Collaborative Systems Thinking:
Exploring systems thinking within teams

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Agenda

- Motivation
- Defining Systems Thinking
  - General Definitions
  - Engineering
  - Team-Based
- Research Methodology
- Results
- Future Directions

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Research Motivation: Increased SE Demand

- Systems Engineering investments linked to smaller overruns of cost and schedule
- Increasingly complex and interdisciplinary programs
- Longer development times

Historical Program

- Manhattan Project: 2.5 years
- Apollo: 8 years
- SR-71: 3 years

Recent Programs

- Joint Strike Fighter: ~13 years
- F-22: 14 years
- Constellation: ~20 years

Pre-Milestone A and Early Phase Systems Engineering: A Retrospective Review and Benefits for Future Air Force Acquisitions.

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Research Motivations: Workforce Shortfalls

Shortfalls in the systems engineering workforce

- Increasing demand for systems engineering skills outpaces supply
- Erosion of engineering competency particularly in aerospace and defense
- Increased interdisciplinary emphasis as world becomes more connected
- Nature of programs necessitates socio-technical rather than pure technical abilities

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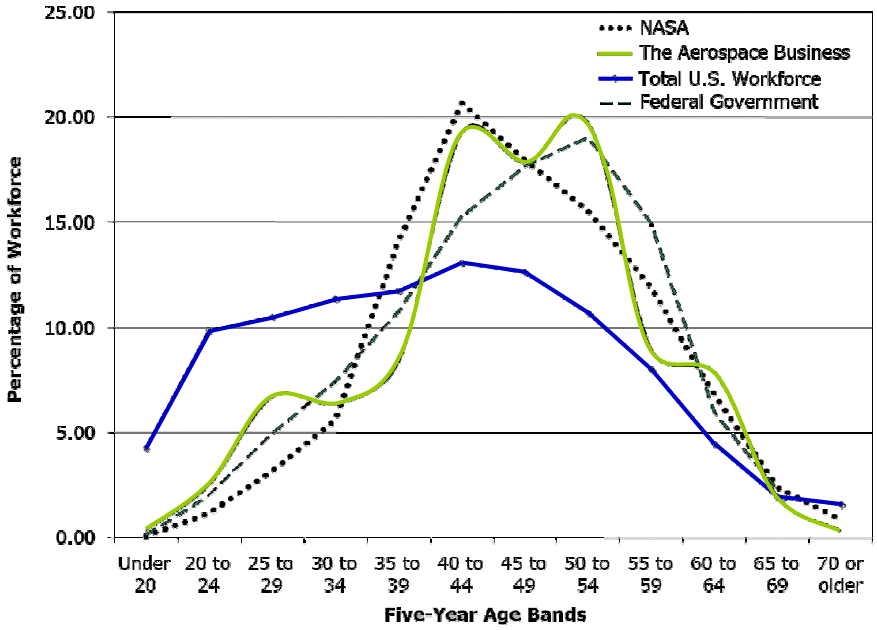
Erosion of Systems Engineering Competency



Engineering Demographics in the US

(Future US Space Workforce 2005)

N. Augustine and The Committee on Prospering in the Global Economy of the 21st Century. Rising Above the Gathering Storm. Technical report, National Academies, 2005.

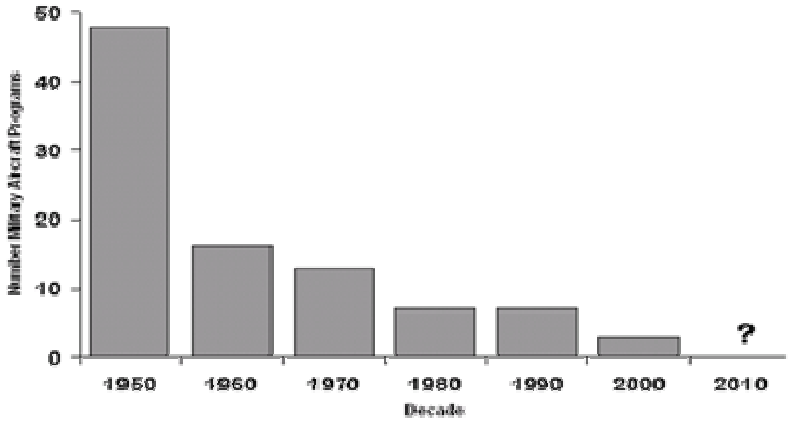
D. Black, D. Hastings, and the Committee on Meeting the Workforce Needs for the National Vision for Space Exploration. Issues Affecting the Future of the U.S. Space Science and Engineering Workforce: Interim report, 2006.

