Systems Engineering Advancement Research Initiative

2009 SEAri Annual Research Summit

Research Report

"Collaborative Systems Thinking: An exploration of the mechanisms enabling team systems thinking"

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Agenda

- Problem Overview
  - Motivation
  - Research Questions
  - Methodology
- Analysis/Contributions
- Implications for Industry, Academia, and Government
- Conclusions

PhD in Aeronautics and Astronautics, June 2009
Thesis Committee:
Prof. Deborah Nightingale (chair)
Dr. Donna Rhodes
Prof. Annalisa Weigel

Terminology: Defining Systems Thinking

A framework for systems with four basic ideas: emergence, hierarchy, communication and control. Human activity concerns all four elements. Natural and designed systems are dominated by emergence. (Checkland 1999)

A method of placing the systems in its context and observing its role within the whole. (Gharajedaghi 1999)

A skill to see the world as a complex system and understanding its interconnectedness. (Sterman 2000)

A skill of thinking in terms of holism rather than reductionism. (Ackoff 2004)

A method and framework for describing and understanding the interrelationships and forces that shape system behavior. (Senge 2006)

Systems thinking is utilizing modal elements to consider the componential, relational, contextual, and dynamic elements of the system of interest. (Davidz 2006)

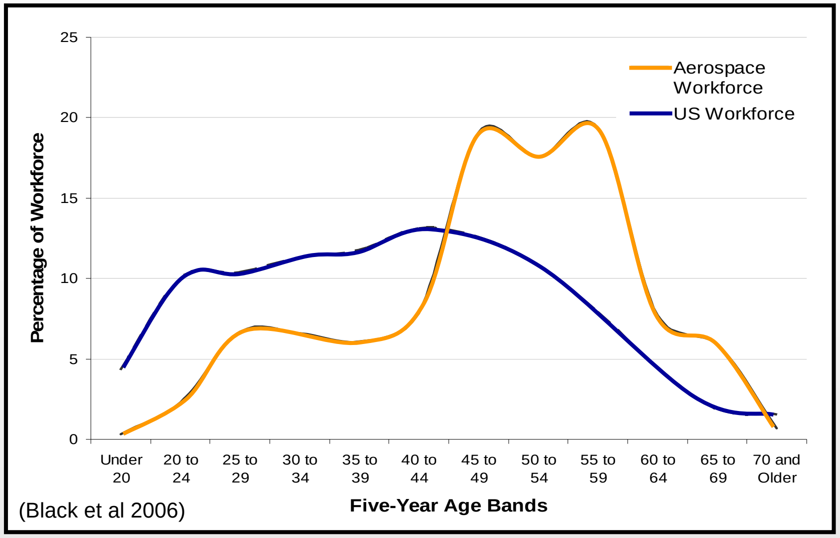
Component Complexity | Interrelationships | Context | Emergence | Wholes

Terminology: Defining Systems Thinking

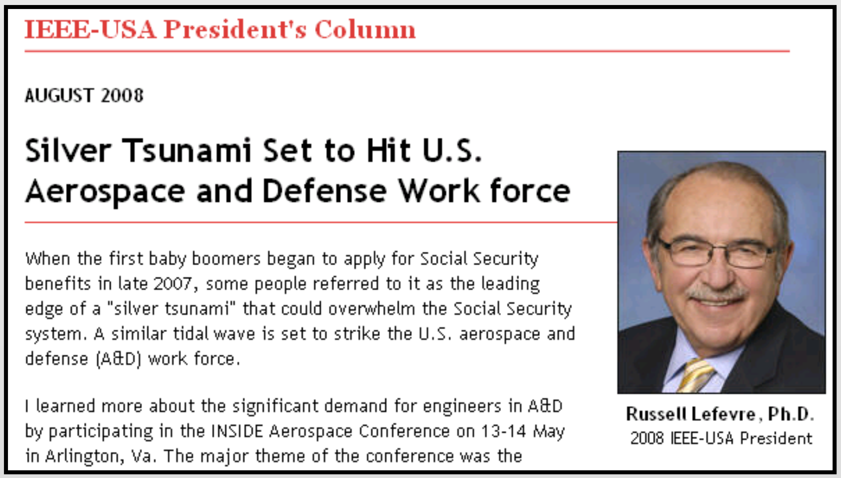
Systems thinking is considering the system, its components, interrelationships, context, and dynamic behavior during engineering design

- Component Complexity
- Interrelationships
- Context
- Emergence
- Wholes

Motivation:
Aerospace Workforce Demographics



(Black et al 2006)



IEEE-USA President's Column

AUGUST 2008

Silver Tsunami Set to Hit U.S. Aerospace and Defense Work force

When the first baby boomers began to apply for Social Security benefits in late 2007, some people referred to it as the leading edge of a "silver tsunami" that could overwhelm the Social Security system. A similar tidal wave is set to strike the U.S. aerospace and defense (A&D) work force.

