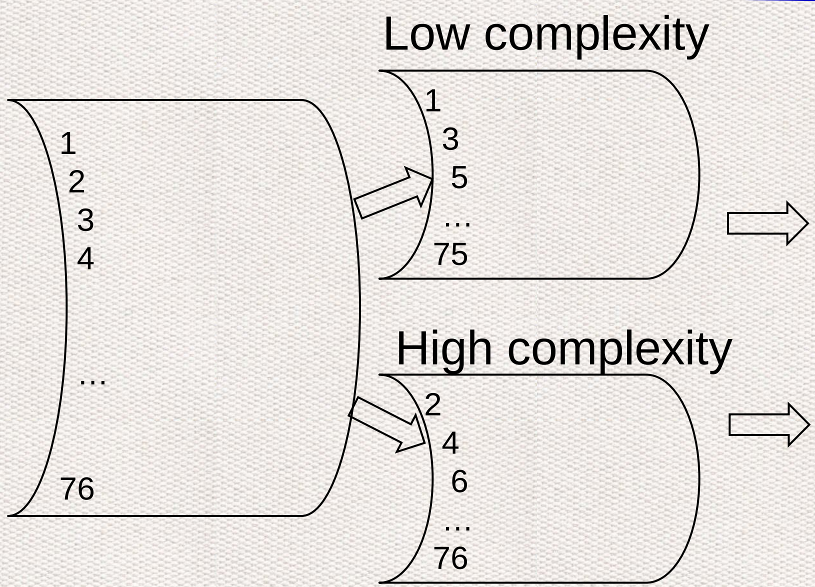
t-test Analysis



Outcomes

	Cost Overrun	Schedule Delay	Performance Shortfall
Low complexity	**2.6 ± 1.3**	**3.0 ± 1.6**	**2.4 ± 1.4**
High complexity	**3.8 ± 1.4**	**3.6 ± 1.2**	**2.5 ± 1.2**

All programs

2 groups based on a complexity measure (e.g., Annual cost)

Are these the same or different?

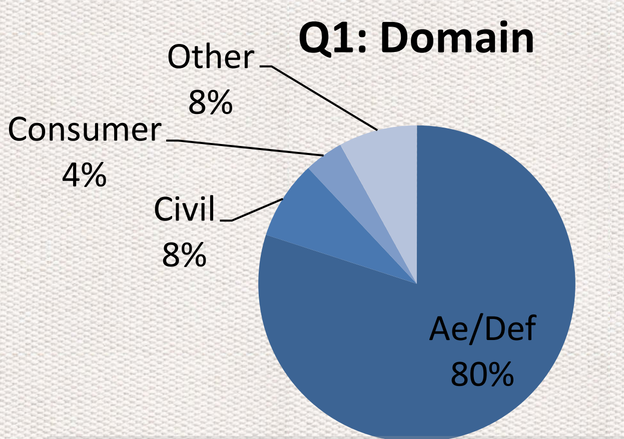
- Null hypothesis: the groups are the same and there is no contribution to success from complexity measure
- If t-test shows probability of difference occurring by chance is <0.05 (2-tail), there is significance
- Two tests; which is chosen depends on F-test.

	C	S	P
F test	0.75	0.20	0.36
t-test1	0.002	0.161	0.902
t-test2	0.002	0.229	0.909
Result			

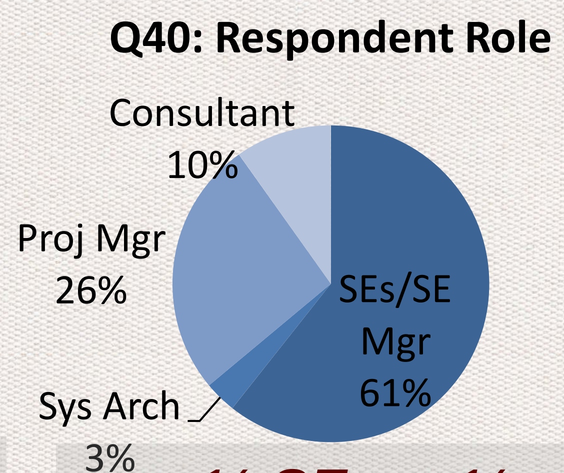
RESULTS AND DISCUSSION

Survey Characteristics

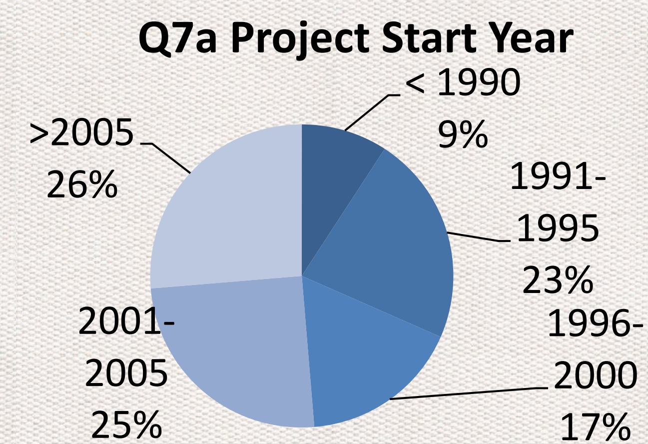
Balance ● Growth ● Connections



80% Aerospace/ defense

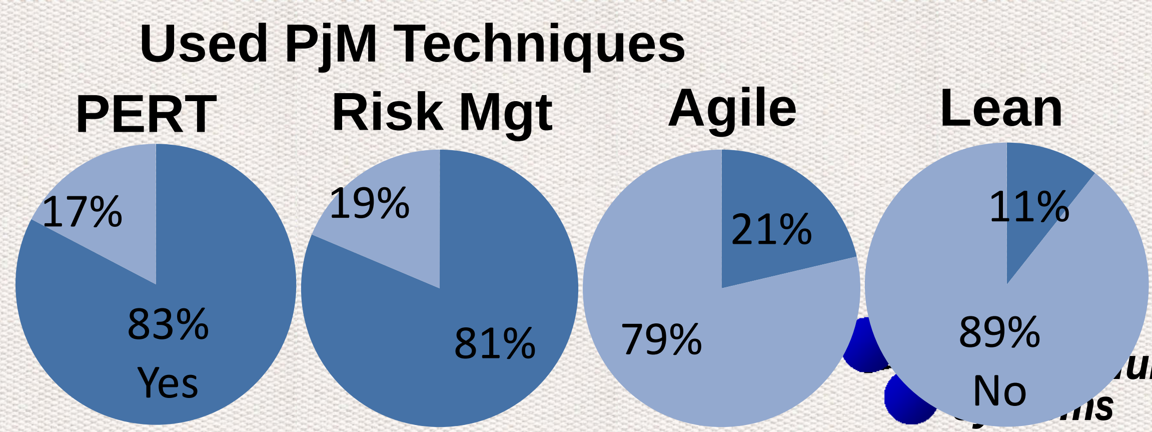


> ½ SEs, ~ ¼ Project Managers



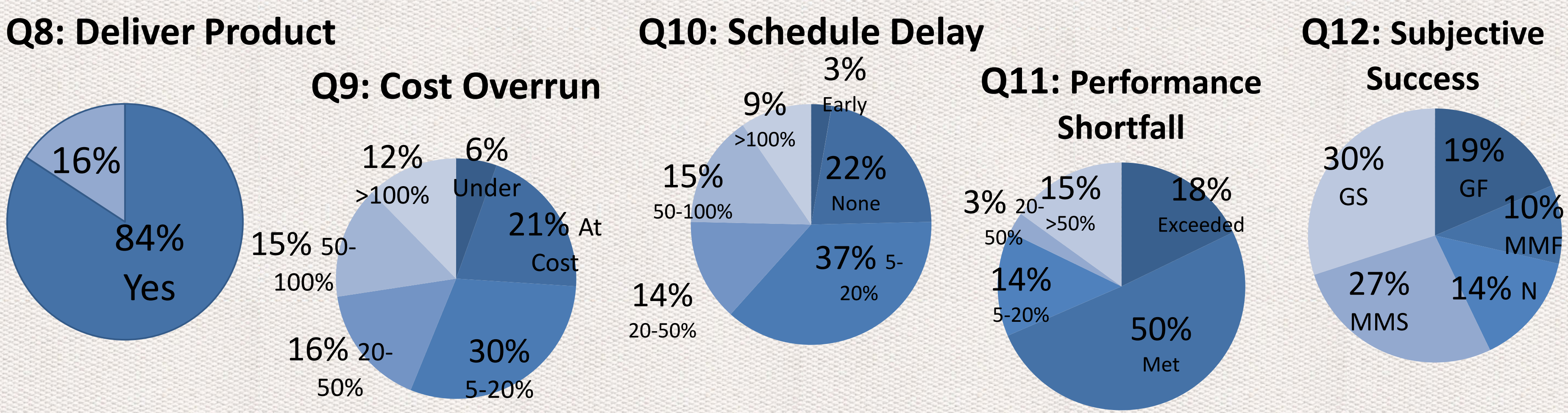
Fairly evenly split over 20 years

Over 80% used PERT-type planning and used Risk Management; only 10-20% used Agile or used Lean



Outcomes

Balance ● Growth ● Connections



Only about ¼ met cost and schedule, but 70% met performance; > ½ a success

Independent (39 Questions)

- Project Characteristics (17)
- System Characteristics (10)
- Environment Characteristics (11)
- Cognitive characteristics (1)

Dependent
(5 questions: Project Outcomes)

- Cost
- Schedule
- Performance
- Deliver product
- Subjective Success

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Results

p-values	Product	Cost	Schedule	Perf.	Subj Succ	Replng	ReqDif	CogFog	Stk Rels
Diff ->	8	9	10	11	12	13	16d	32	38f
Split by v									
8 Delivered Product				0.01106	4.2E-06		0.03762	0.00029	0.03167
9 Cost Overrun			2.6E-10			0.00021		0.01001	
10 Schedule Delay		1.4E-11			0.0228	5.1E-06	0.02194	0.00361	
11 Performance Shortfall	0.0063				9.7E-13	0.01038	0.02625	3.1E-06	0.01082
12 Subjective Success	0.00281	0.02908	0.00059	1.1E-05		0.0054	0.01975	0.00077	
13 Replanning		1.5E-05	5E-07		0.0182			0.001	0.00192
16d Requirements Difficult		0.00027	0.00165	0.00163	0.00115	0.02594		0.00892	0.00244
32 Cognitive Fog	0.00789	0.03948	0.012	0.00074	0.00088	0.0095			
38f Stakeholder Relationships		0.02093	0.02429	0.0245	0.03361	0.00028	0.00272	0.03238	

Black text: Significant (p<0.001). White text: Significant (p<0.05).

- Three top variables strong predictors of Cost, Schedule, Performance shortfall.

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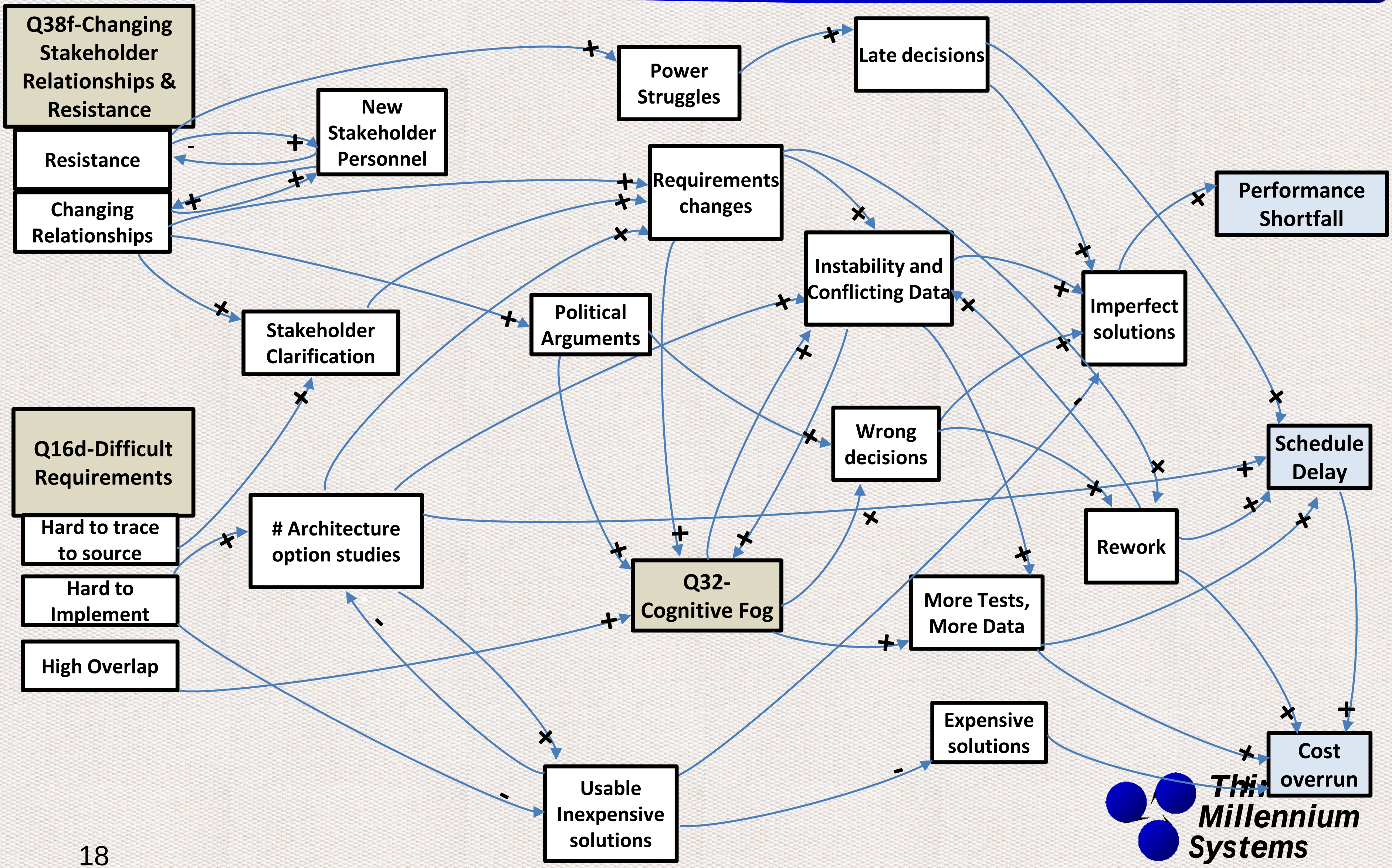
Top Complexity Variables Influence Outcomes

