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Complexity Measures to Predict System Development Project Outcomes

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Agenda

- What is Complexity?
- Research Approach
  - Collecting and Filtering Measures
  - Survey
  - Analysis
- Hypothesis and statistical significance of results
- Discussion
  - Two outcome groups
  - Variable interactions
- Advertisement

What is Complexity?

Design Detail

Difficulty

Stakeholder conflict

Computational Time

Cohesion and Coupling

Technology Readiness

Safety Criticality

Language Maturity

Size ($ or FTE)

Nonlinearity

Algorithmic complexity

Nodes and Edges

Changing needs

First of a kind

Enterprise scope

Connectivity

Requirements conflict

Ultra-high Quality

Operational evolution

Cognitive Fog

Uncertainty

Short-term thinking

No. Requirements

No. Contractors

Frustration

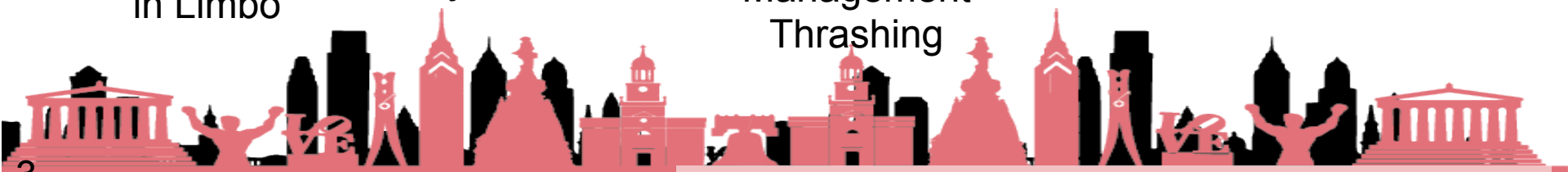
Diversity

Size of Changes in Limbo

Wicked Objectives

Management Thrashing

Independent agents



Research Approach

- Research Question: Are there any complexity measures that predict project success or failure?
- Method:
  - Identify
    - complexity measures
    - outcome measures (cost, schedule, quality, etc.)
  - Survey completed programs
  - Analyze: do “more complex” programs correlate with worse outcomes?
  - Null hypothesize re those measures, then test statistically

Measure Filtering

300 measures

Difficulty
Project Milestones
Design Detail
Language Maturity
No. Contractors
Stakeholder conflict
Diversity
Uncertainty
Computational Time
Cohesion and Coupling
Technology Readiness
Safety Criticality
Size ($ or FTE)
Enterprise scope
Connectivity
First of a kind
Requirements conflict
Cognitive Fog
Nodes and Edges
Requirements
Algorithmic complexity
Independent agents
Nonlinearity
Super-High Tech
Wicked Objectives
Management Thrashing
Operational evolution
Ultra-high Quality
Short-term thinking
Changing needs

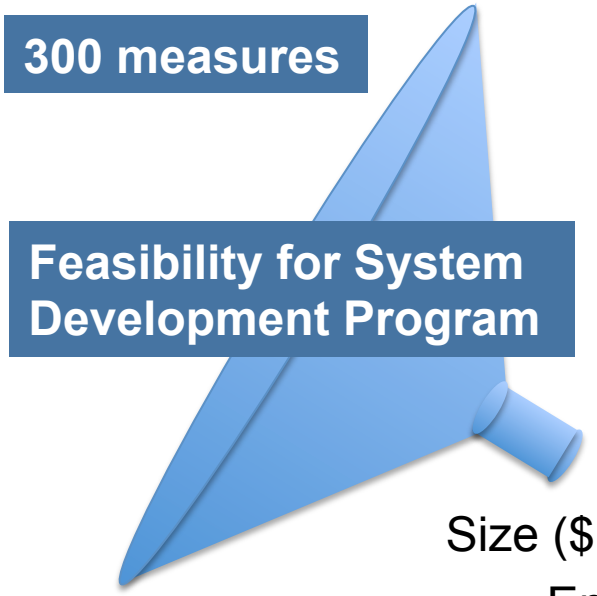
88 measures

Feasibility for System Development Program

34 measures

Comparable across Programs, Include all Types and Entities

Measure Filtering



88 measures

Design Detail

Language Maturity

Connectivity

Size ($ or FTE)