I learned more about the significant demand for engineers in A&D by participating in the INSIDE Aerospace Conference on 13-14 May in Arlington, Va. The major theme of the conference was the

Russell Lefevre, Ph.D.
2008 IEEE-USA President

(IEEE 2008)

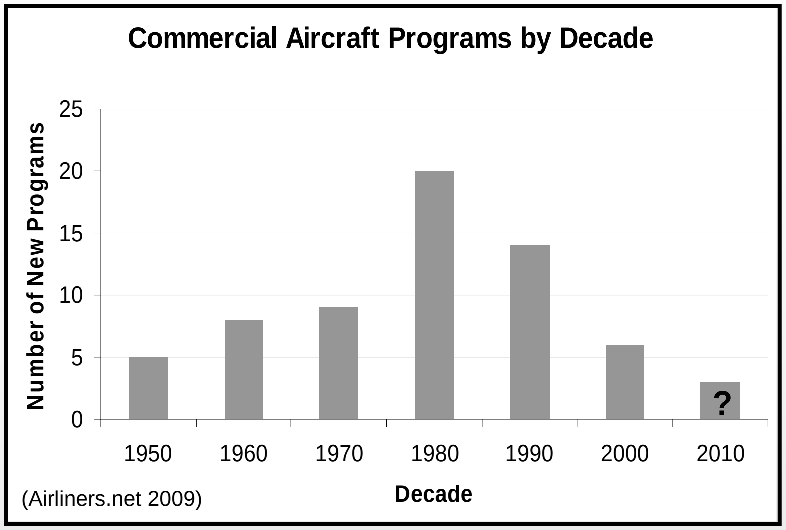
- Shortage of systems skills in aerospace industry
  (Stephens 2003; McMasters and Cummings 2003)
- Industry approaching retirement age
  (Augustine et al 2006; Black et al 2006)
- Not attracting / retaining new workforce
  (Pieronek and Pieronek 2004; Matson 2005)

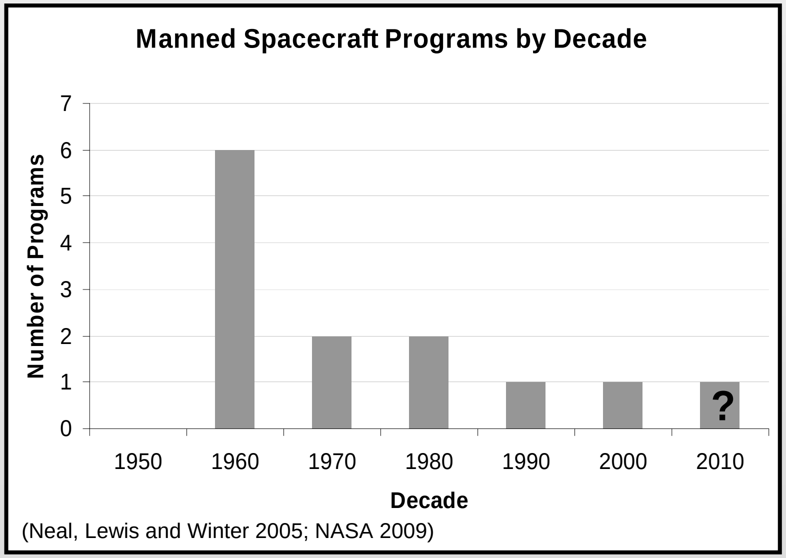
Motivation:
Fewer Aerospace Systems Starts

- Systems experience is an integral component of systems skill development
  (Davidz 2006; Dong 1999; Vincenti 1990)

- Fewer program starts mean fewer opportunities for systems skill development
  (Murman et al 2002)

- Heuristics are an important component of systems knowledge
  (Maier and Rechtin 2002; Vincenti 1990)





Problem Statement: Anticipated Shortage of Systems Skills

- Engineering Systems Thinking
  - Engineering systems thinking is distinct (Frank 2000)
  - Empirical research identified enablers (Davidz 2006)
    - Experiential learning
    - Personal characteristics
    - Supportive environment
- Team Systems Thinking
  - Increasing complexities necessitate teams (Blanchard 1998; Wooley et al 2006)
  - Teams are a more stable unit of knowledge within programs
  - Tighter integration of subsystems, greater efficiency, greater design optimization (Klein et al 2001; Chachere et al 2004)
- Problem Statement:
  - Explore enablers and barriers to team-level systems thinking
  - New Term: **Collaborative Systems Thinking (CST)**