Balance Growth Connections



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Two Outcome Groups

		Delivered Product	Performance Shortfall	Subjective Success	Replanning	Cost Overrun	Schedule Delay
		8	11	12	13	9	10
14d	Use Lean			Sig			
29	No. Government		Sig				
38h	System Behavior Known		Sig	Sig			
31	Experience Level	Sig	Sig	Sig			
38f	Stakeholder Relationships		Sig	Sig	**Very Sig.**	Sig	Sig
32	Cognitive Fog	Sig	**Very Sig.**	**Very Sig.**	Sig	Sig	Sig
16d	Requirements Difficult		Sig	Sig	Sig	**Very Sig.**	Sig
33	Estimates Right		**Very Sig.**	Sig	**Very Sig.**	**Very Sig.**	**Very Sig.**
36	Stakeholder Conflict	Sig		Sig	Sig		Sig
14a	Use PERT		Sig -		Sig -		
38e	Stakeholder Involvement			Sig	Sig	Sig	Sig
18	Technical Rqts Conflict			Sig	Sig		Sig
1	Domain			Sig	Sig	Sig	
16n	Requirements Nominal				Sig	Sig	Sig
19	Tech-C&S Rqts Conflict				**Very Sig.**	Sig	Sig
16e	Requirements Easy				Sig	Sig	
25	Schedule Dependency				Sig	Sig	
4	Annual Cost				Sig	Sig	
23	No. Subcontractors				Sig	Sig	
38b	Scope Function-Enterprise				Sig	Sig	
6	Relative Size				Sig		Sig
27	Staff Skills				Sig		Sig
14b	Use Risk Mgmt				Sig -		Sig -
37	Needs Changed				**Very Sig.**		Sig
28	No. Decision Makers				Sig		
5	Life Cost					Sig	Sig
24	Changes Limbo					Sig	Sig
26	Planned-Agile					Sig -	

Sig: $p<0.05$; Very sig: $p<0.001$

Subsets

Size

Split by v \ Diff ->	30	15	23	28	29	35	16e	16n	16d
30 No. Contractors			S						
15 No. Subsystems	S		S						
23 No. Subcontractors	S	S			VS				
28 No. Decision Makers	S						VS		
29 No. Government			VS	S					
35 No. Sponsors				S					
16e Requirements Easy				S				VS	S
16n Requirements Nominal			S				VS		VS
16d Requirements Difficult		S	S				VS	VS	

Project Basics

Split by v	1	4	5	7a	7b	15	23	30
Domain		S	S	S				
Annual Cost			VS	S		S	S	
Life Cost		VS		S		VS	S	
Start Year	S	S	S		VS			
Finish Year	S			VS				
No. Subsystems		S	S				S	S
No. Subcontractors		VS	VS			S		S
No. Contractors							S	

Proj Mgmt

Split by v \ Diff ->	25	14a	13	33	26	34	38d	14b	14c	14d
25 Schedule Dependency		S	S	S	VS	S	S			
14a Use PERT	S		S	S				S		
13 Replanning		S		VS				S		
33 Estimates Right	S	S	VS							
26 Planned-Agile	S					S				
34 Priorities Short Term	S				S					
38d Acquire Projects Systems					S					
14b Use Risk Mgmt		S	S							
14c Use Agile										
14d Use Lean										

Requirements

Split by v \ Diff ->	16e	16n	16d	18	19	37	38a	20
16e Requirements Easy		VS	S		S			
16n Requirements Nominal	VS		VS	S				
16d Requirements Difficult	VS	VS		S	S	S		
18 Technical Rqts Conflict			S		S	S		
19 Tech-C&S Rqts Conflict	S			VS		S		
37 Needs Changed			S	S	S		S	
38a Mission Environment						S		
20 Expectations Easy								

Stakeholders

Split by v \ Diff ->	20	35	23	28	29	38b	38c	38e	38f	36
20 Expectations Easy										
35 No. Sponsors				S						
23 No. Subcontractors					VS					S
28 No. Decision Makers						S				S
29 No. Government			VS	S						
38b Scope Function-Enterprises									S	S
38c Scale of Users										
38e Stakeholder Involvement						S			VS	VS
38f Stakeholder Relationships			S			S		VS		VS
36 Stakeholder Conflict						S		VS	S	

Changes

Split by v \ Diff ->	24	21	22	37	38h
24 Changes Limbo					
21 TRLs					S
22 Operational Evolution					S
37 Needs Changed					
38h System Behavior Known			S		

Conflict

Split by v \ Diff ->	18	19	32	36
18 Technical Rqts Conflict		S	S	S
19 Tech-C&S Rqts Conflict	VS		S	S
32 Cognitive Fog	S	S		VS
36 Stakeholder Conflict	S	S	VS	

Uncertainty

Split by v \ Diff ->	24	32
24 Changes Limbo		S
32 Cognitive Fog	S	

Skills

Split by v \ Diff ->	27	31
27 Staff Skills		S
31 Experience Level	S	

Early and Late Indicators

Balance ● Growth ● Connections

Beginning of Program

Q1—Domain
Q4—Annual cost
Q6—Relative Size
Q7a—Start Year
Q15—No. Subsystems
Q16e—Requirements Easy
Q16n—Requirements Nominal
Q16d—Requirements Difficult
Q17—Architecture Precedence
Q18—Technical Rqts Conflict
Q19—Tech-C&S Rqts Conflict
Q20—Expectations Easy
Q23—No. Subcontractors
Q25—Schedule Dependency
Q27—Staff Skills
Q29—No. Government
Q30—No. Contractors
Q31—Experience Level
Q38b—Scope Function-Enterprises
Q38d—Acquire Projects Systems
Q38h—System Behavior Known

Beginning to Middle

Q14a—Use PERT
Q14b—Use Risk Mgmt
Q14c—Use Agile
Q14d—Use Lean
Q21—TRLs
Q28—No. Decision Makers
Q35—No. Sponsors
Q38a—Mission Environment
Q38c—Scale of Users
Q38g—New Capability

Middle

Q5—Life Cost
Q24—Changes Limbo
Q26—Planned-Agile
Q32—Cognitive Fog
Q34—Priorities Short Term
Q36—Stakeholder Conflict
Q38e—Stakeholder Involvement
Q38f—Stakeholder Relationships
Q37—Needs Changed
Q13—Replanning

End

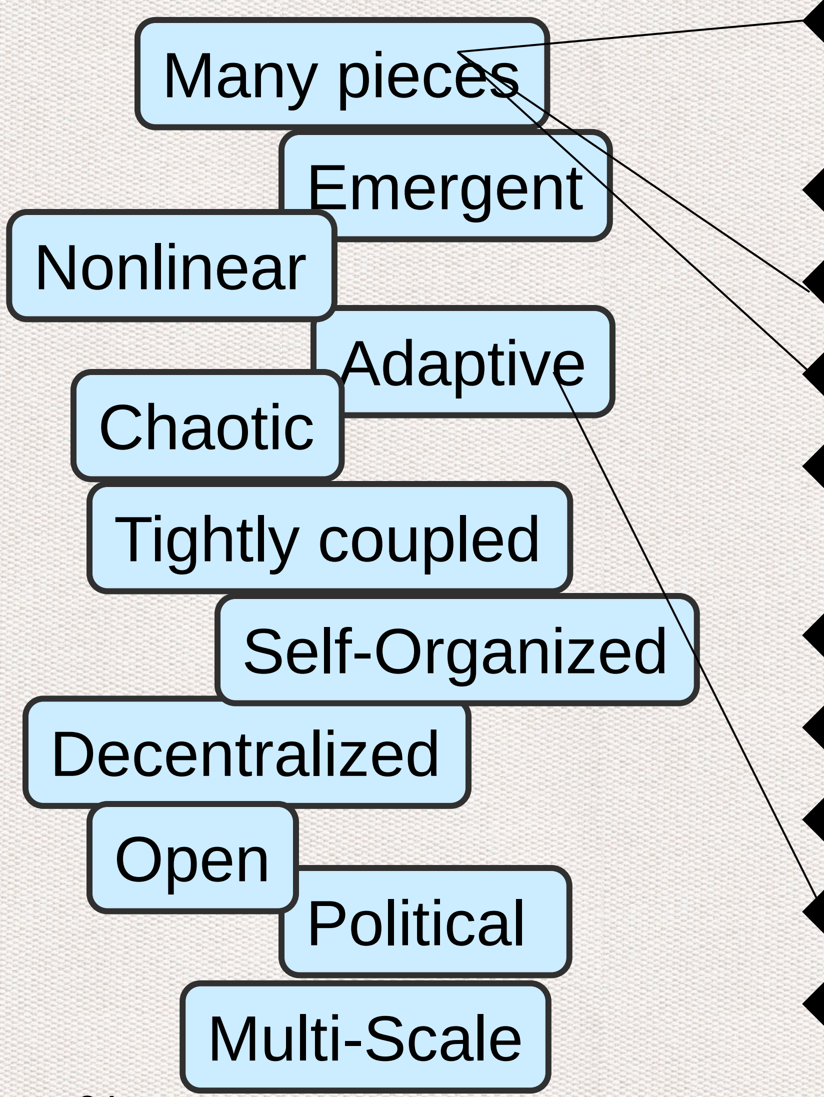
Q7b—Finish Year
Q8—Deliver Product
Q9—Cost Overrun
Q10—Schedule Delay
Q11—Performance Shortfall
Q12—Subjective Success
Q22—Operational Evolution
Q33—Estimates Right

NEXT STEPS

Potential Future Work

- Application of results to projects
  - Identify ways to reduce complexity
  - Develop heuristics for "enough reduction"
  - Architecture complexity, requirements complexity, stakeholder complexity, test complexity, etc. measures can be identified and tested
  - Build a "complexity referent" to compare a program to...how much complexity is typically reduced at what points

Manage Complexity: SE and Complexity



- Planning, and monitoring to ensure compliance
- Control
- Hierarchy and modularization
- Decomposition (Reductionism)
- Order...predicting and avoiding chaotic regimes
- Gaussian distributions
- Trade Studies
- Requirements
- Architecture,Stable intermediates
- Vanquish complexity

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How SE Could Better Address Complexity

Balance ● Growth ● Connections

Many pieces
Emergent
Nonlinear
Adaptive
Chaotic
Tightly coupled
Self-Organized
Decentralized
Open
Political
Multi-Scale

- Planned co-evolution with environment
- Managing the boundaries of safe state spaces
- Understand decentralized control
- Use modularity and hierarchy along with networks
- Decomposition (Reductionism) where appropriate
- Intensive modeling and simulation
- Predicting ordered and chaotic regimes in technological systems and development systems
- Power-law distributions as well as Gaussian
- Trade Studies, Requirements, Architecture, Stable intermediates
- Invoke social sciences
- Manage complexity as risk

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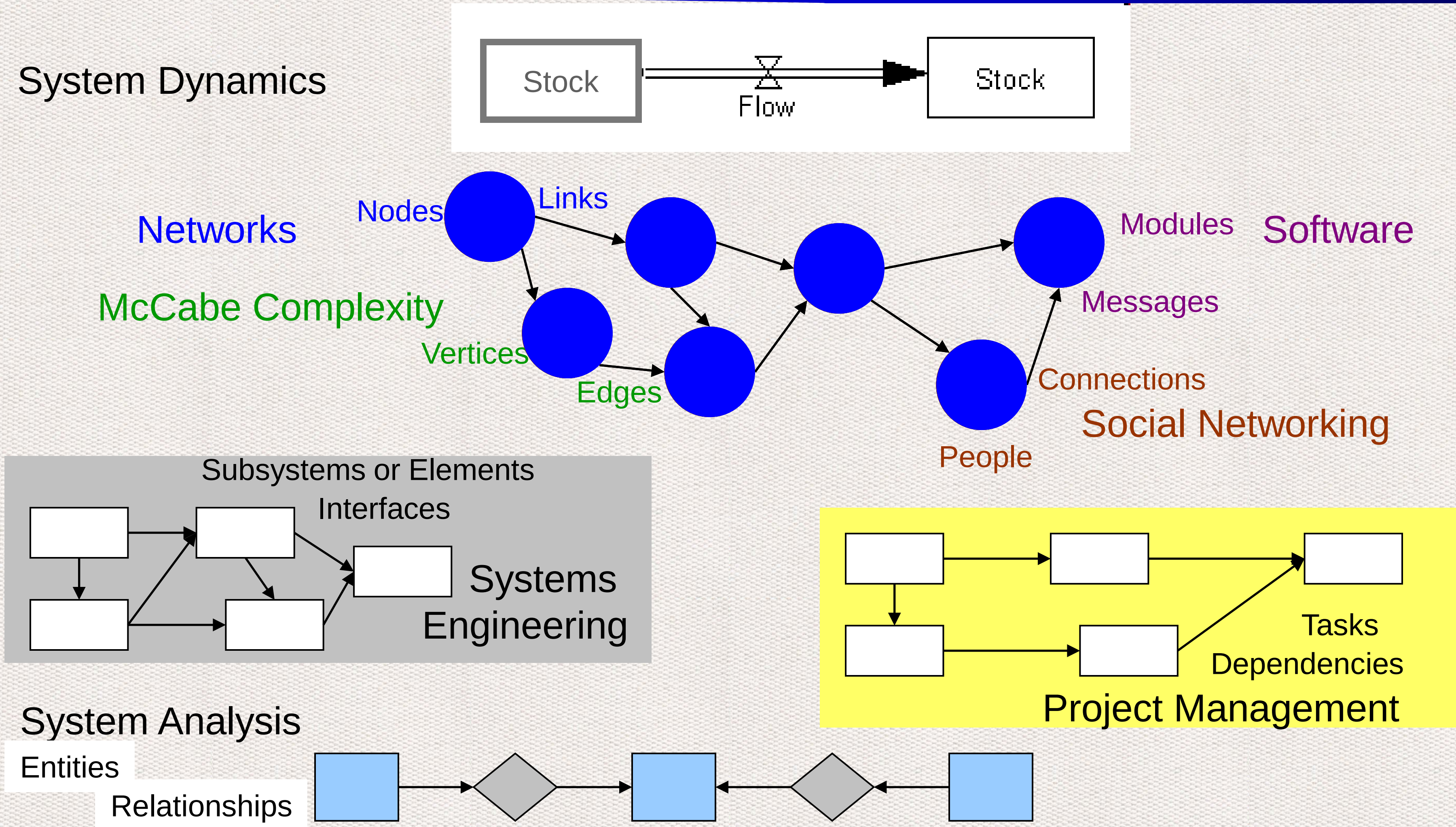
“Atomic Pieces” of Complexity Representation



Model = Things + Relationships

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Problems with measuring complexity

- Measuring=counting
- Measuring=simplification
- Things that used to be very complex (e.g. airplane) are not now
- It depends on purpose: is a small circuit (resistor+capacitor) complex?
- For systems engineering: Complexity of what? Various views and representations
- How do tools vary from standard SE repertoire?