H. Davidz. Enabling Systems Thinking to Accelerate the Development of Senior Systems Engineers. PhD thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, 2006.

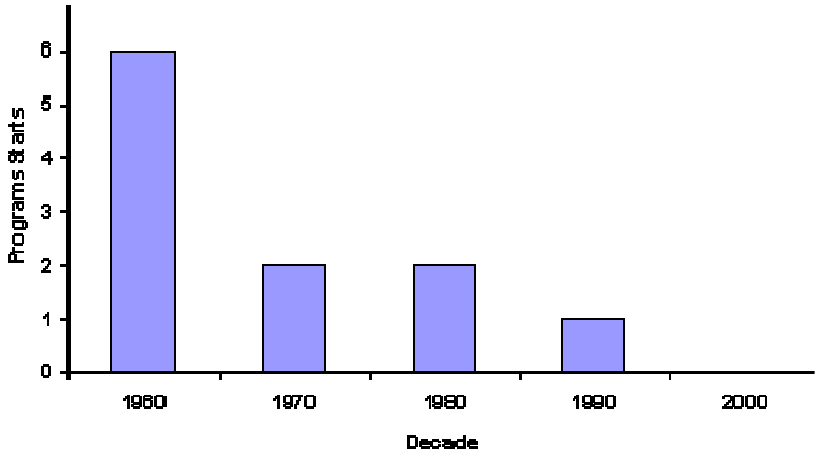
E. Murman et.al. Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative. Palgrave, New York, NY, 2002.

R. Stephens. Ensuring Aerospace Skills of the Future. In Proc. AIAA/ICAS International Air and Space Symposium and Exposition: The Next 100 Years, Dayton, OH, August 2003.

V. Neal, C. Lewis, and F. Winter. Spaceflight. Macmillan, New York, NY, 1995.



Manned Fighter Program Starts by Decade (Murman et al 2002)



Manned Spacecraft Program Starts by Decade (Neal 1995)

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Teams Necessitate Strong Social Abilities

- Engineering is socio-technical activity

- Teams leverage breadth and depth of member experience
  - Multiple thinking styles
  - Experience on different programs
  - Different areas of expertise
  - Teams regarded as better for safety-critical decisions (Salas and Fiore 2004)
- Teams add complexity
  - Coordination costs
  - Communication loses
  - Semantic-based misunderstandings
- Good teams add value that exceeds their complexity
  - Team norms and written processes are important contributors to this balance

E. Salas and S. Fiore. Why team Cognition? An overview. In E. Salas and S. Fiore, editors, Team Cognition, chapter 1, pp 11-32. American Psychological Association, Washington, DC, 2004.

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Defining Systems Thinking: General Definitions

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)

Component Complexity

Interrelationships

Context

Emergence

Wholes

R. Ackoff. Transforming the Systems Movement. Opening Speech at 3rd International Conference on Systems Thinking in Management, May 2004. Philadelphia, PA.

P. Checkland. *Systems Thinking, Systems Practice, Soft Systems Methodology: A 30-year retrospective*. John Wiley and Sons, West Sussex, England, 1999.

J. Gharajedaghi. *Systems Thinking: Managing chaos and complexity*. Butterworth-Heinemann, Burlington, MA, 1999.

P. Senge. *The Fifth Discipline*. Doubleday, New York, NY, 2006.

J. Sterman. *Business Dynamics: Systems thinking and modeling for a complex world*. McGraw-Hill, New York, NY, 2000.

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Defining Systems Thinking: Engineering

*Systems thinking is utilizing modal elements to consider the **componential**, **relational**, **contextual**, and **dynamic elements** of the **system** of interest.*

(Davidz 2006)

- Divergence in definition among engineers, engineering organizations
- Common themes for enabling systems thinking development (Davidz 2008)
  - Experiential learning
  - Individual characteristics
  - Supportive environment

H. Davidz. Enabling Systems Thinking to Accelerate the Development of Senior Systems Engineers. PhD thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, 2006.
H. Davidz. Enabling Systems Thinking to Accelerate the Development of Senior Systems Engineers. Systems Engineering. Vol. 11 No. 1