Research Questions

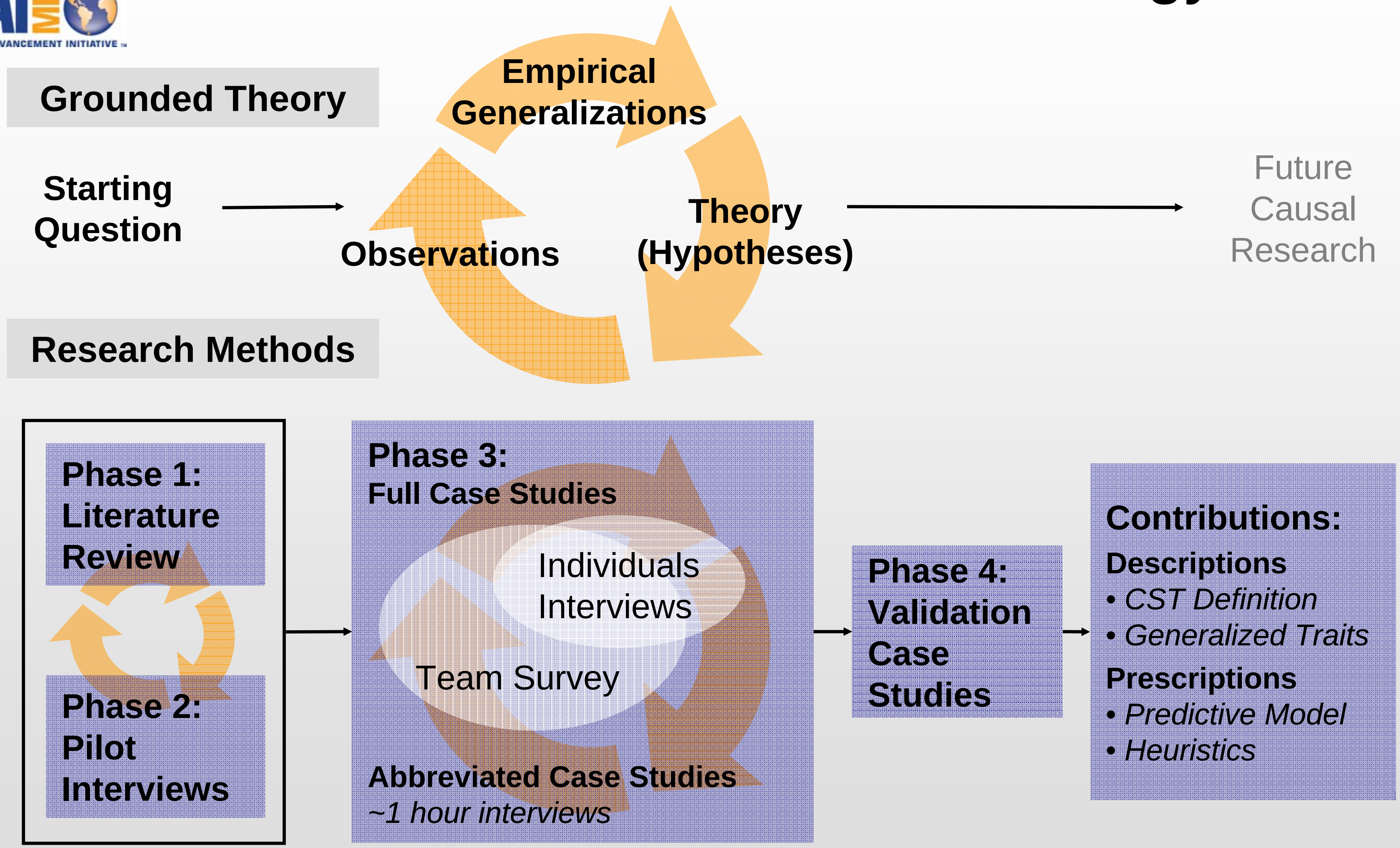
Research Questions:

- What is collaborative systems thinking (CST); how does CST differ from individual systems thinking?
- What are the empirically generalized traits of CST teams within the context of the aerospace industry?
- What observed mechanisms best predict collaborative systems thinking?

Outcomes:

- CST definition and generalized traits
- A set of hypotheses to drive future research
- Heuristics for enabling collaborative systems thinking

Empirically-Based Research Methodology



Question 1:
Defining Collaborative Systems Thinking

Research Questions:

- ***What is collaborative systems thinking (CST); how does CST differ from individual systems thinking?***
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Defining Collaborative Systems Thinking: Links to Literature

Central Concept	Literature Concepts	PI Concepts
Team Interaction	Team thinking is valid concept based on shared processing of information. (Salas and Fiore 2004) Team thinking is supported by interactions that create pointers to knowledge held within team. (Wegner 1986)	"A willingness to ask and answer questions" "Socialized experts with shared reference enable CST"
Multiple Thinking Styles	Creative environments/multiple perspective support systems thinking. (Thompson and Lordan 1999)	"Creativity is an enabler"
Design Process	Normative design processes that utilize divergent and convergent thinking are superior for handling complexity. (Stempfle and Badke-Schaub 2002)	Process provides: "shared language / taxonomy;" "starting place for design"
Multiple Communication Media	Multiple design languages (e.g. sketching, modeling, etc) are required to communicate design knowledge. (Dym et al. 2005)	"High communication bandwidth enables CST"
Importance of End Product	Emphasis on end product a differentiator between successful and failed product development teams. (Dougherty 1990)	"CST involves producing a product"

Collaborative Systems Thinking Defined

Component Complexity
Interrelationships
Context
Emergence
Wholes

Collaborative systems thinking is an emergent behavior of teams resulting from the **interactions of team members** and utilizing a variety of **thinking styles, design processes**, tools and **communication media** to consider the **system**, its **components**, **interrelationships**, **context**, and **dynamics** toward **executing systems design**.