Stakeholder conflict

Enterprise scope

Diversity

Short-term thinking

Unprecedented

Requirements conflict

Requirements
-Easy
-Nominal
-Difficult

Cognitive Fog

Changing needs

No. Contractors

Difficulty

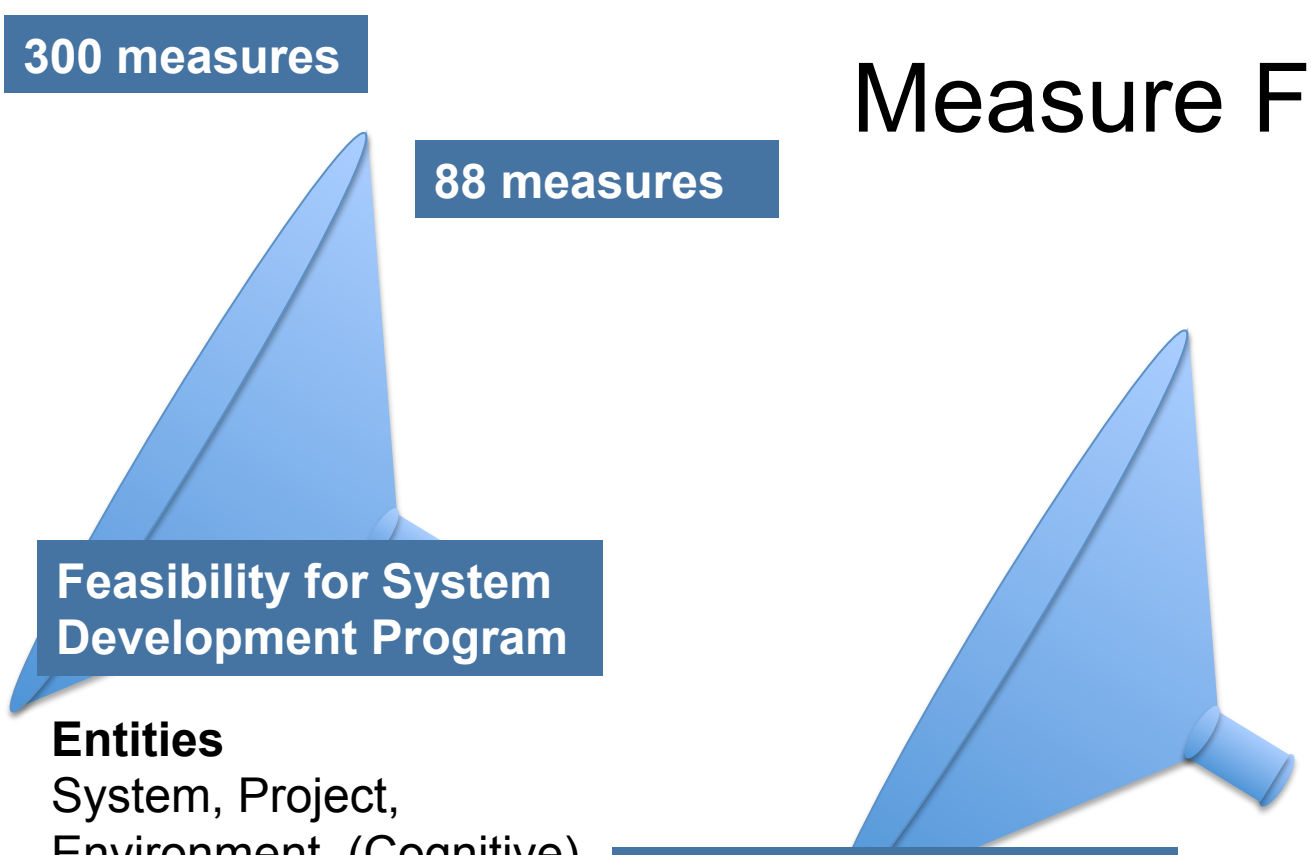
Cohesion and Coupling

Operational evolution

Technology Readiness

Comparable across Programs, Include all Types and Entities

Measure Filtering



Entities
System, Project, Environment, (Cognitive)

Types
Size, Connectivity, Inhomogeneity, Dynamic Short-term, Dynamic Long Term, Sociopolitical

Enterprise scope
Stakeholder conflict
Size ($)
Unprecedented
Requirements
-Easy
-Nominal
-Difficult
Cognitive Fog
No. Contractors
Requirements conflict
Mission Environment
Technology Readiness