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Defining Systems Thinking: Teams

- Engineering thinking: purposeful, reasoned and goal directed action towards solving of problems (Lynn et al 2004)
- Team Thinking (Cooke et al 2004)
  - Emerges from intersection of individual team members' thinking
  - Based in team member behaviors
  - Influenced by team processes.
- No recognized measures for team thinking (Lerch et al 2004)
- Design Thinking as Bridge to CST
  - Inclusion of divergent and convergent thinking styles
  - Communication at multiple levels of abstraction, "multiple design languages" (Dym et al 2005)
  - Inclusion of big picture thinking, tolerance of uncertainty, role of creativity
  - Recognition of engineering tendencies towards convergent thinking, rush to evaluation
  - Importance of critical questioning, analysis (Stempfle and Badke-Schaub 2002)

N. Cooke et al. 2004. Advances in Measuring Team Cognition. Team Cognition, ed. E. Salas and S.M. Fiore. Washington, DC: American Psychological Association.

R. Lerch, J. Espinosa, and R. Kraut, 2004. Explicit versus implicit coordination mechanisms and task dependencies: One size does not fit all. Team Cognition, ed. E. Salas and S.M. Fiore. Washington, DC: American Psychological Association.

G. Lynn, A. Akgun, and R. Reilly 2005. Multi-dimensionality of learning in new product development teams. Journal of Innovation Management 5(2), pp. 57-72.

J. Stempfle and P. Badke-Schaub, "Thinking in Design Teams: An analysis of team communication," Design Studies Vol. 23, No. 1, pp 473-496, 2002.

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Research Methodology: SE Research Needs

Increasing demand for systems leaders coupled with the growing need to address significant socio-technical challenges motivates research in engineering systems thinking and practice

- Empirical studies and case based research
- Factors underlying competency in workforce
- Identification of enablers, barriers, precursors
- Systems thinking at multiple levels – individual, **team**, enterprise

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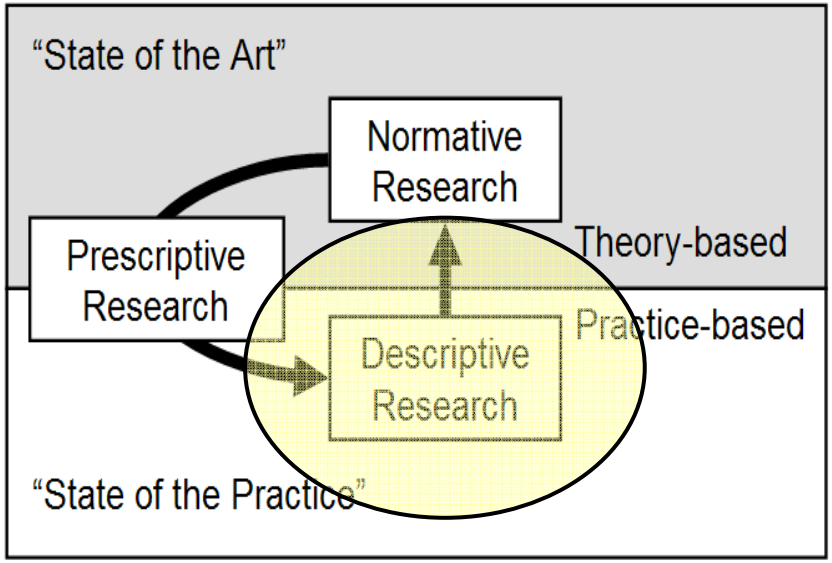
Leveraging Qualitative and Empirical Research Methods

- Collecting empirical data towards generating systems engineering theory (Valerdi and Davidz 2007)
  - Grounded data required to move systems engineering from art to science
  - Generating understanding/description of current practice
- Previous team-based studies almost exclusively using student teams
- Industry team-based studies often based on 1-2 team member interviews

SEAri Research Structure



R. Valerdi and H. Davidz. Empirical Research in Systems Engineering: Challenges and opportunities of a new frontier. In Proc. *5th CSER Conference on Systems Engineering Research*, Hoboken, NJ, March 2007.