(Lamb 2008)

Team Interaction
Multiple Thinking Styles
Design Process
Communication Media
End Product

Question 2: Generalized Traits of CST Teams

Research Questions:

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Rating a Team's Collaborative Systems Thinking

No Universally Accepted Measures of Systems Thinking

- Emergent engineering systems thinking certification programs

Team-level measures non-existent

- CST new construct
- No universal metrics for team thinking

Steps for Obtaining an Assessment

1. Solicit Individual's Definition of Systems Thinking
2. Calibration Discussion
3. Obtain Individual Assessment of Team
4. Repeat with multiple team members and 3rd party

Use Triangulation To Obtain A More Reliable Rating

- Team Rating = mean(set of individual assessments of team)
- Acceptable to treat data as interval
  - Individuals were instructed a rating of '5' was average
  - Precedent in literature (Labovitz 1970; Jaccard and Wan 1996; Dawes 2008)

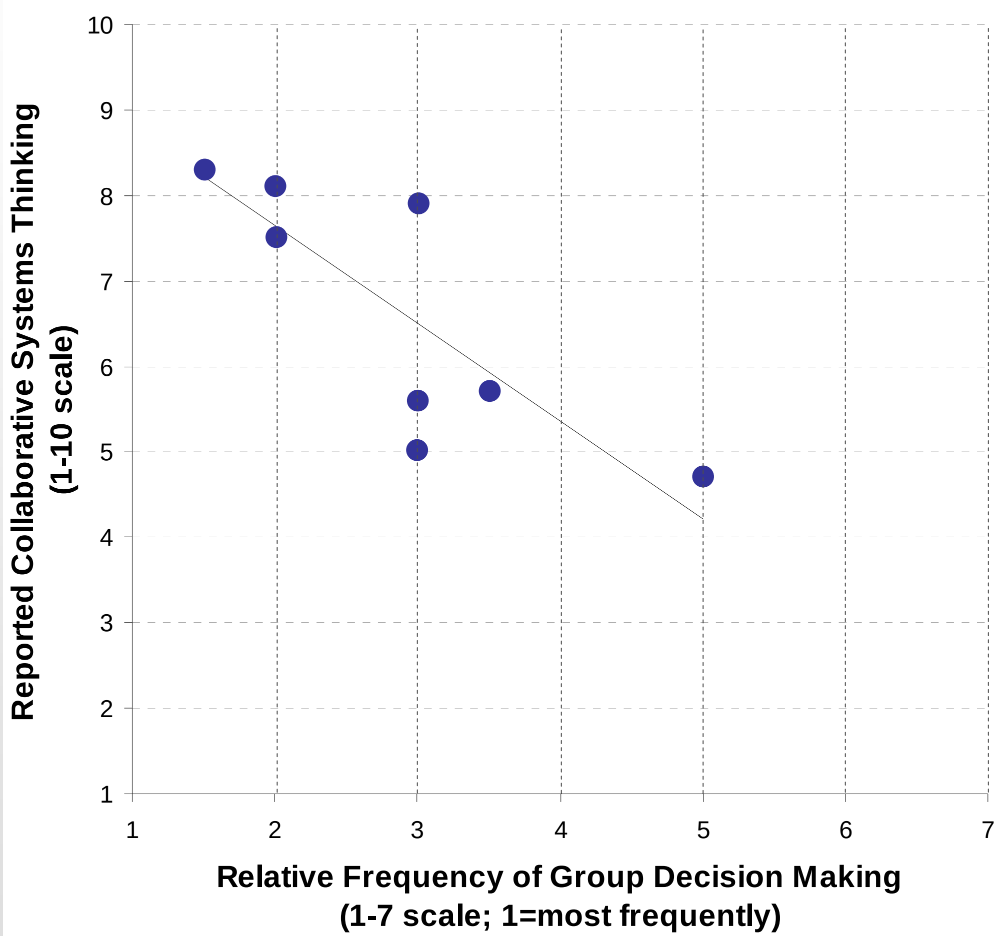
Trait 1: CST Teams Use Consensus Decision Making

Consensus decision making

– Def: everyone feels their ideas have been heard and considered

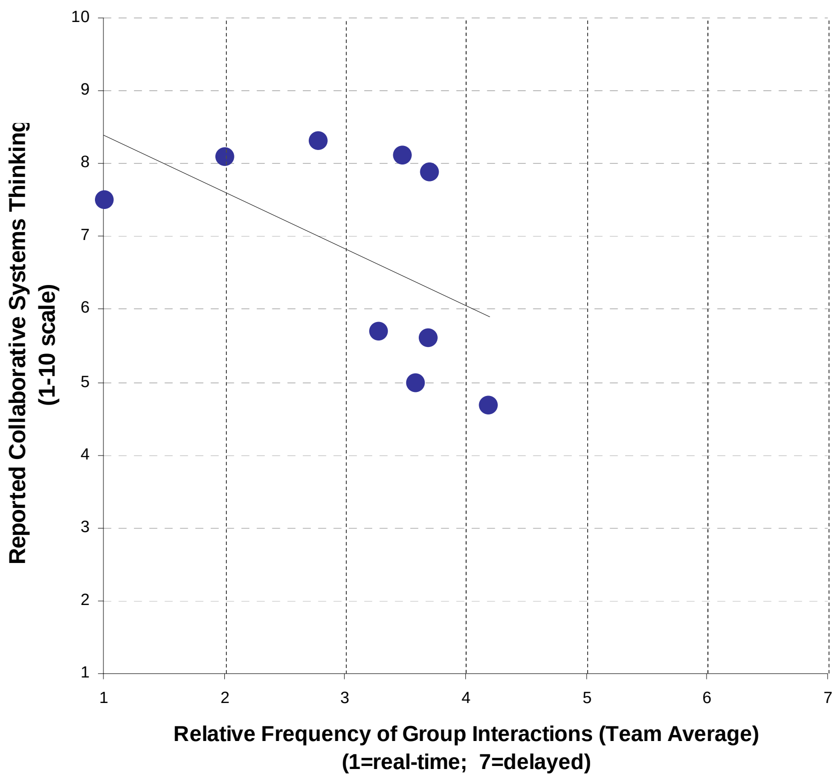
- Requires strong leadership 'willing to make a decision'
- Forces recognition of 'multiple valid options'
- Non-collocation influences perceptions of decision making process