Definition of Complexity

- Complexity is the inability to predict behavior due to nonlinearity, emergent behavior and chaotic principles.
  - Characterizes systems, projects, and the external environment.
  - Has structural (size, connectivity, and inhomogeneity), dynamic, and socio-political factors,
  - Manifests as spectra, from less complex to more complex, in a large number of variables
  - Displayed by a system, its representation, and the interpretation of the variables by humans

Research Methodology: Method's Validity

Balance ● Growth ● Connections

- Empirical
  - Calibration... Difficult; used bins.
  - Measures what it purports to measure...Difficult: many definitions of complexity...Literature→taxonomy, respondent roles
- Content
  - Face...Delphi group
  - Sampling...Broad variety and moderately large number of programs; used INCOSE
- Model
  - Internal...Ask questions in unbiased manner. Verify whether other explanations are possible. Example: Estimates good, Replanning
  - Internal consistency…separate questionnaire into sections for "system", "project", and "environment"
  - External...Tested for stability of linear correlations; backed off. Domain is aerospace/defense and may be extensible
  - Theoretical...Literature review
  - Pragmatic...Designed around usability and practicality

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Research Limitations

- Limitations
  - Correlation is not causation…no guarantee that changing these variables will improve success rate.
  - Results are qualitative, not quantitative
  - Retrospective surveys and data categories; survey did not also interview participants to tease out their meanings of ambiguous terms
  - Small numbers of non-aerospace/defense, and failed projects
  - May have been confusion about some questions, e.g., "double-loop learning/set-based engineering"; operational evolution; meaning of "performance."
  - Did not address how complexity of different aspects of systems and projects might differ (management vs technical experience level, technical vs programmatic estimates, e.g.)

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Research Methodology: Measurement criteria

• Real	{Entire research question}
• Reproducible	
– Equivalence	Careful phrasing and testing of questions
– Stability	After 1 year (4): 64% same, 93% nearly.
• Predictive	{Point of research question}
• Usable	Feedback from surveys and interviews...no problems filling them out; also data stability
– Convenient data	
– Interpretable data	
• Robust	Careful phrasing, measures selection
• Complete	Lit. review, grouping, correlation
• Individual	Measures selection
• Orthogonal	Measures selection, some analysis
• *Valid*	*See separate chart*

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Measures, Types, and Entities

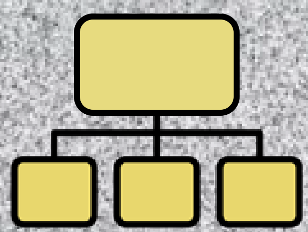
Balance ● Growth ● Connections

(32 addresses cognitive entity)	System	Project	Environ- ment
How many pieces?	5, 15, 16	4, 6, 28, 29, 30	35
How many connections?	16,18, 19	25	36, 38e,
What kind of structure?	17	23	38d
How rapidly must react to changes?	21	24	38f
How much evolving?	22	26	38a, 38g, 38h
How much socio-political complexity?	20	27, 31	38b, 38c

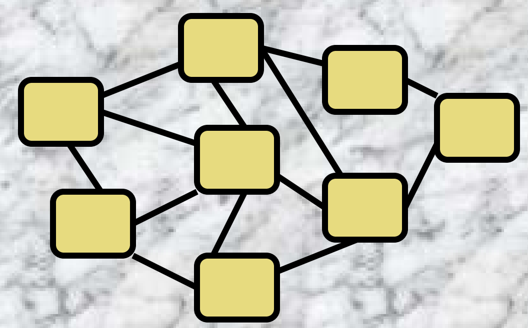
Complexity

Simple systems

Systems using systems engineering

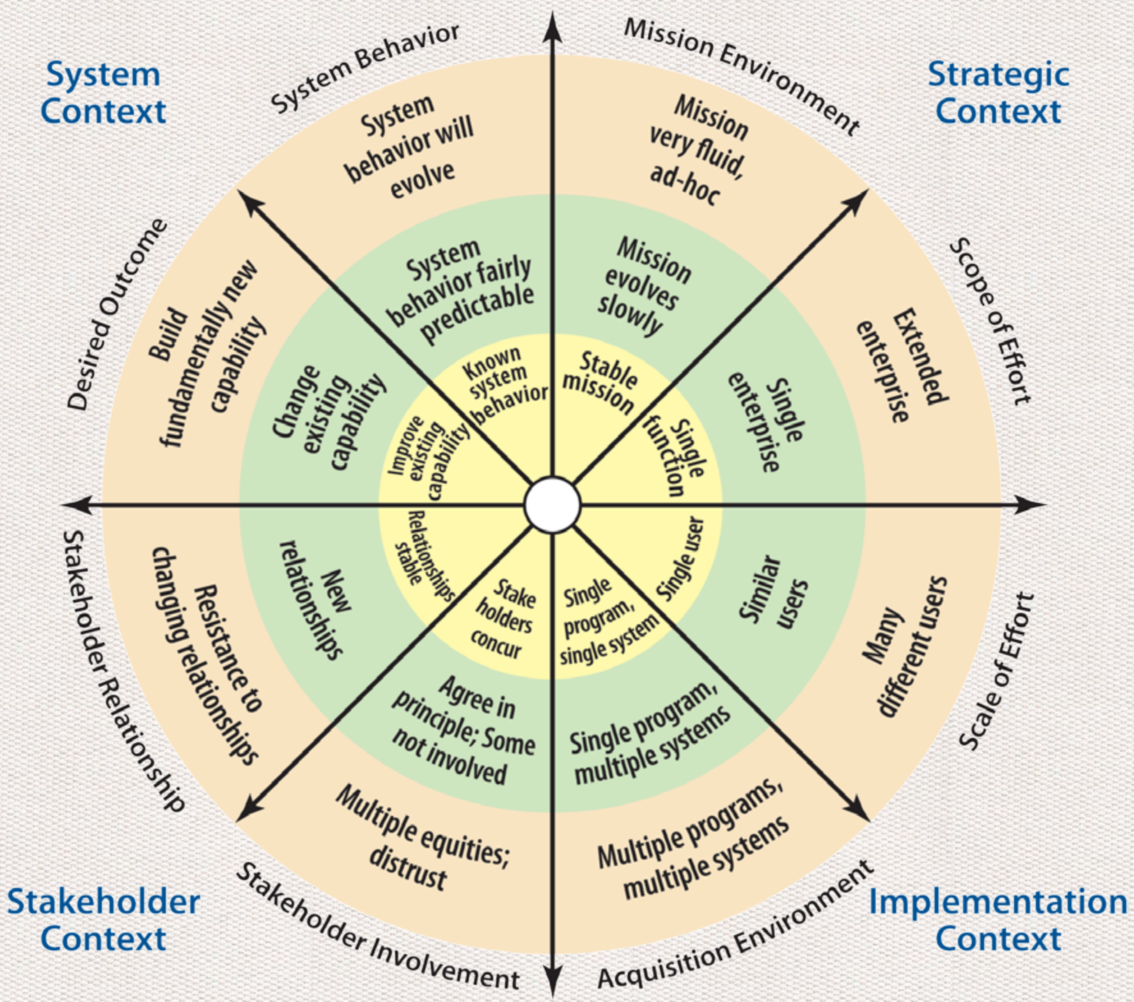


Complex systems



MITRE's ESE Profiler (Renee Stevens)

Balance ● Growth ● Connections



Traditional program domain

- *Well-bounded problem*
- *Predictable behavior*
- *Stable environment*

Transitional domain

- *Systems engineering across boundaries*
- *Influence vs. authority*

Messy frontier

- *Political engineering (power, control…)*
- *High risk, potentially high reward*
- *Foster cooperative behavior*

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Typical questions

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(1) 1 (2) 2-3 (3) 4-6 (4) 7-10 (5) >10

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3:Mission very fluid, ad-hoc

Survey Questions

Balance ● Growth ● Connections

☞ Projects must be finished (so result is known)

- **Project** questions (characteristics of project, when was it, size)
- **Success and management** (how successful, cost overrun, schedule overrun, performance, replanning, management techniques used)
- **System** questions (# subsystems, # and difficulty of requirements, precedence of architecture, requirements conflict, ease of meeting requirements, tech maturity, evolution)
- **Organizational effort (project)** questions (structure, # changes in limbo, tightly connected project network, management agility, skills, # signatures, # government organizations, # contractors, cognitive fog, estimates, short-term vs long-term focus)
- **Environment** questions (# stakeholders, # sponsors, conflict, changes in needs, ESE profiler)
- **Biographical** questions about responder (name, contact info, how knowledgeable)

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Wording of Questions

Balance ● Growth ● Connections

Q32 'The project frequently found itself in a fog of conflicting data and cognitive overload.' Do you agree with this statement?

(1)Strongly Agree (2)Agree (3)Neutral (4)Disagree (5)Strongly Disagree

Q16d. "Approximately how many system-level requirements did the project have initially? Difficult requirements are considered difficult to implement or engineer, are hard to trace to source, and have a high degree of overlap with other requirements. How many system requirements were there that were Difficult?

(1)1-10 (2)10-100 (3)100-1000 (4)1000-10,000 (5)Over 10,000

Q38."Where did your project fit, on a scale of Traditional, Transitional, or Messy Frontier, in the following eight attributes?"

38f. Stakeholder relationships: (1) Relationships stable; (2) New relationships; (3) Resistance to changing relationships.

6
13

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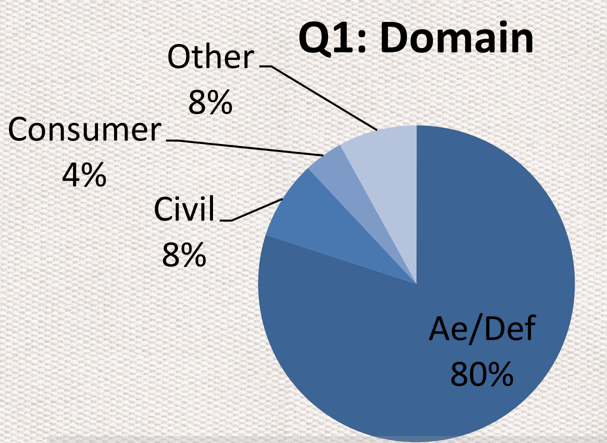
Which Complexity Measures Predict Problems?

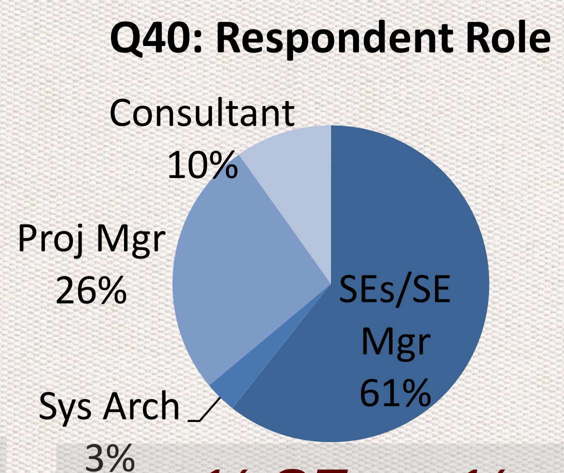
- Identify measures
- Draft survey
- Survey 75 programs
  - Values of measures
  - Outcomes
- Analyze statistics
  - t-test for difference of means
  - Find measures that predict differences in outcomes

Survey Characteristics

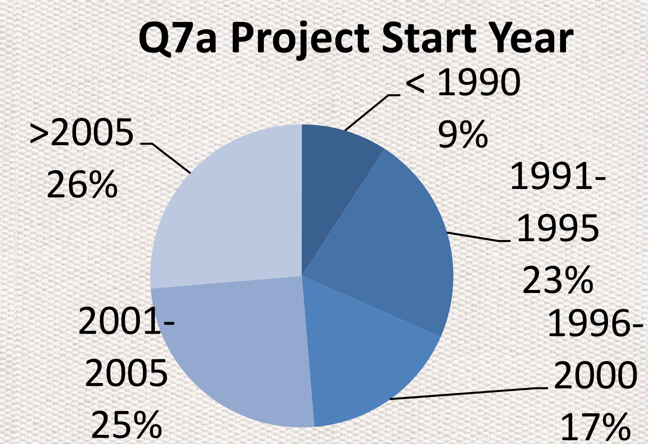
Balance ⬤ Growth ⬤ Connections



80% Aerospace/ defense

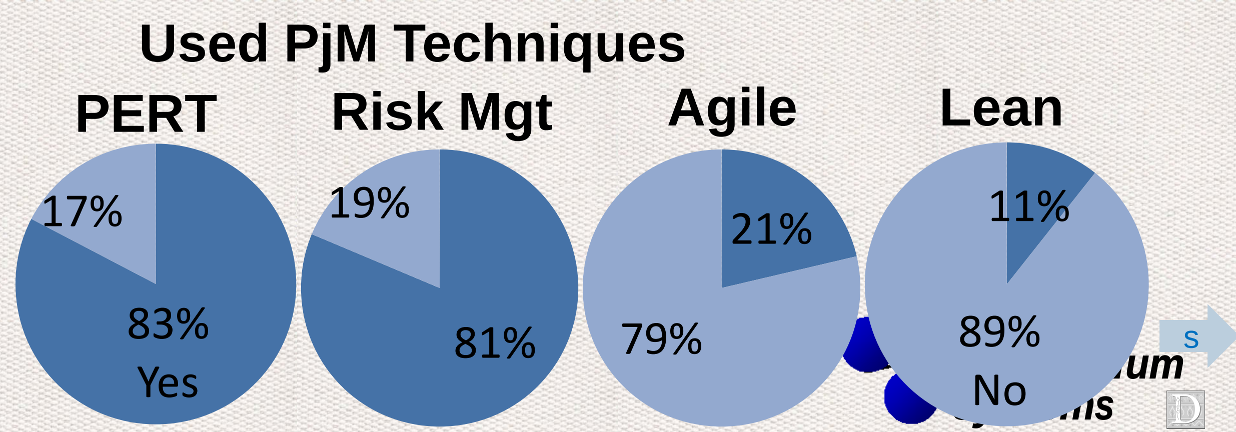


> ½ SEs, ~ ¼ Project Managers



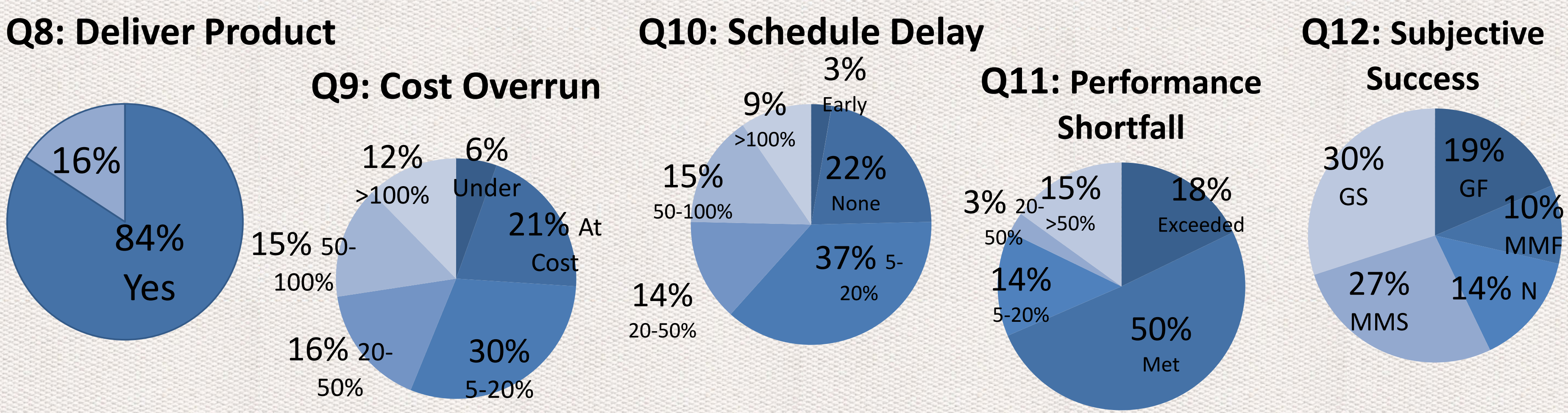
Fairly evenly split over 20 years

Over 80% used PERT-type planning and used Risk Management; only 10-20% used Agile or used Lean



Outcomes

Balance ● Growth ● Connections



Only about ¼ met cost and schedule, but 70% met performance; > ½ a success

Independent (39 Questions)

- Project Characteristics (17)
- System Characteristics (10)
- Environment Characteristics (11)
- Cognitive characteristics (1)

Dependent
(5 questions: Project Outcomes)

- Cost
- Schedule
- Performance
- Deliver product
- Subjective Success

Third Millennium Systems

Research Statement

Balance ● Growth ● Connections

◆ Research Question

Does complexity predict program failure?