Survey Characteristics

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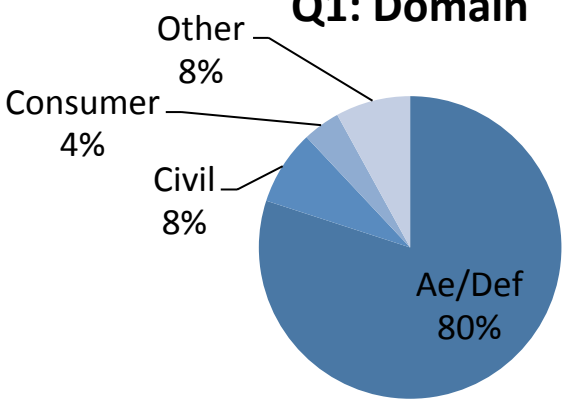
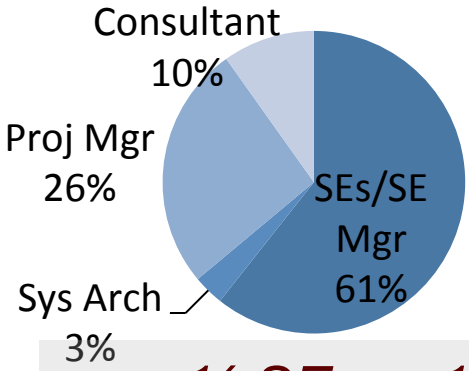
Q1: Domain



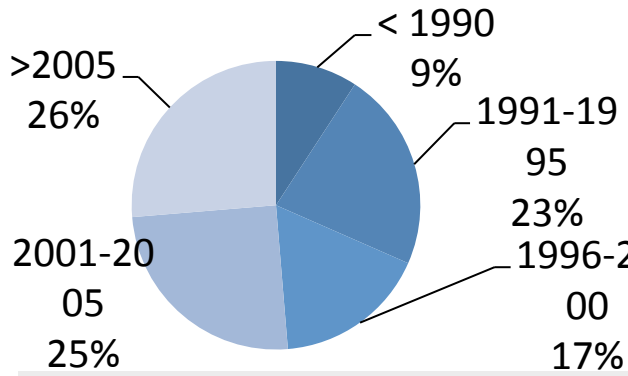
80% Aerospace/ defense

Q40: Respondent Role



> ½ SEs, ~ ¼ Project Managers

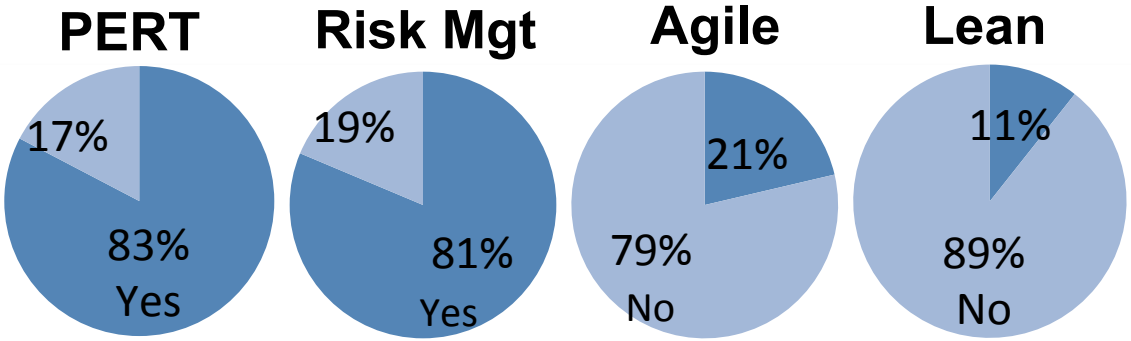
Q7a Project Start Year



Fairly evenly split over 20 years

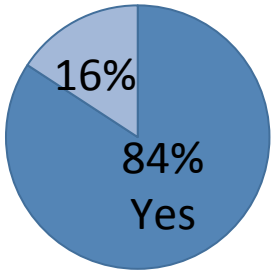
Over 80% used PERT-type planning and used Risk Management; only 10-20% used Agile or used Lean