Decision Making Preference: Correlation = -0.82

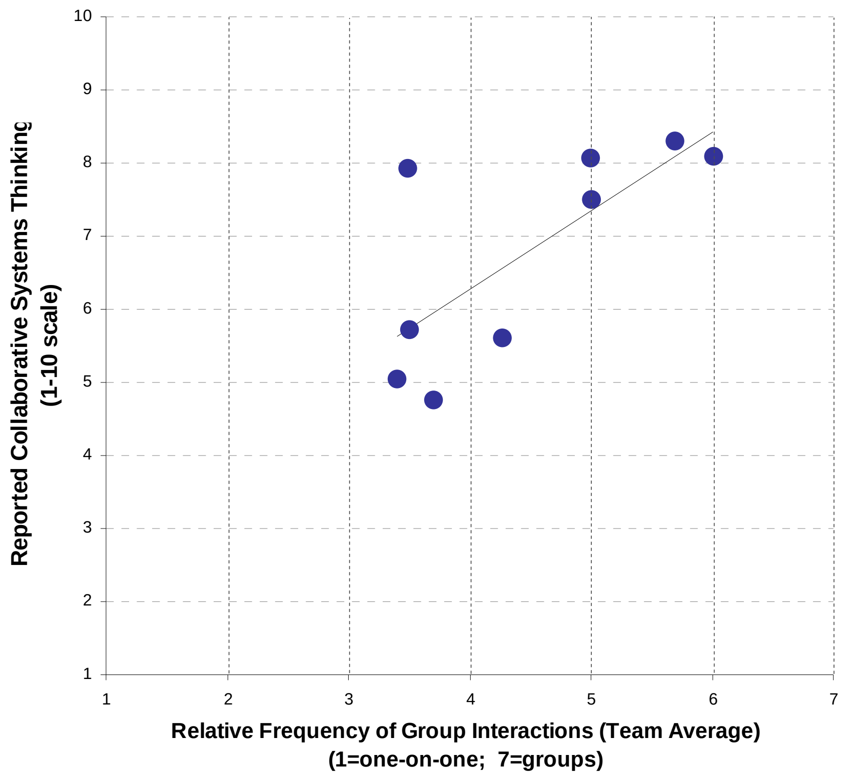


Trait 2: CST Teams Communicate in Real-Time Groups

Delayed Interactions: Correlation = -0.50



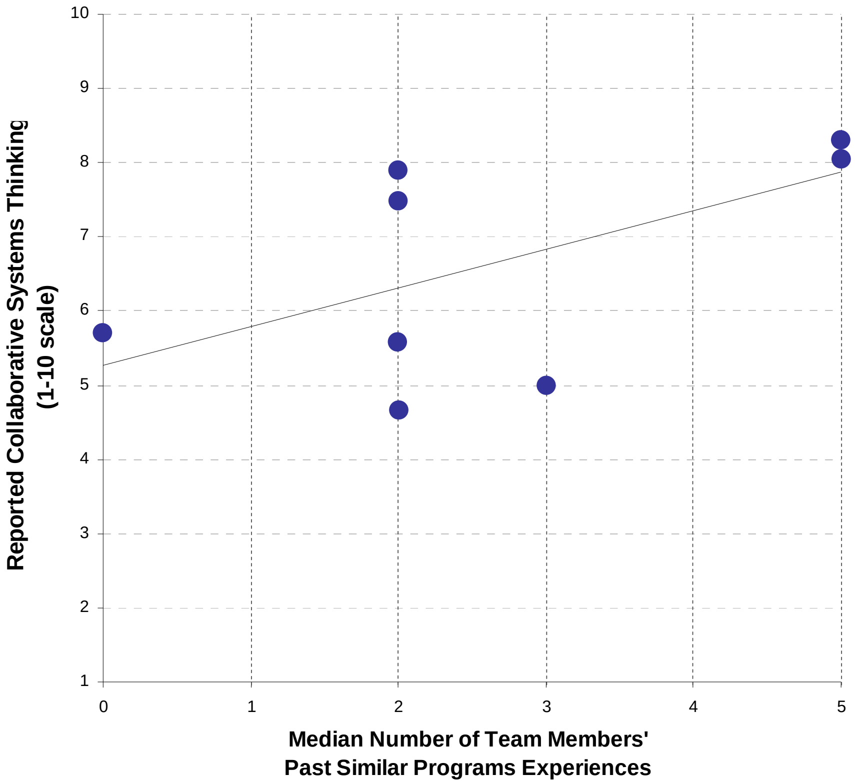
Group Interactions: Correlation = 0.72



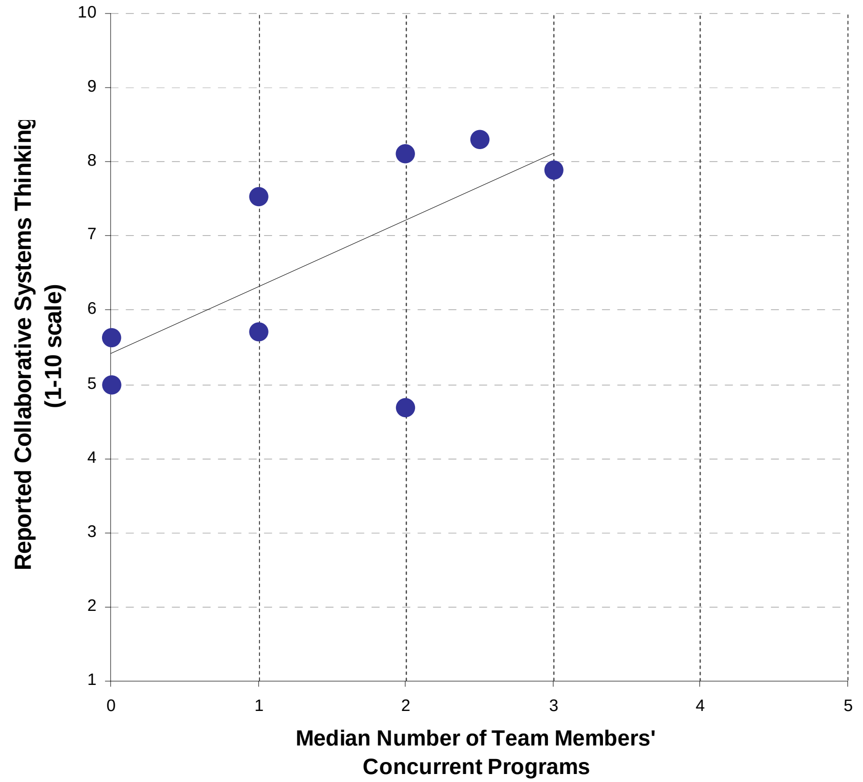
- Complements preference for consensus decision making
- Evidence of good team communication norms
- Weak additional preference for in-person interactions (Corr=0.43)

Trait 3: CST Teams Have More Program Experience

Past Program Experience: Correlation = 0.62



Concurrent Programs: Correlation = 0.64

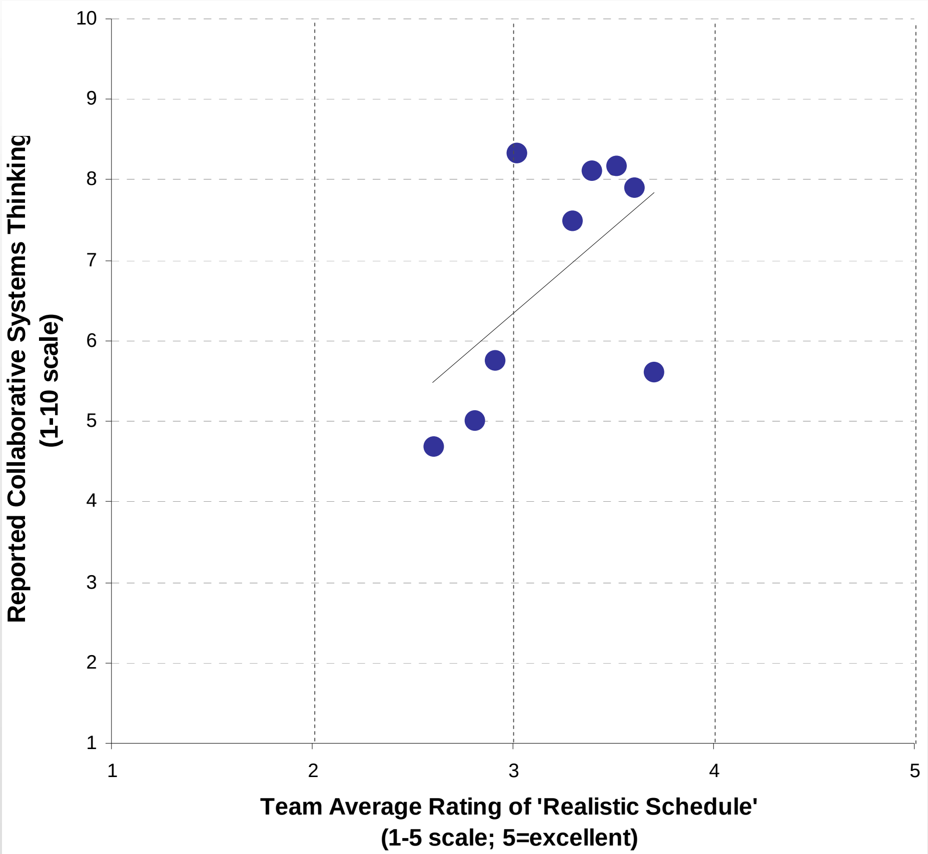


- Data reinforce systems thinking enabling benefits of program experience
- Concurrent programs provide ‘weak links’ to other programs

Trait 4: CST Teams Have More Creative Environments

- Creativity Framework
  (Thompson and Lordan 1999)
  - Project Management
  - Access to Resources
  - **Decision Freedom**
  - **Realistic Schedule**
  - Individual Incentives and Recognition
  - Team Incentives and Recognition
  - Interesting and Challenging Work
  - **Collaborative Environment**
  - Organizational Interest in Mission of Team
- 'Realistic Schedule' appeared in interviews from 7 of 10 full case studies
  - 'Schedule pressures inhibit CST'
  - 'Good timelines counterbalance tendency to wait until last minute'
- 'Individual and Team Incentives' low for all teams
- 'Interesting and Challenging Work' high for all teams