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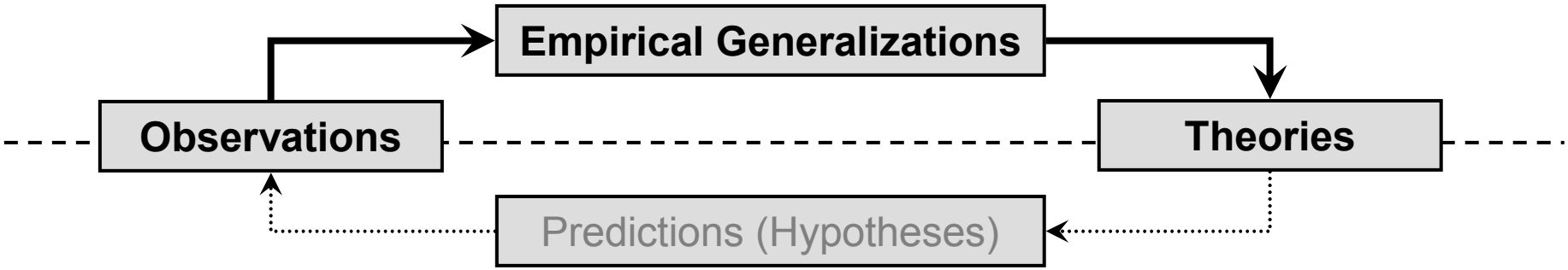
Grounded Theory Methods

- Grounded Theory is a research method for the 'top half' of the scientific process (Glaser and Strauss 1967)
  - Starts with a question and observations
  - Ends with an explanatory theory and a set of hypotheses
  - Method is exploratory in nature
  - Has prescribed data collection and analysis methods



- Grounded Theory methods (Strauss and Corbin 1998)
  - **Description:** Use of words to describe a mental image
  - **Conceptual ordering:** Organization of data according to pertinent dimensions
  - **Theory building:** A set of related concepts within a relational framework suitable for explaining the observed behavior

B. Glaser and A. Strauss. *The Discovery of Grounded Theory: Strategies for qualitative research*. Aldine Publishing Company, Chicago, IL, 1967.
A. Strauss and J. Corbin. *Basics of Qualitative Research: Techniques and procedures for developing grounded theory*. Sage Publications, Thousand Oaks, CA, 1998.

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Addressing the Needs: Team-level systems thinking

Research Questions

- What are the empirically generalized traits of systems thinking teams?
- What aspects of team culture and technical process usage correlate with team-level systems thinking?

Research Objectives

1. An operational definition characterizing team-level systems thinking
2. A set of heuristics for enabling collaborative systems thinking
3. Descriptive theory of collaborative systems thinking
4. Potential influences
   - Workforce development
   - Technical process tailoring
   - Enterprise architecture

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Research Structure

- Phase 1: Literature Review
  - Define what is team-level systems thinking
  - Establish framework for further inquiry
- Phase 2: Pilot Interviews
  - Validation of research directions
  - Identification of focused areas of inquiry
- Phase 3: Case Studies
  - Empirical data
  - Basis for theory development

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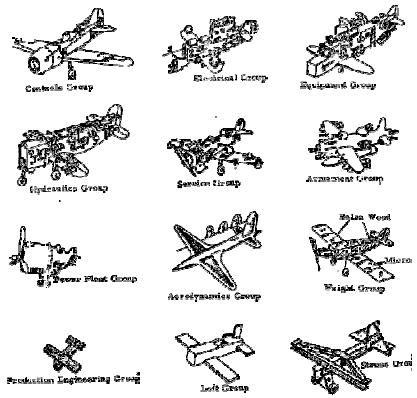
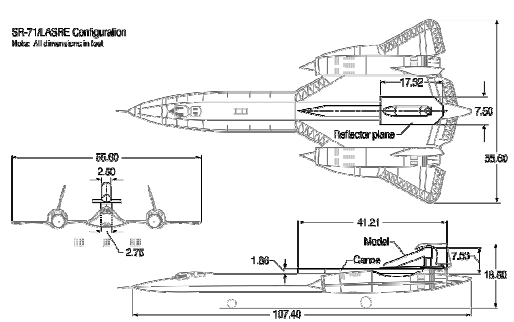
Phase 1: Collaborative Systems Thinking

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)