Used PjM Techniques

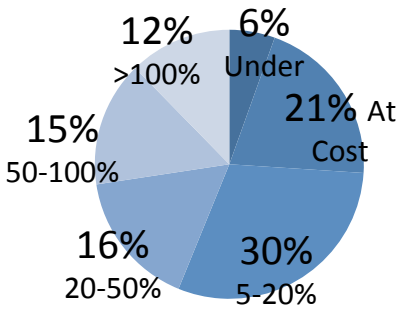


Outcomes

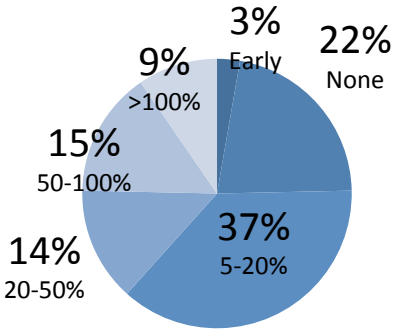
Q8: Deliver Product



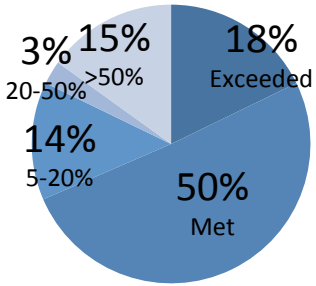
Q9: Cost Overrun



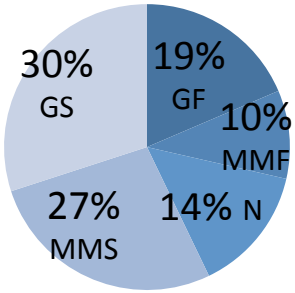
Q10: Schedule Delay



Q11: Performance Shortfall



Q12: Subjective Success



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)

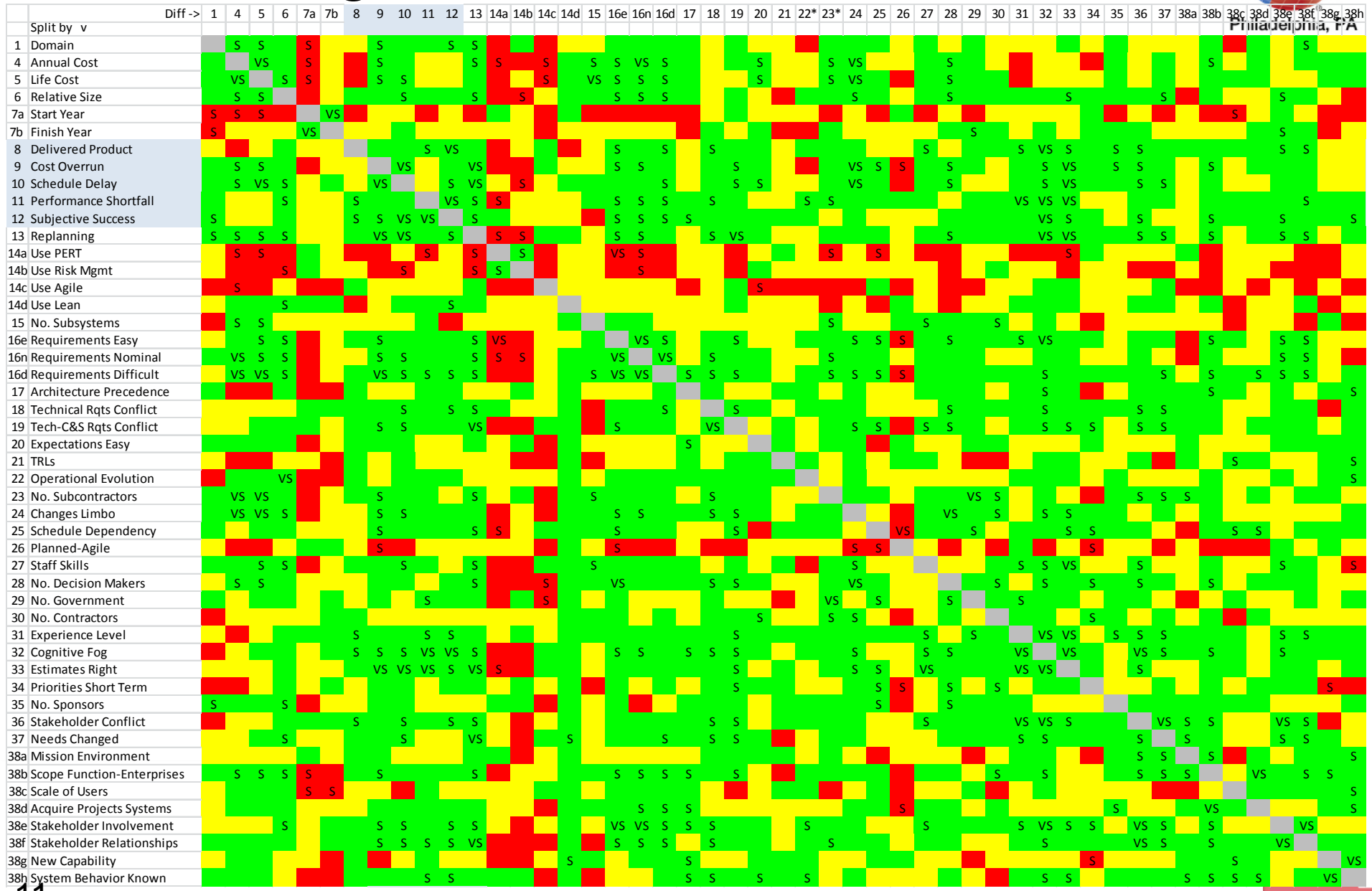
Dependent
(5 questions: Project Outcomes)