'Realistic Schedule': Correlation = 0.58



Empirically Generalized 'Non-Traits' of CST Teams

- Team Size (Corr = -0.17)
  - Literature: Smaller teams enable CST
  - Caveat: Limited range of team sizes (5-20 individuals)
- Measures of Technical Process Use / Tailoring (Corr ~ 0.11, 0.20)
  - Literature: Greater process use and/or tailoring enables CST
  - Caveat: Proprietary concerns; limited access to process documentation
- Self-Reported Individual Systems Thinking (Corr = 0.27)
  - Literature: Individual systems thinking enables CST
  - Caveat: Individual and supervisor ratings differed greatly. No objective measure for ST
- Team Collocation (Corr = 0.17)
  - Literature: Collocation enables CST
  - Caveat: Productive team norms can overcome

Question 3: Towards Predicting CST

Research Questions:

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Expected Outcomes:

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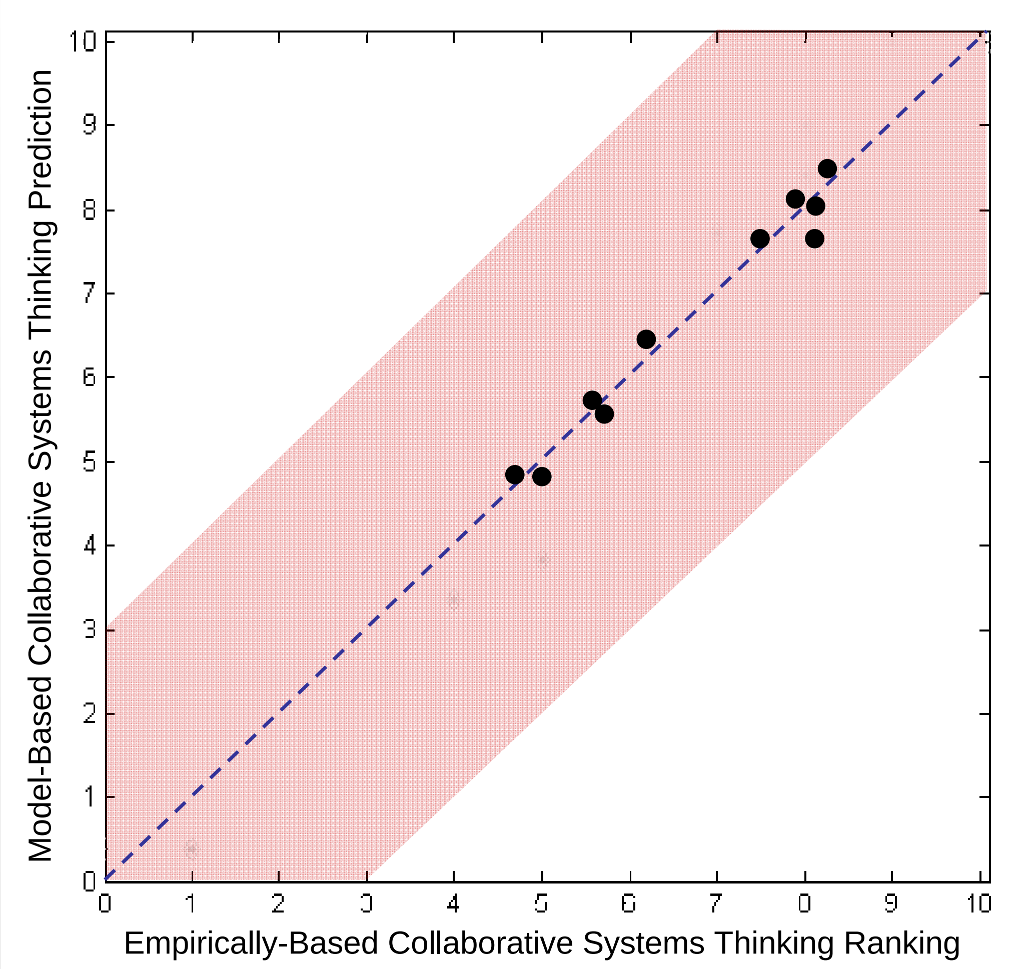
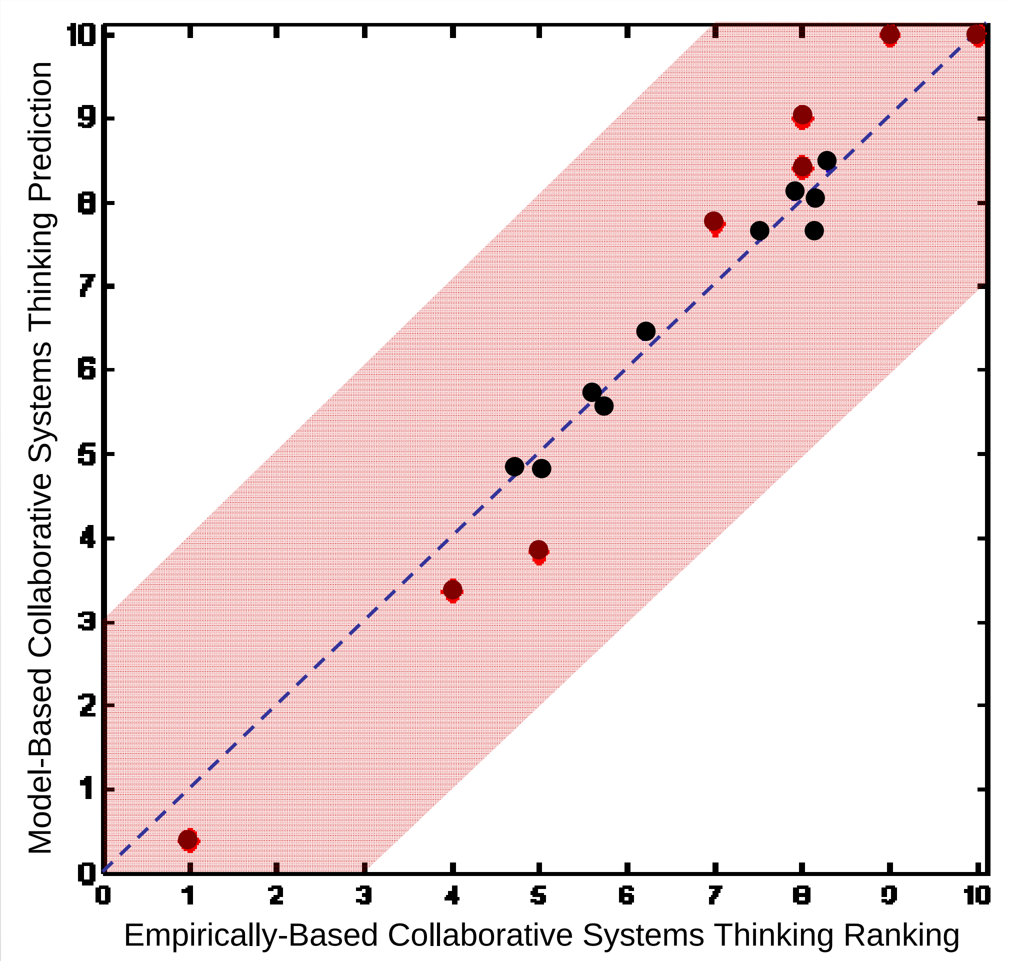
Regression Modeling Identified Five Best Predictors of CST