◆ Hypothesis

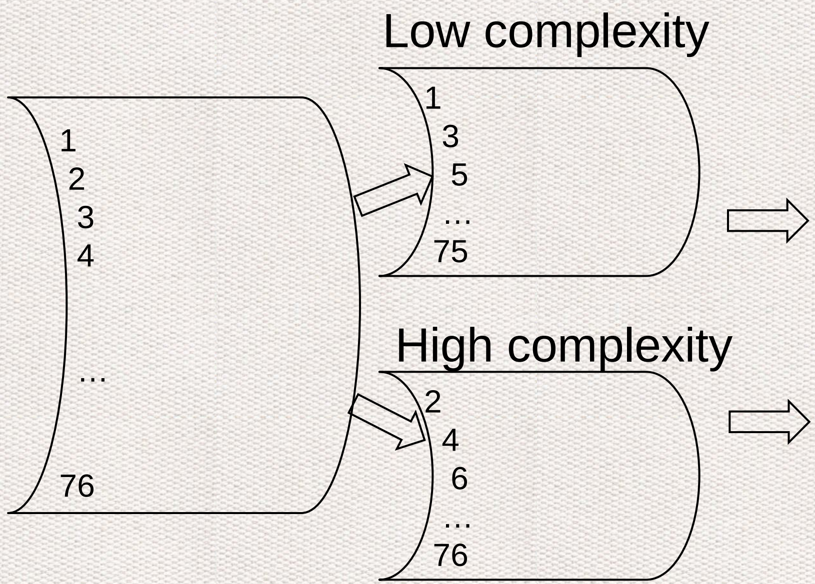
*Programs characterized by higher numbers of "difficult" * requirements, higher cognitive overload and more complex stakeholder relationships demonstrate significantly higher performance issues (cost overrun, schedule delay, and performance shortfall).*

Third Millennium Systems

*"Difficult" is defined by COSYSMO (Valerdi 2008)

t-test Analysis

Balance ● Growth ● Connections



Outcomes

	Cost Overrun	Schedule Delay	Performance Shortfall
Low complexity	**2.6 ± 1.3**	**3.0 ± 1.6**	**2.4 ± 1.4**
High complexity	**3.8 ± 1.4**	**3.6 ± 1.2**	**2.5 ± 1.2**

All programs

2 groups based on a complexity measure (e.g., Annual cost)

Are these the same or different?

- Null hypothesis: the groups are the same and there is no contribution to success from complexity measure
- If t-test shows probability of difference occurring by chance is <0.05 (2-tail), there is significance
- Two tests; which is chosen depends on F-test.

	C	**S**	**P**
F test	0.75	0.20	0.36
t-test1	0.002	0.161	0.902
t-test2	0.002	0.229	0.909
Result			

Results

p-values	Product	Cost	Schedule	Perf.	Subj Succ	Replng	ReqDif	CogFog	Stk Rels
Diff ->	8	9	10	11	12	13	16d	32	38f
Split by v									
8 Delivered Product				0.01106	4.2E-06		0.03762	0.00029	0.03167
9 Cost Overrun			2.6E-10			0.00021		0.01001	
10 Schedule Delay		1.4E-11			0.0228	5.1E-06	0.02194	0.00361	
11 Performance Shortfall	0.0063				9.7E-13	0.01038	0.02625	3.1E-06	0.01082
12 Subjective Success	0.00281	0.02908	0.00059	1.1E-05		0.0054	0.01975	0.00077	
13 Replanning		1.5E-05	5E-07		0.0182			0.001	0.00192
16d Requirements Difficult		0.00027	0.00165	0.00163	0.00115	0.02594		0.00892	0.00244
32 Cognitive Fog	0.00789	0.03948	0.012	0.00074	0.00088	0.0095			
38f Stakeholder Relationships		0.02093	0.02429	0.0245	0.03361	0.00028	0.00272	0.03238	

Black text: Significant ($p<0.001$). White text: Significant ($p<0.05$).

- Three top variables strong predictors of Cost, Schedule, Performance shortfall.

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Hypothesis Variables vs. Outcomes

		Outcome Variable		
		Cost	Schedule	Performance
Complexity Variable	N	Overrun	Overrun	Shortfall
Q16d—Requirements Difficult				
Low (Under 100) mean	57	3.37	3.30	2.26
High (Over 100) mean	12	5.00	4.64	3.60
p-value		0.00027	0.00165	0.00163
Significance		Very (p<0.001)	Significant	Significant
Q32—Cognitive Fog				
Low (D-SD) mean	33	3.03	2.97	2.00
High (A-SA) mean	19	3.89	4.11	3.53
p-value		0.0395	0.0120	0.00074
Significance		Significant	Significant	Very (p<0.001)
Q38f—Stakeholder Relationships				
Low (Stable) mean	20	3.30	3.11	2.15
High (Resistance) mean	16	4.50	4.19	3.27
p-value		0.0209	0.0243	0.0245
Significance		Significant	Significant	Significant

Means:
1 = better
2 = +/- 5%
3 = worse 5-20%
4 = worse 20-50%
5 = worse 50-100%
c&s only:
6 = worse >100%

Two Outcome Groups

		Delivered Product	Performance Shortfall	Subjective Success	Replanning	Cost Overrun	Schedule Delay
		8	11	12	13	9	10
14d	Use Lean			Sig			
29	No. Government		Sig				
38h	System Behavior Known		Sig	Sig			
31	Experience Level	Sig	Sig	Sig			
38f	Stakeholder Relationships		Sig	Sig	**Very Sig.**	Sig	Sig
32	Cognitive Fog	Sig	**Very Sig.**	**Very Sig.**	Sig	Sig	Sig
16d	Requirements Difficult		Sig	Sig	Sig	**Very Sig.**	Sig
33	Estimates Right		**Very Sig.**	Sig	**Very Sig.**	**Very Sig.**	**Very Sig.**
36	Stakeholder Conflict	Sig		Sig	Sig		Sig
14a	Use PERT		Sig -		Sig -		
38e	Stakeholder Involvement			Sig	Sig	Sig	Sig
18	Technical Rqts Conflict			Sig	Sig		Sig
1	Domain			Sig	Sig	Sig	
16n	Requirements Nominal				Sig	Sig	Sig
19	Tech-C&S Rqts Conflict				**Very Sig.**	Sig	Sig
16e	Requirements Easy				Sig	Sig	
25	Schedule Dependency				Sig	Sig	
4	Annual Cost				Sig	Sig	
23	No. Subcontractors				Sig	Sig	
38b	Scope Function-Enterprise				Sig	Sig	
6	Relative Size				Sig		Sig
27	Staff Skills				Sig		Sig
14b	Use Risk Mgmt				Sig -		Sig -
37	Needs Changed				**Very Sig.**		Sig
28	No. Decision Makers				Sig		
5	Life Cost					Sig	Sig
24	Changes Limbo					Sig	Sig
26	Planned-Agile					Sig -	

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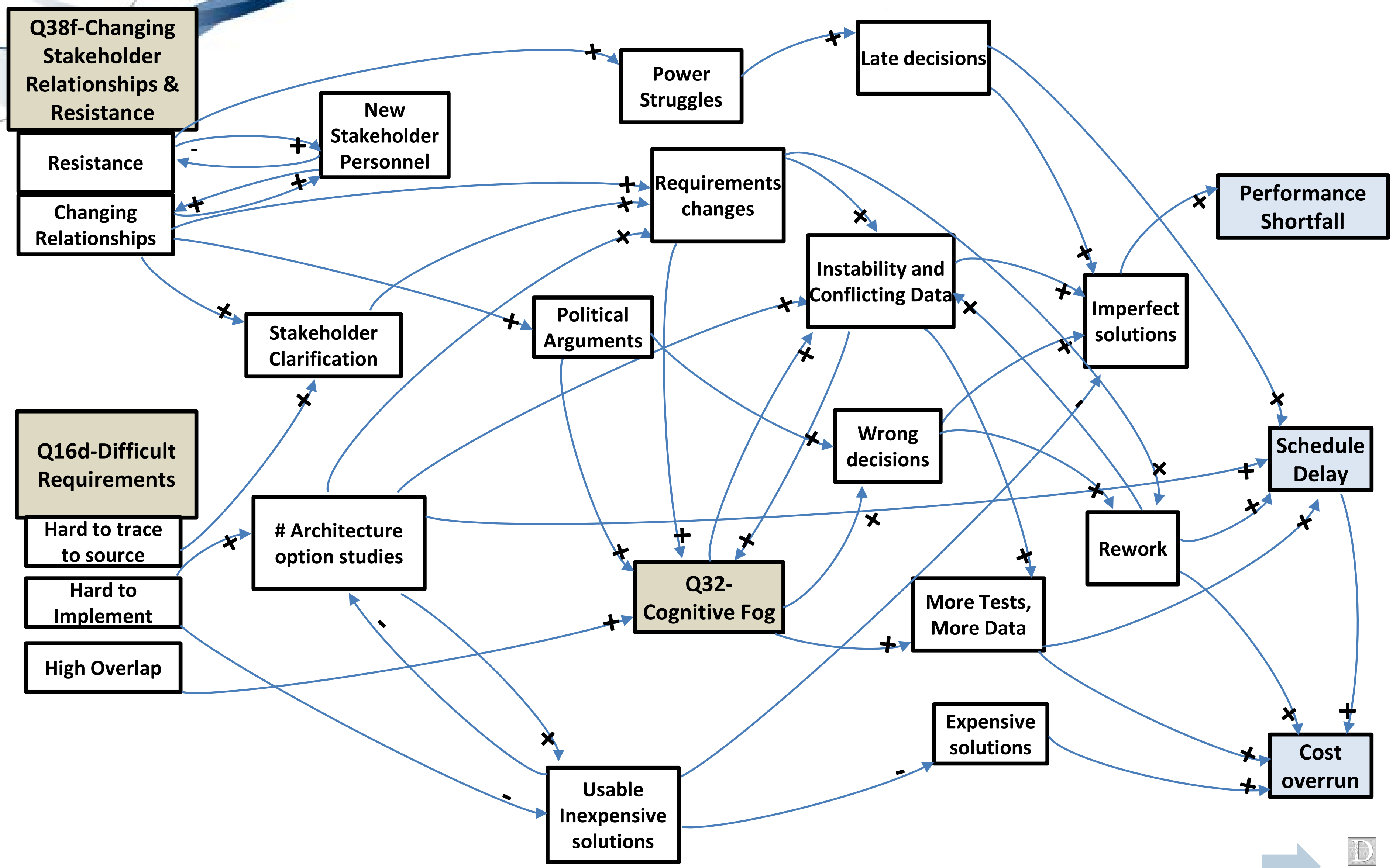
How Do Top 3 Complexity Variables Lead to Outcomes?



Subsets

Size

	Diff -> Split by v	30	15	23	28	29	35	16e	16n	16d
30	No. Contractors			S						
15	No. Subsystems	S		S						
23	No. Subcontractors	S	S			VS				
28	No. Decision Makers	S						VS		
29	No. Government			VS	S					
35	No. Sponsors				S					
16e	Requirements Easy				S				VS	S
16n	Requirements Nominal			S				VS		VS
16d	Requirements Difficult		S	S				VS	VS	

Requirements

	Diff -> Split by v	16e	16n	16d	18	19	37	38a	20
16e	Requirements Easy		VS	S		S			
16n	Requirements Nominal	VS		VS	S				
16d	Requirements Difficult	VS	VS		S	S	S		
18	Technical Rqts Conflict			S		S	S		
19	Tech-C&S Rqts Conflict	S			VS		S		
37	Needs Changed			S	S	S		S	
38a	Mission Environment						S		
20	Expectations Easy								

Project Basics

Split by v	1	4	5	7a	7b	15	23	30
Domain		S	S	S				
Annual Cost			VS	S		S	S	
Life Cost		VS		S		VS	S	
Start Year	S	S	S		VS			
Finish Year	S			VS				
No. Subsystems		S	S				S	S
No. Subcontractors		VS	VS			S		S
No. Contractors							S	

Stakeholders

	Diff ->	20	35	23	28	29	38b	38c	38e	38f	36
20	Expectations Easy										
35	No. Sponsors				S						
23	No. Subcontractors					VS					S
28	No. Decision Makers						S				S
29	No. Government			VS	S						
38b	Scope Function-Enterprises									S	S
38c	Scale of Users										
38e	Stakeholder Involvement						S			VS	VS
38f	Stakeholder Relationships			S			S		VS		VS
36	Stakeholder Conflict						S		VS	S	

Proj Mgmt

	Diff -> Split by v	25	14a	13	33	26	34	38d	14b	14c	14d
25	Schedule Dependency		S	S	S	VS	S	S			
14a	Use PERT	S		S	S				S		
13	Replanning		S		VS				S		
33	Estimates Right	S	S	VS							
26	Planned-Agile	S					S				
34	Priorities Short Term	S				S					
38d	Acquire Projects Systems					S					
14b	Use Risk Mgmt		S	S							
14c	Use Agile										
14d	Use Lean										

Changes

	Diff -> Split by v	24	21	22	37	38h
24	Changes Limbo					
21	TRLs					S
22	Operational Evolution					S
37	Needs Changed					
38h	System Behavior Known			S		

Uncertainty

	Diff -> Split by v	24	32
24	Changes Limbo		S
32	Cognitive Fog	S	

Skills

	Diff -> Split by v	27	31
27	Staff Skills		S
31	Experience Level	S	

Conflict

	Diff -> Split by v	18	19	32	36
18	Technical Rqts Conflict		S	S	S
19	Tech-C&S Rqts Conflict	VS		S	S
32	Cognitive Fog	S	S		VS
36	Stakeholder Conflict	S	S	VS	

Complexity Variables and Spectra

- Desire: Determine whether complexity is correlated with problems
- Each question becomes a variable with a spectrum of answers: one end of which is assumed to be more complex; test that hypothesis
- Bigger: Higher annual cost, more decision makers, more stakeholders, more requirements
- Other reasons to consider one end of the spectrum to be more complex are on next slide

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Assumptions of "More Complex"

Each variable needed a polarity. Must define "more complex" for every variable:

- Anything larger (dollars, numbers, ...)
- More conflict or more unprecedented
- More change
- Lower technology maturity
- Not using project management methods, or prioritizing short-term over long-term*
- Agile/incremental rather than planned/controlled*
- Later programs*
- Fewer skills or less experience, more confusion
- More failure (more overrun, performance shortfall, not delivering a product, subjective failure...)