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

Complexity Variables

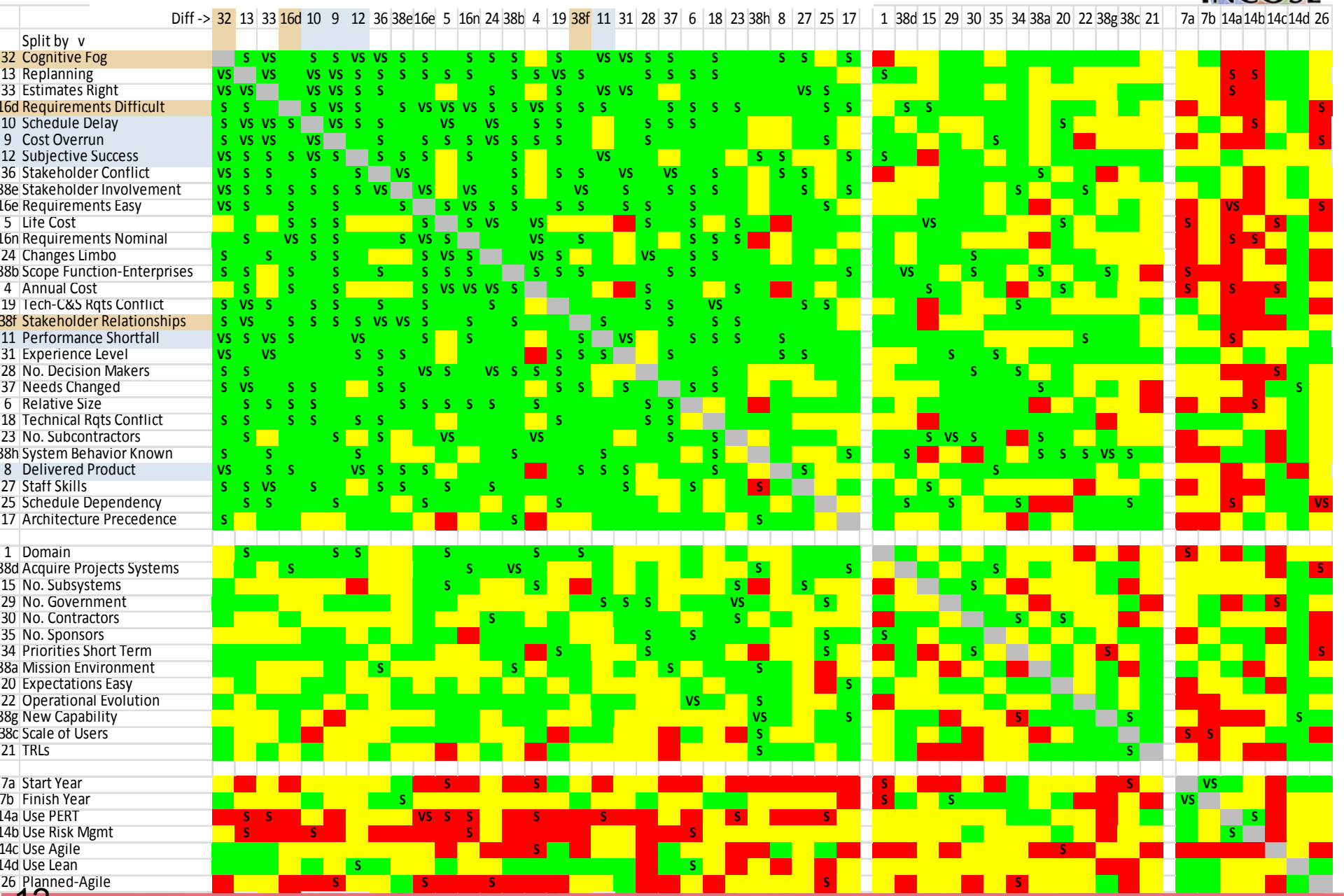
- Did the complexity of 2 variables correlate in the same direction? (green; yellow=0, red=no)
- Did a complexity variable correlate in the same direction as an outcome (i.e., worse)?

Significance, Unsorted



S=significant at p≤0.05 VS=significant at p ≤ 0.001

Coherence


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

Research Statement

- Research Question: Does complexity predict project 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).