- Purpose:
  - Identify 5 best predictors
  - Facilitate validation
- Results:
  - Model explains 85% of observed variability in CST rating
  - Each trait passed null hypothesis test
- Best Predicting Traits (high-low):
  - **Consensus Decision Making**
  - **Concurrent Program Experience**
  - **Realistic Schedule**
  - **Overall Creative Environment**
  - **Real-Time Interactions**

Eight Validation Case Studies: Predictive Value of Traits



- Applying results to new case studies accepted validation procedure within Grounded Theory (Strauss and Corbin 1998)
- Theoretical Sampling Used (Yin 2003)
  - Eight validation case studies
  - Include software and I&T phase programs
- Five model components explain 72% of observed variability within validation cases

Third Expected Outcome: Heuristics for Enabling CST

Research Questions:

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Expected Outcomes:

- CST definition and generalized traits
- A set of hypotheses to drive future research
- **Heuristics for enabling collaborative systems thinking**

Eight Heuristics Offer Insights for Enabling Collaborative Systems Thinking

- Heuristics
  - Rules-of-thumb (Maier and Rechtin 2002);
  - A bridge between the art and science of engineering (Vincenti 1990)
- Identified eight heuristics from interview transcripts

Trait	Heuristic
Program Experience	*Engineering mistakes repeat every 7-10 years. This is the time it takes for critical people to rotate off a program and for important knowledge to be lost and rediscovered through failure.*
Creative Environment	*The asking and answering of questions brings both parties to new realizations. A team needs the leader to ask the right questions: an individual who is curious, imaginative, knowledgeable, and can help others look at the problem from outside of the box.*
Real-Time Interactions	*Teams tend to over-use email and other IT tools. Sometimes you just need to walk around and speak with others. After all, you can't delete a walk-in.*

Implications for Industry, Academia, and Government

Government

- Support policies that incentivize corporate IR&D funding to provide the workforce systems experience
- Promote creativity and entrepreneurship through small business grants
- Support research funding within academic to ensure sufficient numbers of students are in the systems skill development pipeline

Academia

- Use capstone projects, or similar, to provides students systems experiences
- Use team activities to provide guidance on effective norms and communications within teams
- Coursework should introduce drawing, drafting, and model making to improve communication skills and creativity

Key

- Demographics
- Consensus Decision Making
- Effective Team Communication
- Systems Experience
- Social and Technical Leadership
- Creativity

Industry

- Use IR&D funds for small development programs that provide employees systems experiences
- Emphasize both technical and social skills when selecting team leadership

Conclusions

- Collaborative systems thinking is a ***distinct concept*** from individual systems thinking
- Collaborative systems thinking teams have ***differentiating traits***
- These traits are ***generalizable*** to aerospace case studies beyond the initial set
- Results ***confirm*** some aspects of ***conventional wisdom*** and ***challenge*** others
- CST team traits emphasize importance of ***technical and social skills***

Questions?