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Additional analysis: Coherence

- Do two variables go up together or opposite?

Together | Opposite | No difference in means

Coherence conclusions

- 22 variables have high coherence with outcome variables (upper left)
- Several variable together are likely to be better indicator than any one variable
- No variables were unanimously opposite
- Project Management and Start Year were somewhat red
  - Polarity likely wrong; explanations speculative

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Significance, Unsorted

	Diff ->	1	4	5	6	7a	7b	8	9	10	11	12	13	14a	14b	14c	14d	15	16e	16n	16d	17	18	19	20	21	22*	23*	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38a	38b	38c	38d	38e	38f	38g	38h
	Split by v																																																	
1	Domain		S	S		S			S			S	S																																			S		
4	Annual Cost			VS		S			S				S	S		S		S	S	VS	S				S			S	VS				S											S						
5	Life Cost		VS		S	S			S	S						S		VS	S	S	S				S			S	VS				S																	
6	Relative Size		S	S						S			S		S				S	S	S								S				S					S				S					S			
7a	Start Year	S	S	S			VS																																						S					
7b	Finish Year	S				VS																												S													S			
8	Delivered Product										S	VS							S		S		S									S				S	VS	S		S	S						S	S		
9	Cost Overrun		S	S						VS			VS						S	S				S					VS	S	S		S				S	VS		S	S			S						
10	Schedule Delay		S	VS	S				VS			S	VS		S						S			S	S				VS				S				S	VS			S	S								
11	Performance Shortfall				S			S				VS	S	S					S	S	S		S				S	S								VS	VS	VS										S		
12	Subjective Success	S						S	S	VS	VS		S						S	S	S	S															VS	S			S			S			S			S
13	Replanning	S	S	S	S				VS	VS		S		S	S				S	S			S	VS									S				VS	VS			S	S		S			S	S		
14a	Use PERT		S	S							S		S		S				VS	S								S		S								S												
14b	Use Risk Mgmt				S					S			S	S						S																														
14c	Use Agile		S																						S																									
14d	Use Lean				S							S																																						
15	No. Subsystems		S	S																								S				S			S															
16e	Requirements Easy			S	S				S				S	VS						VS	S			S					S	S	S		S			S	VS							S			S	S		
16n	Requirements Nominal		VS	S	S				S	S			S	S	S				VS		VS		S					S																			S	S		
16d	Requirements Difficult		VS	VS	S				VS	S	S	S	S					S	VS	VS		S	S	S				S	S	S	S						S					S		S		S	S	S		
17	Architecture Precedence																																				S							S						S
18	Technical Rqts Conflict									S		S	S								S			S									S				S				S	S								
19	Tech-C&S Rqts Conflict								S	S			VS						S				VS						S	S		S	S				S	S	S		S	S								
20	Expectations Easy																					S																												
21	TRLs																																												S					S
22	Operational Evolution				VS																																													S
23	No. Subcontractors		VS	VS					S				S					S					S											VS	S						S	S	S							
24	Changes Limbo		VS	VS	S				S	S									S	S			S	S									VS		S		S	S												
25	Schedule Dependency								S				S	S					S					S							VS			S				S	S						S	S				
26	Planned-Agile								S										S										S	S									S											
27	Staff Skills			S	S					S			S					S											S							S	S	VS			S						S			S
28	No. Decision Makers		S	S									S			S			VS				S	S					VS						S		S		S		S			S						
29	No. Government										S					S												VS		S			S			S														
30	No. Contractors																								S			S	S										S											
31	Experience Level							S			S	S												S								S		S			VS	VS		S	S	S					S	S		
32	Cognitive Fog							S	S	S	VS	VS	S						S	S		S	S	S					S			S	S			VS		VS			VS	S		S			S			
33	Estimates Right								VS	VS	VS	S	VS	S										S					S	S		VS				VS	VS				S									
34	Priorities Short Term																							S						S	S		S		S														S	
35	No. Sponsors	S			S																									S			S																	
36	Stakeholder Conflict							S		S		S	S										S	S								S				VS	VS	S				VS	S	S			VS	S		
37	Needs Changed				S					S			VS				S				S		S	S												S	S				S		S				S	S		
38a	Mission Environment																																								S	S		S						S
38b	Scope Function-Enterprises		S	S	S	S			S				S						S	S	S	S		S											S		S				S	S	S			VS		S	S	
38c	Scale of Users					S	S																																											S
38d	Acquire Projects Systems																			S	S	S									S									S				VS						S
38e	Stakeholder Involvement				S				S	S		S	S						VS	VS	S	S	S				S					S				S	VS	S	S		VS	S		S				VS		
38f	Stakeholder Relationships								S	S	S	S	VS						S	S	S		S					S									S				VS	S		S			VS			
38g	New Capability																S					S																	S						S					VS
38h	System Behavior Known										S	S										S	S		S		S										S	S					S	S	S	S			VS	

S=significant; VS=very significant

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Coherence

	Diff ->	32	13	33	16d	10	9	12	36	38e	16e	5	16n	24	38b	4	19	38f	11	31	28	37	6	18	23	38h	8	27	25	17	1	38d	15	29	30	35	34	38a	20	22	38g	38c	21	7a	7b	14a	14b	14c	14d	26
	Split by v																																																	
32	Cognitive Fog		S	VS		S	S	VS	VS	S	S		S	S	S		S		VS	VS	S	S		S			S	S		S																				
13	Replanning	VS		VS		VS	VS	S	S	S	S	S	S		S	S	VS	S			S	S	S	S							S															S	S			
33	Estimates Right	VS	VS			VS	VS	S	S					S			S		VS	VS								VS	S																	S				
16d	Requirements Difficult	S	S			S	VS	S		S	VS	VS	VS	S	S	VS	S	S	S			S	S	S	S				S	S		S	S																	S
10	Schedule Delay	S	VS	VS	S		VS	S	S			VS		VS		S	S				S	S	S																S								S			
9	Cost Overrun	S	VS	VS		VS			S		S	S	S	VS	S	S	S				S								S							S														S
12	Subjective Success	VS	S	S	S	VS	S		S	S	S		S		S				VS							S	S			S	S																			
36	Stakeholder Conflict	VS	S	S		S		S		VS					S		S	S		VS		VS		S			S	S										S												
38e	Stakeholder Involvement	VS	S	S	S	S	S	S	VS		VS		VS		S			VS		S		S	S	S				S		S							S			S										
16e	Requirements Easy	VS	S		S		S			S		S	VS	S	S		S	S		S	S		S						S																	VS				S
5	Life Cost				S	S	S				S		S	VS		VS					S		S		S								VS						S					S				S		
16n	Requirements Nominal		S		VS	S	S			S	VS	S				VS		S					S	S	S																					S	S			
24	Changes Limbo	S		S		S	S				S	VS	S			VS	S				VS		S	S											S															
38b	Scope Function-Enterprises	S	S		S		S		S		S	S	S			S	S	S				S	S							S		VS			S			S			S			S						
4	Annual Cost		S		S		S				S	VS	VS	VS	S						S				S								S						S					S		S		S		
19	Tech-C&S Rqts Conflict	S	VS	S		S	S		S		S			S							S	S		VS				S	S								S													
38f	Stakeholder Relationships	S	VS		S	S	S	S	VS	VS	S		S		S				S			S		S	S																									
11	Performance Shortfall	VS	S	VS	S			VS			S		S					S		VS			S	S	S		S													S						S				
31	Experience Level	VS		VS				S	S	S							S	S	S			S					S	S						S		S														
28	No. Decision Makers	S	S						S		VS	S		VS	S	S	S							S											S		S											S		
37	Needs Changed	S	VS		S	S			S	S							S	S		S			S	S														S											S	
6	Relative Size		S	S	S	S				S	S	S	S	S		S					S	S																									S			
18	Technical Rqts Conflict	S	S		S	S		S	S								S				S	S																												
23	No. Subcontractors		S				S		S			VS				VS						S		S									S	VS	S			S												
38h	System Behavior Known	S		S				S							S				S					S						S		S						S	S	S	VS	S								
8	Delivered Product	VS		S	S			VS	S	S	S							S	S	S				S				S								S														
27	Staff Skills	S	S	VS		S			S	S		S		S						S			S			S							S																	
25	Schedule Dependency		S	S			S				S						S															S		S			S					S				S				VS
17	Architecture Precedence	S													S											S																								
1	Domain		S				S	S				S				S		S																										S						
38d	Acquire Projects Systems				S								S		VS											S				S						S														S
15	No. Subsystems											S				S									S			S						S																
29	No. Government																		S	S	S				VS				S																			S		
30	No. Contractors													S											S												S		S											
35	No. Sponsors																				S		S						S		S																			
34	Priorities Short Term																S				S								S					S							S									S
38a	Mission Environment								S						S							S				S																								
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7b	Finish Year									S																					S			S										VS						
14a	Use PERT		S	S							VS	S	S			S			S						S				S																		S			
14b	Use Risk Mgmt		S			S							S										S																							S				
14c	Use Agile															S																								S										
14d	Use Lean							S															S																											
26	Planned-Agile						S				S			S															S								S													

Potential Future Work

- Research use in developing a program of research
  - Complexity can be correlated with risk, cost, skills, customer
  - Architecture complexity, requirements complexity, stakeholder complexity, test complexity, etc. can be measured
  - Could build a “complexity referent” to compare a program to…how much complexity is typically reduced at what points

F

- Intent after PhD
  - Possible: Profess, Consult, DARPA, FFRDC, Lab, Industry?

E

Potential Areas of Future Inquiry

Project management surprises

Socio-political complexity

Changeability

Theory

Benefits of Complexity

Complexity reduction

Model stability

Terminology

Additional measures

Quantification

Maintenance and improvement

Allocation of complexity to technical system vs people

Allocation of complexity

Representation of complexity

Complexity Referent

Measure specification

Conway's law

Guided evolution

Inherent Models

Kinds of systems engineering complexity

Heuristics

Systems engineering process

Relationship of complexity to causes and effects

Reducible complexity

Uncertainty

Knee of the curve

Boundaries and spatial inhomogeneity

Interdependencies

Entropy

Unintended consequences

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Early and Late Indicators

Beginning of Program

- Q1—Domain
- Q4—Annual cost
- Q6—Relative Size
- Q7a—Start Year
- Q15—No. Subsystems
- Q16e—Requirements Easy
- Q16n—Requirements Nominal
- Q16d—Requirements Difficult
- Q17—Architecture Precedence
- Q18—Technical Rqts Conflict
- Q19—Tech-C&S Rqts Conflict
- Q20—Expectations Easy
- Q23—No. Subcontractors
- Q25—Schedule Dependency
- Q27—Staff Skills
- Q29—No. Government
- Q30—No. Contractors
- Q31—Experience Level
- Q38b—Scope Function-Enterprises
- Q38d—Acquire Projects Systems
- Q38h—System Behavior Known

Beginning to Middle

- Q14a—Use PERT
- Q14b—Use Risk Mgmt
- Q14c—Use Agile
- Q14d—Use Lean
- Q21—TRLs
- Q28—No. Decision Makers
- Q35—No. Sponsors
- Q38a—Mission Environment
- Q38c—Scale of Users
- Q38g—New Capability

Middle

- Q5—Life Cost
- Q24—Changes Limbo
- Q26—Planned-Agile
- Q32—Cognitive Fog
- Q34—Priorities Short Term
- Q36—Stakeholder Conflict
- Q38e—Stakeholder Involvement
- Q38f—Stakeholder Relationships
- Q37—Needs Changed
- Q13—Replanning

End

- Q7b—Finish Year
- Q8—Deliver Product
- Q9—Cost Overrun
- Q10—Schedule Delay
- Q11—Performance Shortfall
- Q12—Subjective Success
- Q22—Operational Evolution
- Q33—Estimates Right

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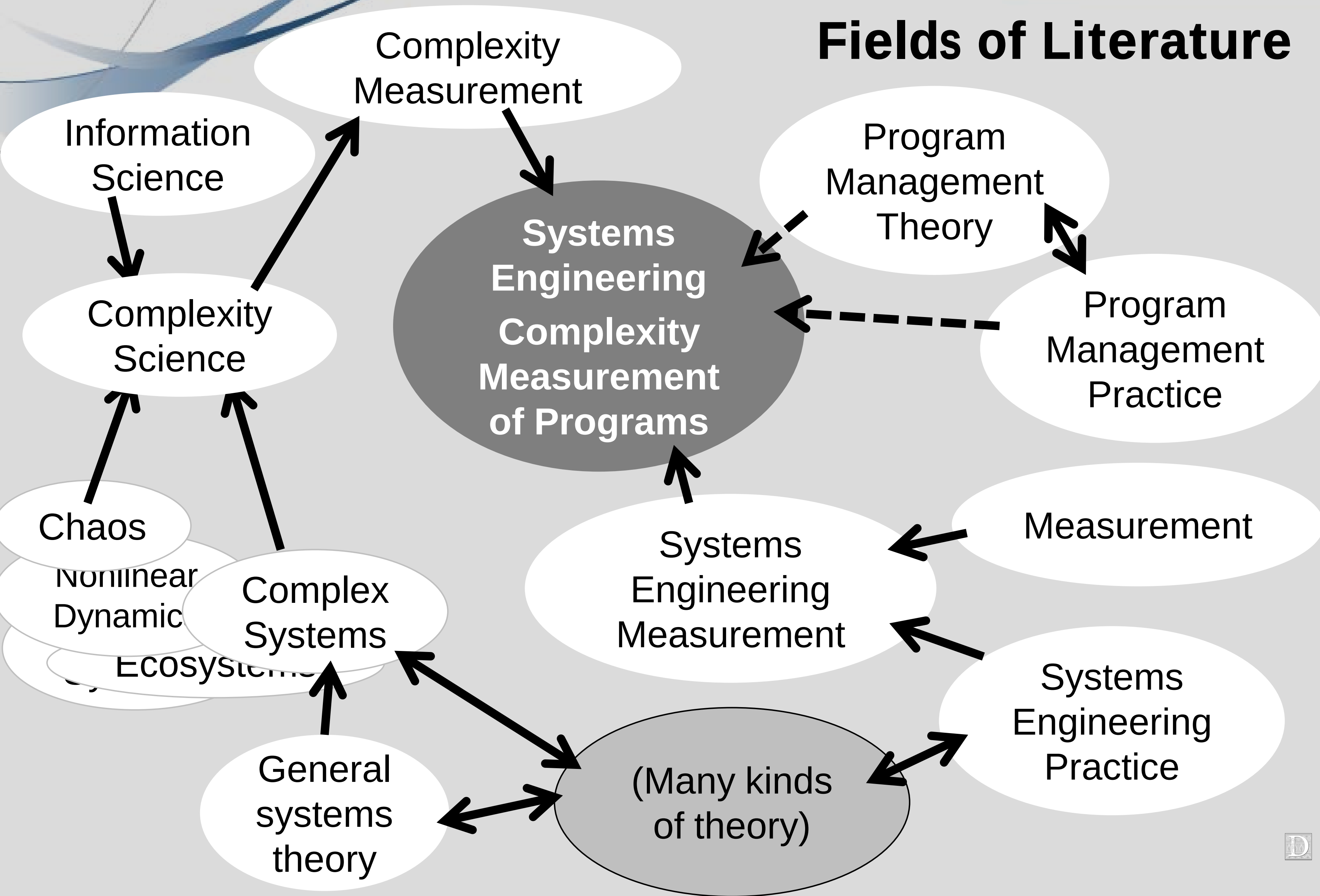
Fields of Literature