*“Difficult” is defined by COSYSMO (Valerdi 2008)

Hypothesis Variables vs. Outcomes

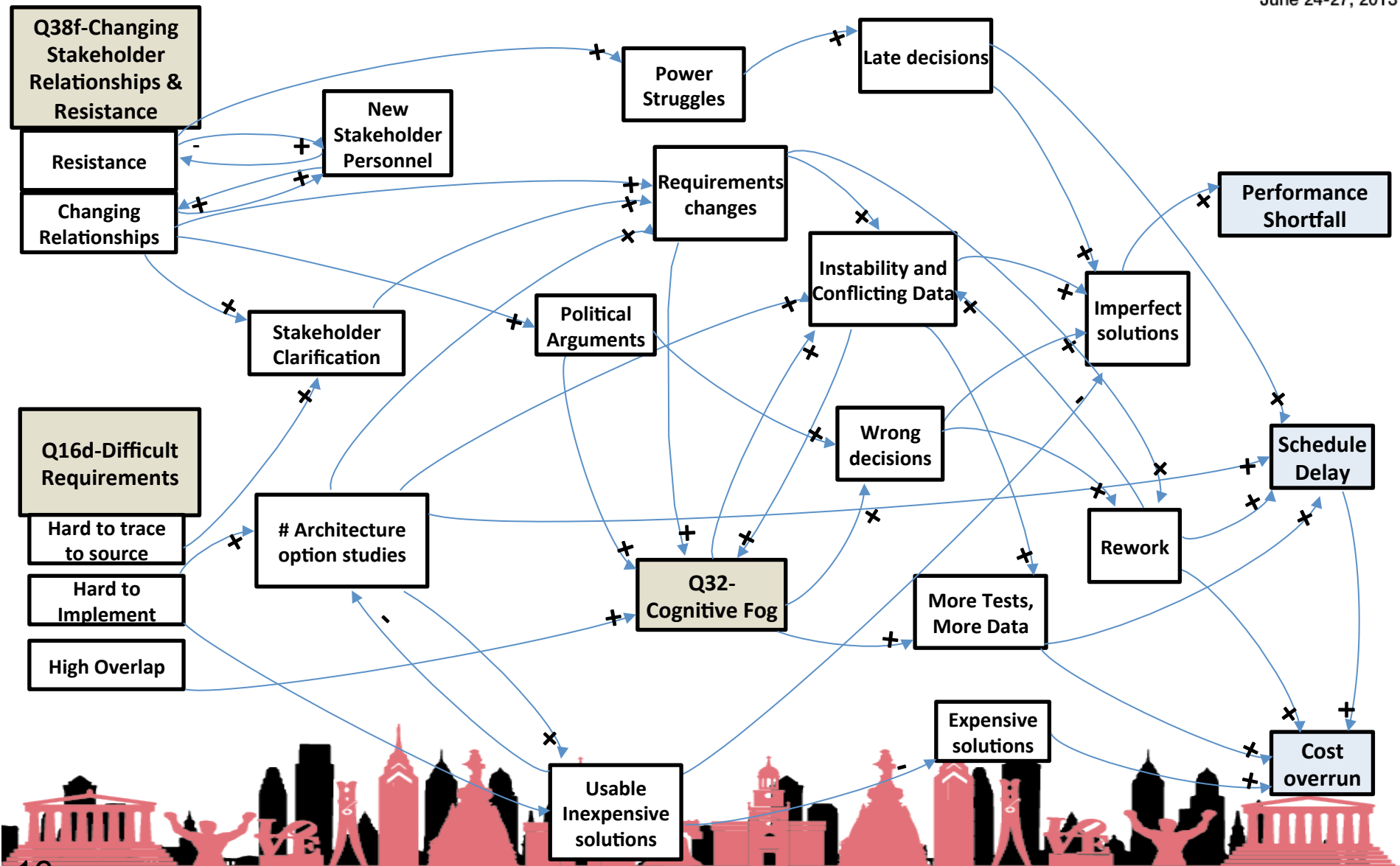
		Outcome Variable		
		Cost	Schedule	Performance
Complexity Variable	N	Overrun	Overrun	Shortfall
Q16d—Requirements Difficult				
Low (Under 100) mean	57	3.37	3.30	2.26
High (Over 100) mean	12	5.00	4.64	3.60
p-value		0.00027	0.00165	0.00163
Significance		Very (p<0.001)	Significant	Significant
Q32—Cognitive 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%