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Definition of Complexity

- Complexity is the inability to predict behavior due to nonlinearity, emergent behavior and chaotic principles.
  - Characterizes systems, projects, and the external environment.
  - Has structural (size, connectivity, and inhomogeneity), dynamic, and socio-political factors,
  - Manifests as spectra, from less complex to more complex, in a large number of variables
  - Displayed by a system, its representation, and the interpretation of the variables by humans

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Research Method

- Previous definitions of complexity are difficulty to measure on real projects or are difficult to trace to complexity literature
- Assess a large number of potential complexity measures for projects and narrow to small set
- Survey a large number of development programs to see whether any of the measures correlates to program outcomes
- Identify the complexity measures that can be taken early in a program and correlate to program outcomes
- These should be refined in follow-on work

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Types and Entities

- Complexity has six types
  - Structural* (Size, Connectivity, Inhomogeneity)
  - Dynamic (Short-term or Operational; Long-term or Evolutionary)
  - Sociopolitical
- Complexity of what? Entities
  - System being built (usually technical, sometimes socio-technical)
  - Program building system (usually socio-technical)
  - Environment (usually socio-political)
  - Cognitive (mental limitations; also frustration, subjective complexity)
- Measured 1^{st} 3 kinds of entities, +1 cognitive measure
- "Sociopolitical" used questions from SE literature

S

(*Sometimes size without connectivity is called "Complicated")

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Publications

Title	Publication Venue	Date
A Framework for Systems Resilience Discussions	INCOSE symposium	July 2008
Principles of Complex Systems for Systems Engineering	Systems engineering	November 2009
Complexity in Large-Scale Technical Project Management	International Journal of Complexity in Leadership and Management	2011
Proposed: Complexity Attributes Impacting Program Outcomes	IEEE	2012
Proposed: Congruence in complexity factors in system development programs	TBD	2012
Proposed: Early, mid-program, and late complexity factors predicting outcomes	TBD	2012

Other Questions

- Perform t-tests of every variable with every other
- Example: Do large and small programs (cost) have a statistically significant different number of requirements? (ans. yes).
- Example: Do programs that meet cost targets also meet schedule targets? (ans. yes, not so much for performance)

- Coherence: In what direction is this statistically significant difference: are programs that are more complex in one variable more or less complex in others?

Assessing the Impact of Complexity Attributes on System Development Program Outcomes

Ph. D. Dissertation of Sarah Sheard

Doctoral Advisory Committee

Dr. Ali Mostashari, School of Systems and Enterprises, Chairman

Dr. Dinesh Verma, Dean, School of Systems and Enterprises

Dr. Arthur Pyster, School of Systems and Enterprises

Dr. Brian Sauser, School of Systems and Enterprises

Dr. Tal Ben-Zvi, Howe School of Technology Management

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Research Limitations

- Limitations
  - Correlation is not causation…no guarantee that changing these variables will improve success rate.
  - Results are qualitative, not quantitative
  - Retrospective surveys and data categories; survey did not also interview participants to tease out their meanings of ambiguous terms
  - Small numbers of non-aerospace/defense, and failed projects
  - May have been confusion about some questions, e.g., “double-loop learning/set-based engineering”; operational evolution; meaning of “performance.”
  - Did not address how complexity of different aspects of systems and projects might differ (management vs technical experience level, technical vs programmatic estimates, e.g.)

Research Methodology: Measurement criteria

• Real	{Entire research question}
• Reproducible	
– Equivalence	Careful phrasing and testing of questions
– Stability	After 1 year (4): 64% same, 93% nearly.
• Predictive	{Point of research question}
• Usable	Feedback from surveys and interviews…no problems filling them out; also data stability
– Convenient data c	
– Interpretable dat	
• Robust	Careful phrasing, measures selection
• Complete	Lit. review, grouping, correlation
• Individual	Measures selection
• Orthogonal	Measures selection, some analysis
• *Valid*	*See separate chart*

Assumptions of "More Complex"

Each variable needed a polarity: "more complex" is:

- Anything larger (dollars, numbers, ...)
- More conflict or more unprecedented
- More change
- Lower technology maturity
- Fewer skills or less experience, more confusion
- More failure (more overrun, performance shortfall, not delivering a product, subjective failure…)
- Not using project management methods, or prioritizing short-term over long-term*
- Agile/incremental rather than planned/controlled*
- Later programs*

*not congruent (results)

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Research Methodology: Method's Validity

- Empirical
  - Calibration… Difficult; used bins.
  - Measures what it purports to measure…Difficult: many definitions of complexity…Literature→taxonomy, respondent roles
- Content
  - Face…Delphi group
  - Sampling…Broad variety and moderately large number of programs; used INCOSE
- Model
  - Internal…Ask questions in unbiased manner. Verify whether other explanations are possible. Example: Estimates good, Replanning
  - Internal consistency…separate questionnaire into sections for "system", "project", and "environment"
  - External…Tested for stability of linear correlations; backed off. Domain is aerospace/defense and may be extensible
  - Theoretical…Literature review
  - Pragmatic…Designed around usability and practicality

Related Dissertation, David J. Williamson

- Oct. 2011, Capella University
- Advisor Lawrence R. Ness
- "IT Project Complexity, Complication, and Success"
- Correlated IT Project Complexity (ITPCx) and IT ProjectComplication (ITPCn) with IT Project Success (ITPS)
- Complication: Size, detail, number of parts; linearity and predictability; can be managed with rational systems approaches (r^2=0.12, -)
- Complexity: Interaction between the parts; nonlinearity, unpredictability, evolution; cannot be managed directly, can only be accommodated or mitigated (r^2=0.05, -)

13 Cx Factors:
Objectives
Opportunity
Solution
Team Ability
Methodology
Schedule
Requirements
Environment
IT Complexity
Tech Change
Org Change
Staffing (r^2=0.28, +)
IT Integration
Change, Unknowns

9 Cn Factors:
Leadership
Schedule Duration
Team Size
Cost
Scope Flexibility
Tech. Content
Org. Support
Org. Units
Contractors
Size, Familiarity

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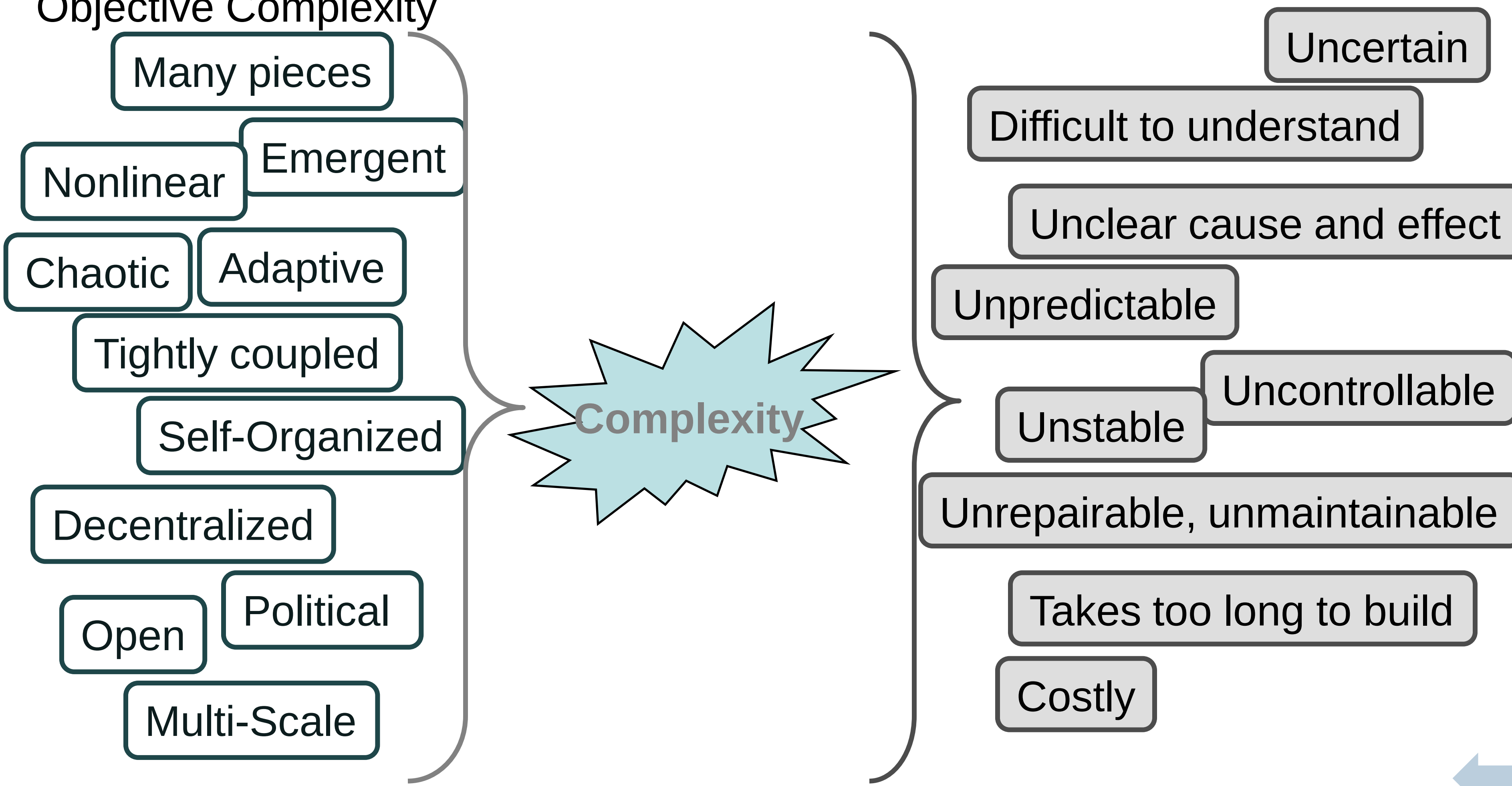
Outcome Variables

#	Variable	Low Complexity	High Complexity	Pol	Split (N of split variable)
8	Delivered Product: Assume more complex projects less likely to deliver	1 Yes	2 No	1	Choice 1 yes (64) vs. Choice 2 no(12)
9	Cost Overrun	1 Below cost	6 >100% over plan	1	Choices 1-2 <Under budget to within 5% (19) vs. Choices 4-6 >20% over (32)
10	Schedule Delay	1 Early	6 > 100% late	1	Choices 1-2 On time or early (18) vs. Choices 4-6 Over 20% late (28)
11	Performance Shortfall	1 Higher than spec	5 < 50% of spec or cancelled	1	Choices 1-2 Per spec or better (50) vs. Choices 4-5 More than 20% shortfall (13)
12	Subjective Success: Assume complexity = failure.	5 Great Success	1 Great Failure	-1	Choices 1-2 Failure (20) vs. Choices 4-5 Success (40)

Complexity Characteristics

Technical Characteristics/
System Characteristics/
Objective Complexity

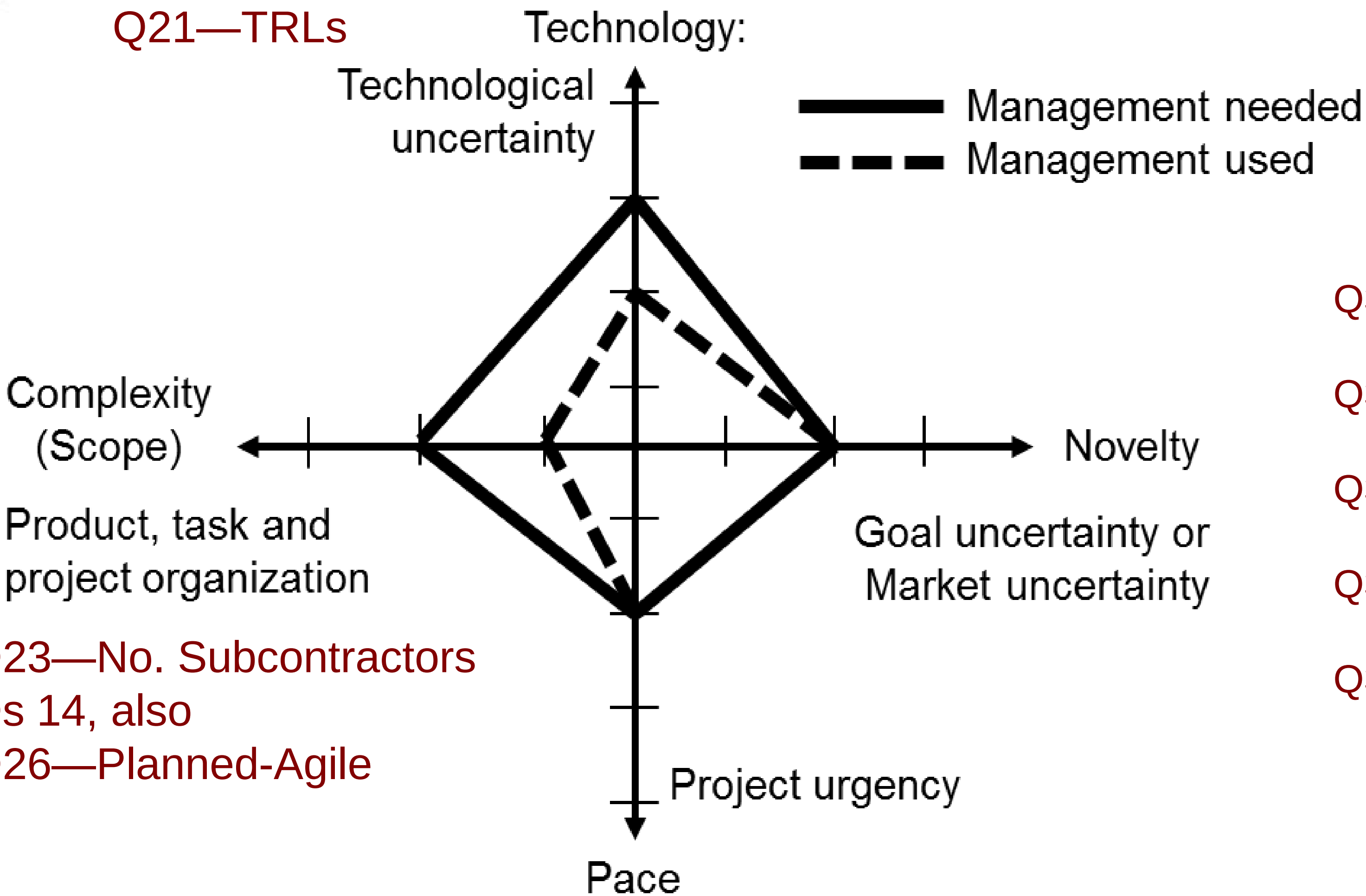
Cognitive Characteristics/
Subjective Complexity