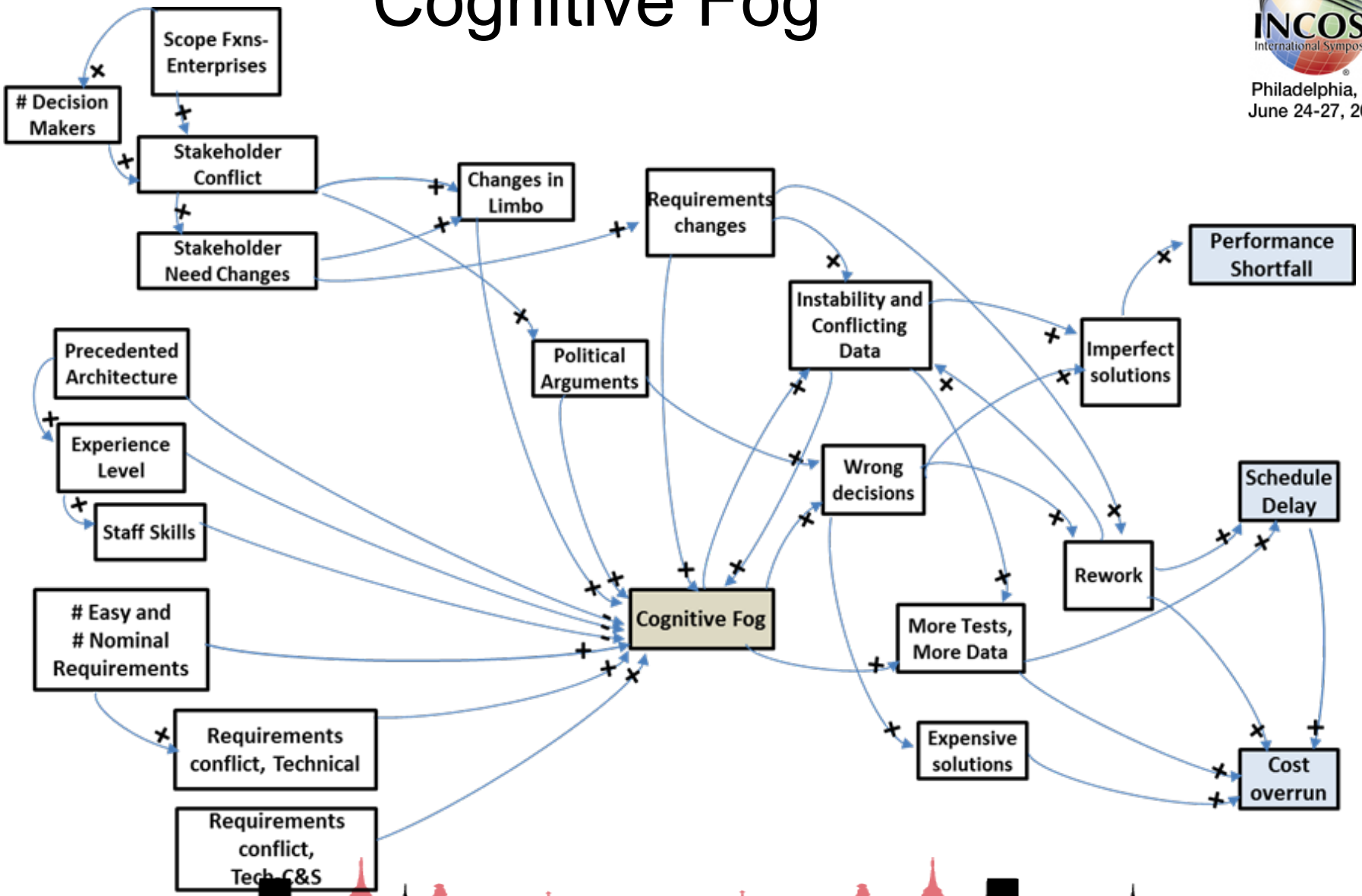
Two Outcome Groups

		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 -	

How Do Top 3 Complexity Variables Lead to Outcomes?



Cognitive Fog



Summary

- Project outcomes (cost, schedule, performance) do go up and down with many “complexity variables”
- Three variables predict all three outcomes (both project success and system success); 20 more predict one or the other
- A focus on complexity probably is useful to improve systems engineering
  - But not oversimplified to one variable, or additive

Advertisement:

- Complex Systems Working Group (CxSWG) has just written a ***Complexity Primer***
- Review comments being adjudicated
- 9 pages, non-academic
- For Joe/Jo Ordinary Systems Engineer (JOSE) and manager