Shenhar/Dvir Adaptive Diamond

Q12—Subjective Success

Q21—TRLs



Q36—Stakeholder Conflict
Q37—Needs Changed
Q38b—Mission Environment
Q38g—New Capability
Q38h—System Behavior known

Q23—No. Subcontractors
Qs 14, also
Q26—Planned-Agile

Q25—Schedule Dependency

Source: Shenhar & Dvir 2007

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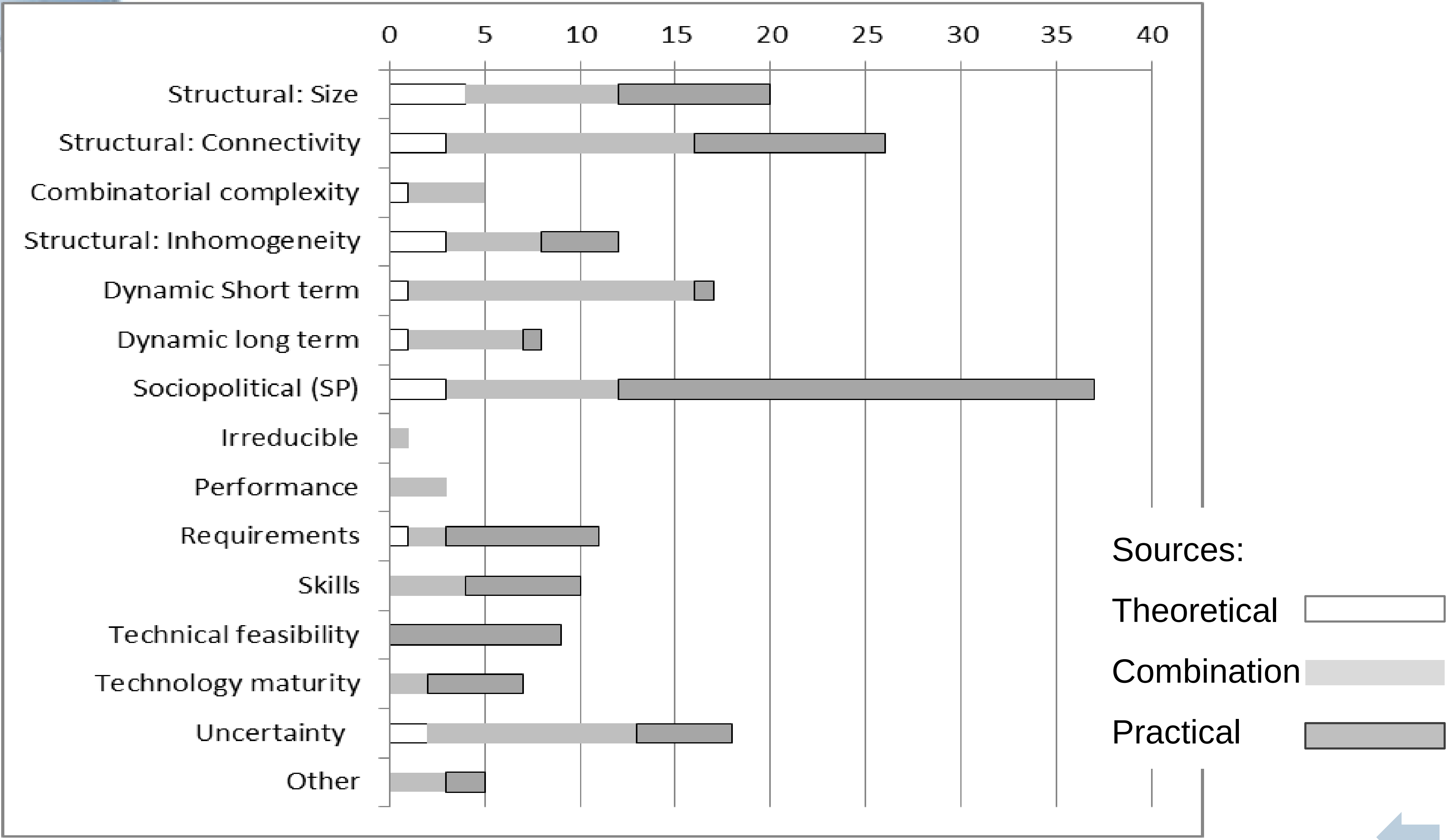
Arguable Polarity

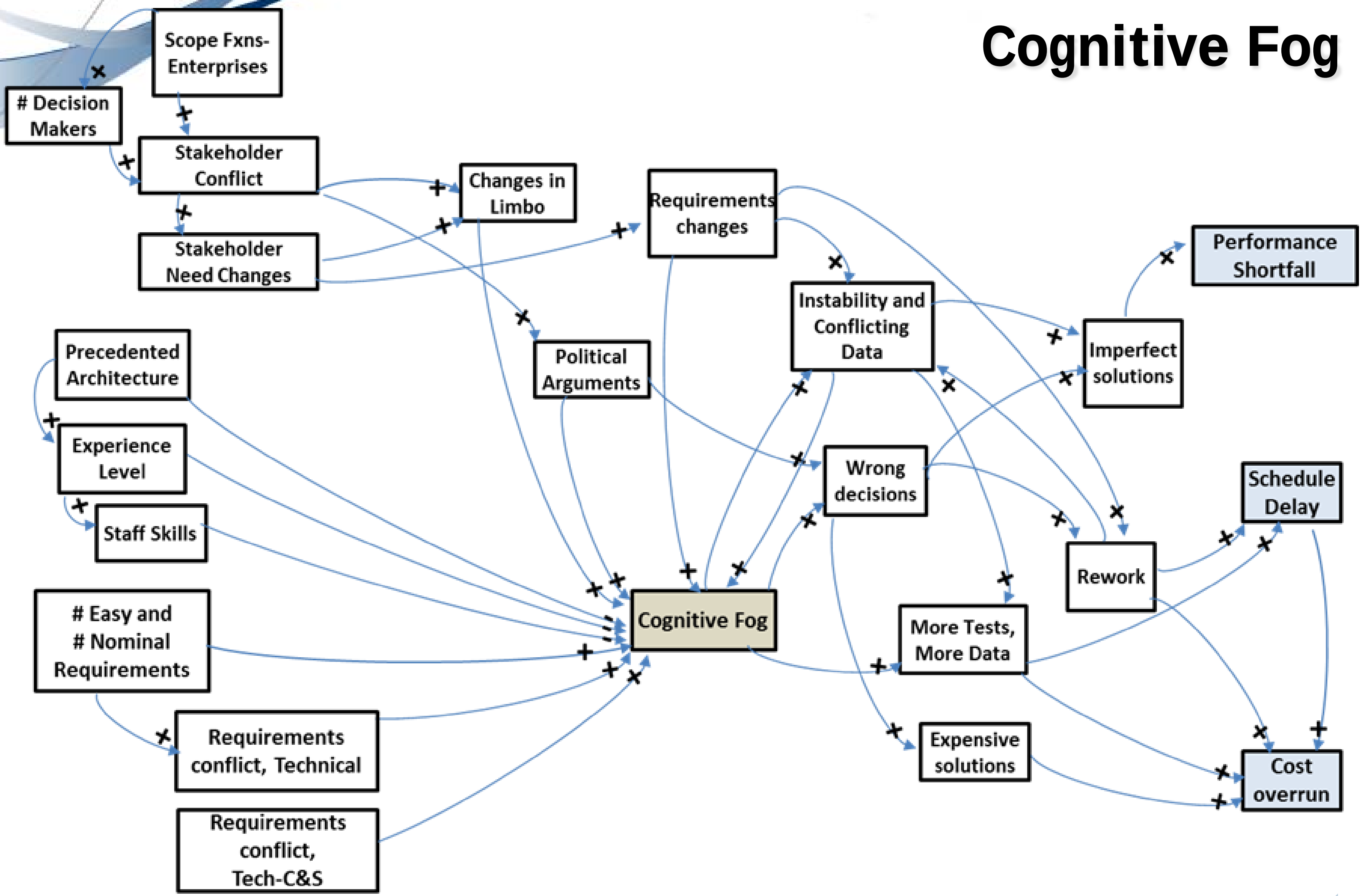
#	Variable	Low Complexity	High Complexity	Pol	Split (N of split variable)
7a	Start Year: Systems getting more complex?	1 Earlier	5 Later	1	Choices 1-3 Up to 2000 (37) vs. Choices 4-5 2001 and later (39)
14 a	Used PERT	1 Use	0 No use	-1	Choice 1 yes (62) vs. Choice 0 no (13)
26	Planned-Agile	1 Very Planned/ Controlled	5 Very Incremental/ Agile	1	Choice 1 Very PC (16) vs. Choices 4-5 Somewhat or very I&A(18)
22	Operational Evolution:1 and 2 were “did not start therefore did not evolve”; n/a	3 Essentially as delivered	5 Became a different system	1	Choices 3-4 (41) vs. Choice 5 (10)
34	Priorities Short Term	5 SD	1 SA	-1	Choices 1-2 Agree (32) vs. Choices 4-5 Disagree (23)

Types of Measures from Sources



Number of Measures in Each Category

Cognitive Fog



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Research Impact

- How does this research complement the existing body of knowledge?
  - Interprets scientific definitions of complexity, as organized into a taxonomy, for engineering use
  - Identifies which measures work well to measure complexity on practical programs
  - Identifies those entities whose complexity must be measured, and identifies measures of complexity for them, that can be measured early- and mid-program
  - Identifies which measures of complexity actually track together and which seem to be opposite the others
- What has this research demonstrated?
  - Difficult requirements, stakeholder relationships, and amounts of confusion and conflicting data influence all outcomes: cost, schedule, and performance
  - 20-25 other variables also support the evaluation of complexity of systems, development programs, and the environment

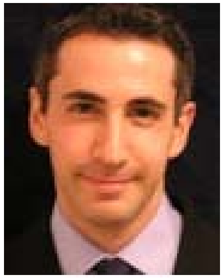
Thanks to My Committee

Dr. Ali Mostashari
Stevens School of Systems and Enterprises

Dr. Dinesh Verma, Stevens School of Systems and Enterprises

Dr. Brian Sauser
Stevens School of Systems and Enterprises

Dr. Tal Ben Zvi
Howe School of Technology Management



Dr. Art Pyster, Stevens School of Systems and Enterprises

Problems with measuring complexity

- Measuring=counting
- Measuring=simplification
- Things that used to be very complex (e.g. airplane) are not now
- It depends on purpose: is a small circuit (resistor+capacitor) complex?
- For systems engineering: Complexity of what? Various views and representations
- How do tools vary from standard SE repertoire?

Problem

Balance ● Growth ● Connections

- Larger, more complex systems and development efforts
  - Interconnected software, multiple sources, interoperability
  - Larger and more distributed programs
  - Even constituent systems are complex
- Acquisition and development program failures often attributed to complexity
- Enterprises want to know risks and mitigations early
- Systems engineering measures to date do not include complexity measures; Gaps:
  - Divergent definitions of complexity
  - Scattershot approach to managing
  - No consistent way to measure

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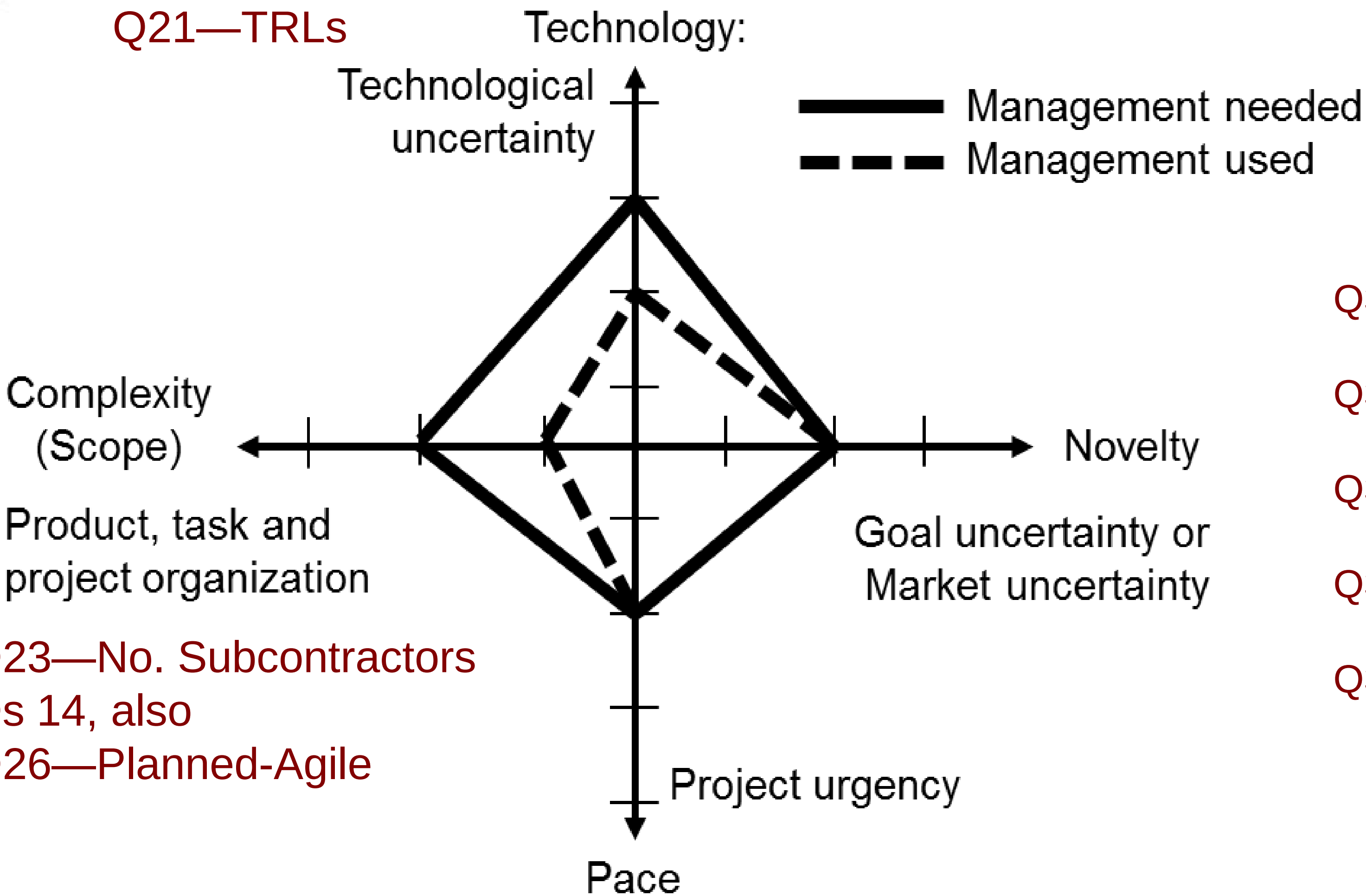
Shenhar/Dvir Adaptive Diamond