- Longer and better cited papers next
- Need your help including what topics

BACKUP SLIDES

Wording of Questions

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

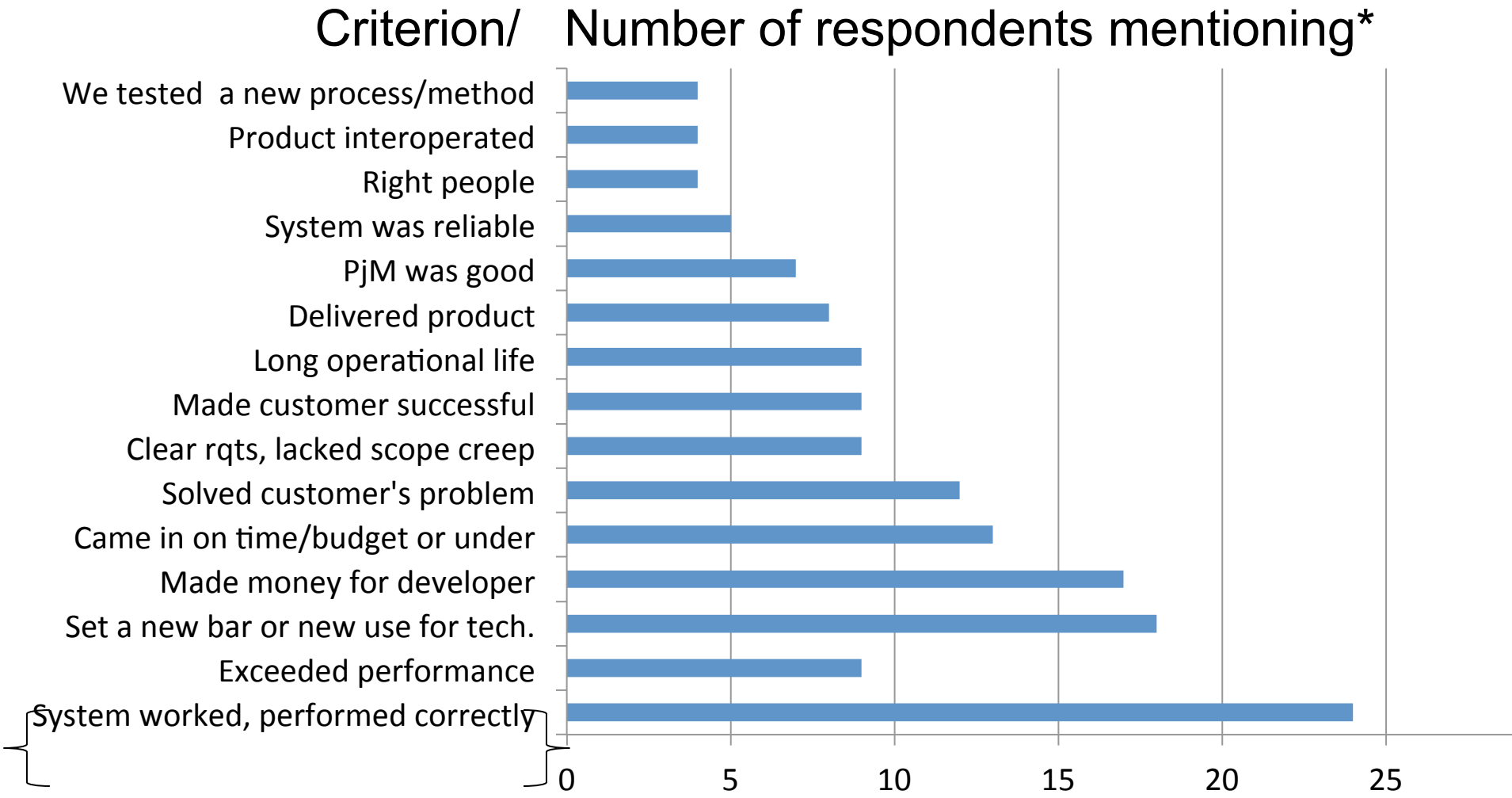
Q16d. "Approximately how many system-level requirements did the project have initially? Difficult requirements are considered difficult to implement or engineer, are hard to trace to source, and have a high degree of overlap with other requirements. How many system requirements were there that were Difficult?

(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.

Success Criteria



* (Either + or - : We succeeded because we did, or we failed because we did not.)

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

Potential Areas of Future Inquiry

Project management surprises

Socio-political complexity

Changeability

Benefits of Complexity

Model stability

Theory

Complexity reduction

Terminology

Boundaries and spatial inhomogeneity

Interdependencies

Additional measures

Maintenance and improvement

Allocation of complexity to technical system vs people

Representation of complexity

Allocation of complexity

Quantification

Complexity Referent

Entropy

Measure specification

Conway's law

Inherent Models

Guided evolution

Kinds of systems engineering complexity

Systems engineering process

Heuristics

Unintended consequences

Relationship of complexity to causes and effects

Reducible complexity

Uncertainty

Knee of the curve

Complexity Characteristics

Technical Characteristics/
System Characteristics/
Objective Complexity

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

Early and Late Indicators

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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

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 Types and Entities

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Entity:	Project	System	Environment	Cognitive
Type				
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