Q12—Subjective Success

Q21—TRLs



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Q23—No. Subcontractors
Qs 14, also
Q26—Planned-Agile

Q25—Schedule Dependency

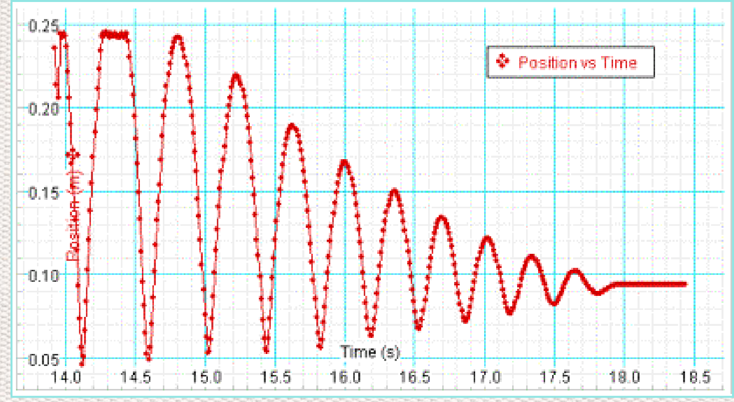
Source: Shenhar & Dvir 2007

A View of the Spectrum

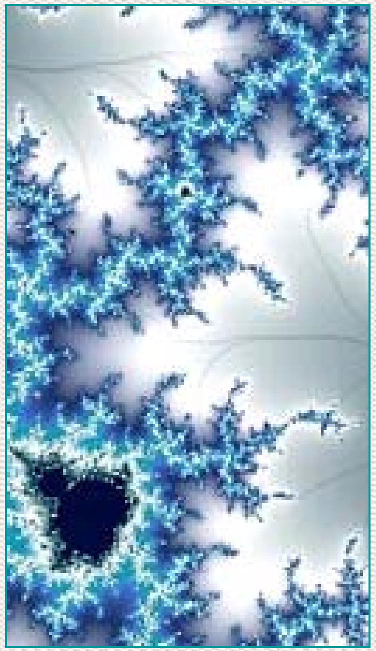
Balance ● Growth ● Connections

Order	Complexity	Disorder
Stability Oscillation	Chaos	Randomness

Short-Term Order Long-Term Order	Short-Term Order Long-Term Disorder	Short-Term Disorder Long-Term Disorder



Source: http://www.personal.psu.edu/ref7/apparatus/2005%20competition/flores.htm



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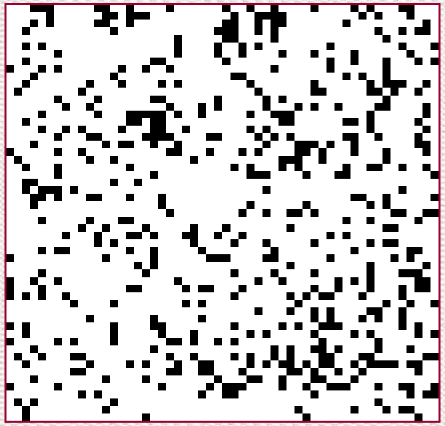

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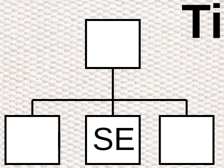
Multi-Discipline Systems Engineering (vs. IT SE)

Balance ● Growth ● Connections

Org Charts Titles



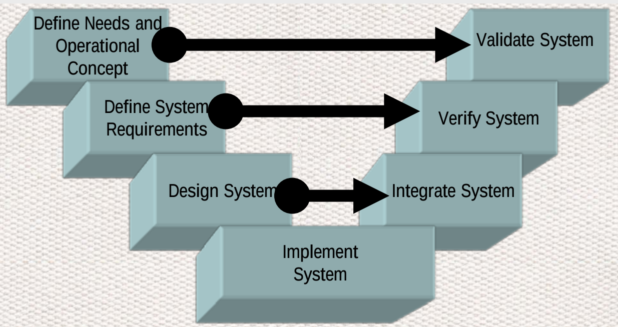
Twelve SE Roles

- Requirements
- **Designer**
- Analyst
- V&V
- Logistics
- Glue
- **Cust. Interface**
- Tech Manager
- Info Manager
- Process
- Coordinator
- Classified Ads

Information Technology SE

Software and computer system development done with an eye to the larger system

The SE Vee (Life Cycle)

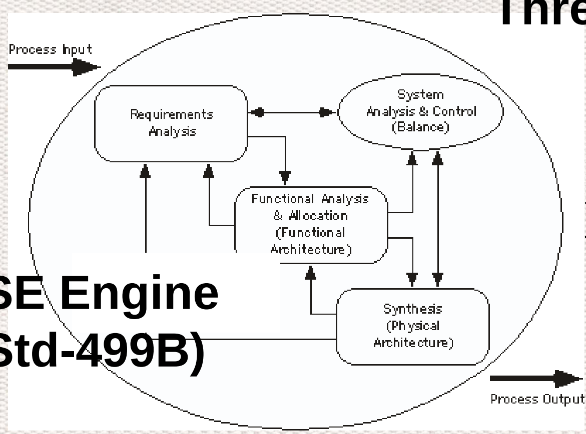


SE Principles & Heuristics

- Know the problem, the customer, and the consumer.
- Use effectiveness criteria based on needs to make systems decisions. ...

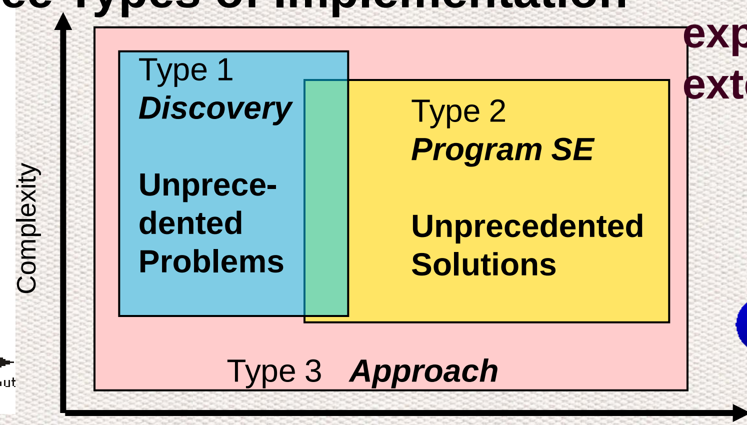
SE of Complex Systems (CxSE)

- **We don't know!**
- **Heuristics, based on research**
- **Principles, based on experience as extended by research**



The SE Engine (Mil-Std-499B)

Three Types of Implementation



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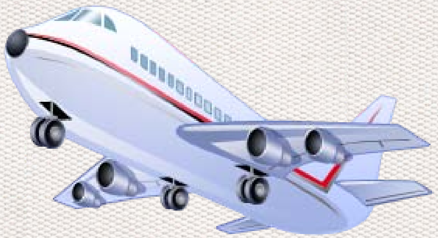
Systems Have Evolved



Source: Monica Farah-Stapleton, IEEE SOS conference, 2006
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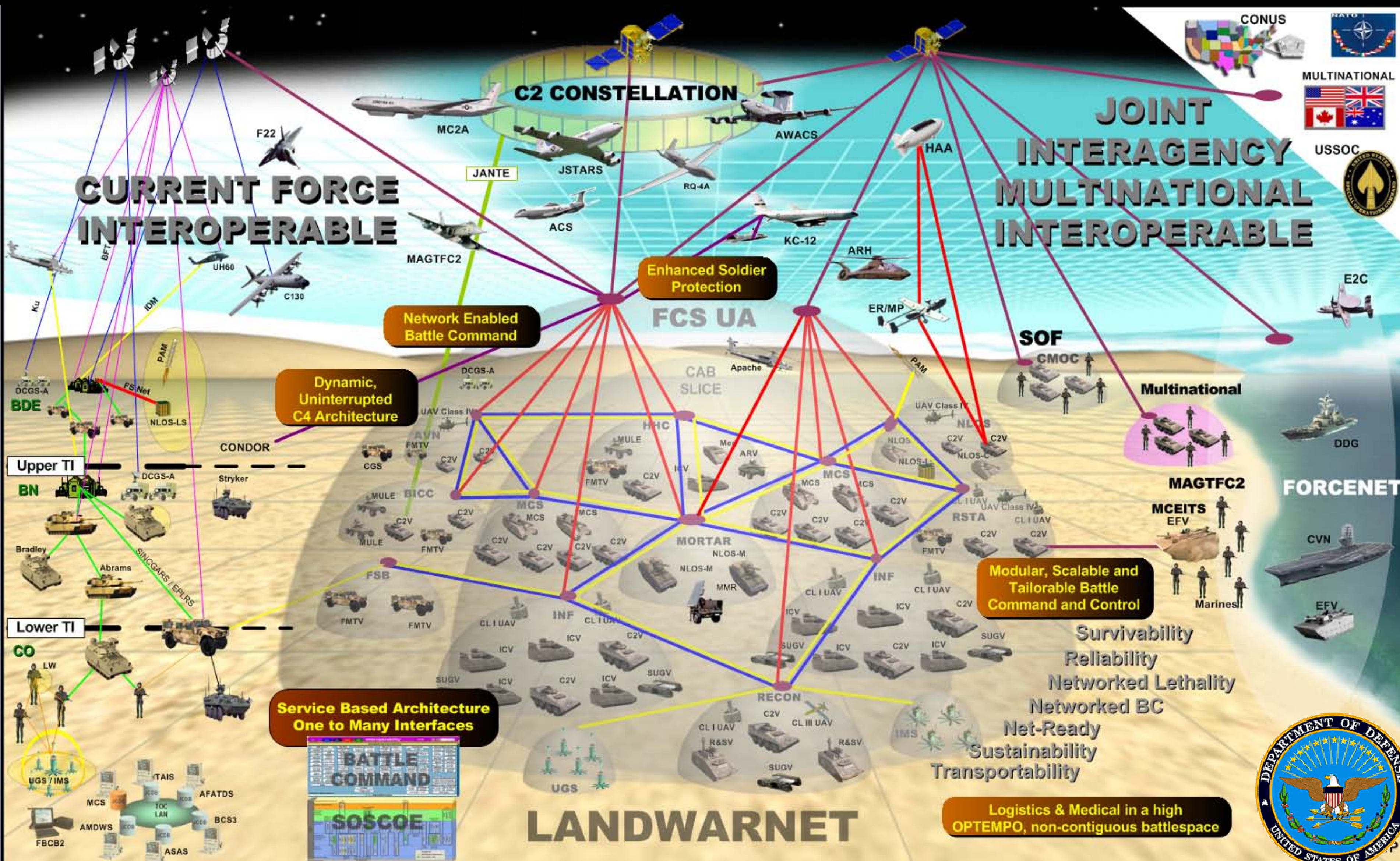
Army SOS perception

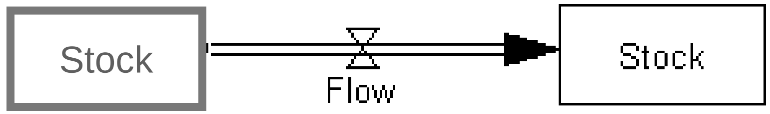


Quotations

- *It is a magnificent feeling to recognize the unity of complex phenomena which appear to be things quite apart from the direct visible truth.* - Albert Einstein
- *The capacity to tolerate complexity and welcome contradiction, not the need for simplicity and certainty, is the attribute of an explorer.* - Heinz Pagels
- *I know that most men, including those at ease with problems of the greatest complexity, can seldom accept even the simplest and most obvious truth if it be such as would oblige them to admit the falsity of conclusions which they have delighted in explaining to colleagues, which they have proudly taught to others, and which they have woven, thread by thread, into the fabric of their lives.* -Leo Nikolaevich Tolstoy
- *Abandon the urge to simplify everything, to look for formulas and easy answers, and begin to think multidimensionally, to glory in the mystery and paradoxes of life, not to be dismayed by the multitude of causes and consequences that are inherent in each experience—to appreciate the fact that life is complex.* - M. Scott Peck
- *Three reasons problems are inevitable: first, we live in a world of growing complexity and diversity; second, we interact with people; and third, we cannot control all the situations we face.* -John C. Maxwell
- *Some problems are so complex that you have to be highly intelligent and well informed just to be undecided about them.* - Dr. Laurence J. Peter
- *I think the next century will be the century of complexity. We have already discovered the basic laws that govern matter and understand all the normal situations. We don't know how the laws fit together, and what happens under extreme conditions. But I expect we will find a complete unified theory sometime this century. There is no limit to the complexity that we can build using those basic laws.* -Stephen Hawking

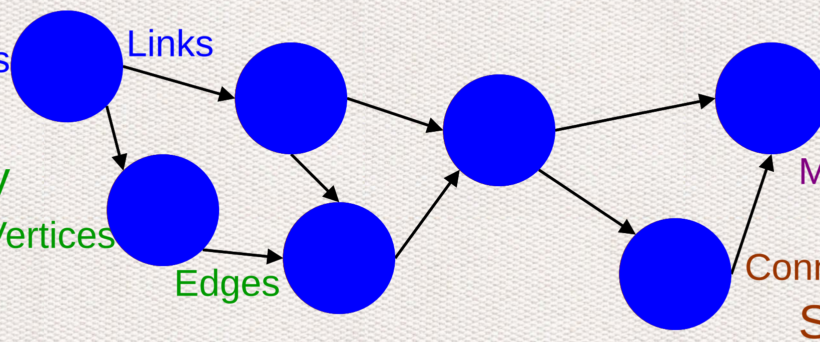
“Atomic Pieces” of Complexity Representation

System Dynamics



Networks

McCabe Complexity

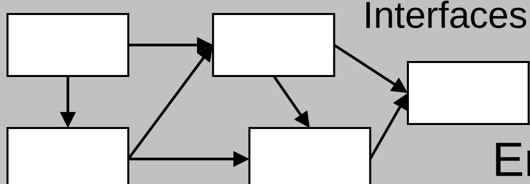


Software

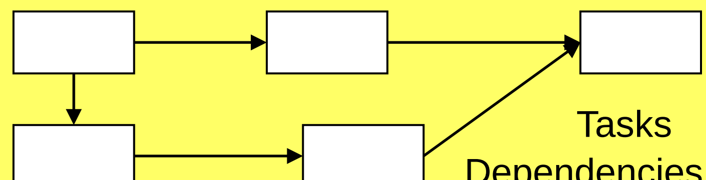
Social Networking

Subsystems or Elements

Interfaces



Systems Engineering



Tasks

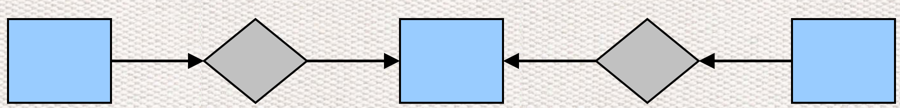
Dependencies

Project Management

System Analysis

Entities

Relationships



Model = Things + Relationships

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