C. Lamb Systems Thinking as an Emergent Team Property. IEEE Systems Conference, Toronto, Canada, April 2008

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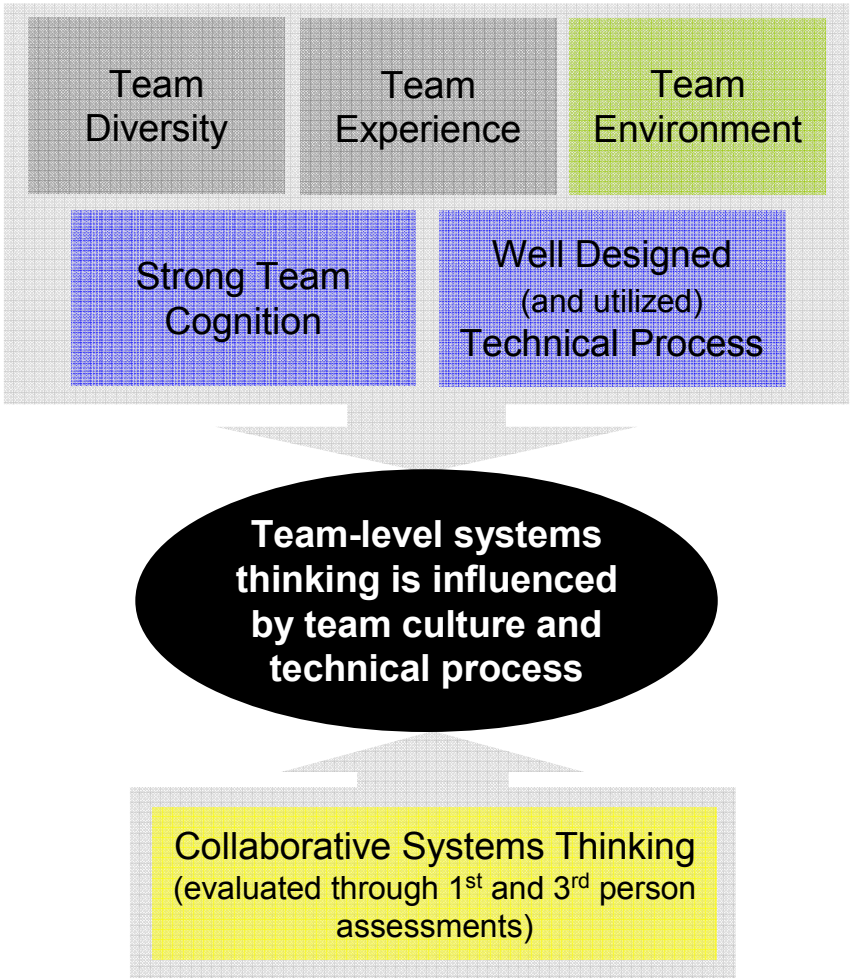
Phase 1: Conceptual Framework



Organizational Culture	Standardized Technical Process
Team norms	Documented tasks and methods
Espoused beliefs	Vision statements
Underlying assumptions	Strategy for standardization
Social networks	Process flow maps, org-charts

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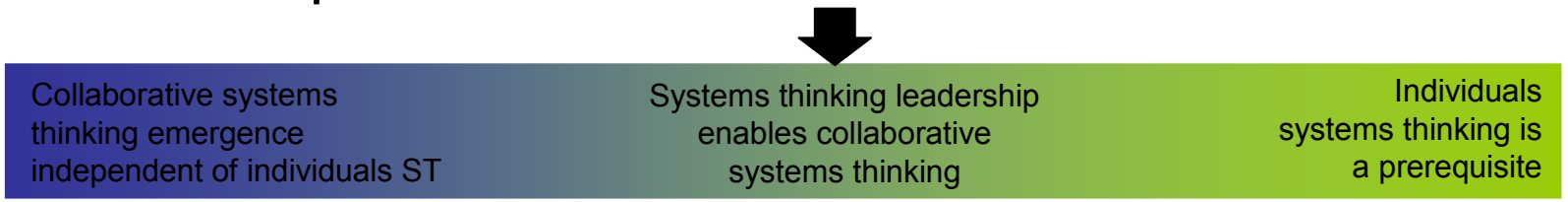
Phase 2: Pilot Interviews

- Collaborative systems thinking (CST) is different from systems thinking
  - Team product products
  - CST is concerned not only with wholes, but systems completion
- Team composition influences CST



- Culture and process are important enablers and barriers

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Phase 3: Literature Based Case Study Framework

A. Team Diversity: Heterogeneity is a team asset and is linked with better team performance (Hackman 2002). Diversity also limits the risks of groupthink (Janis 1972).

1. Degree concentration
2. Job title
3. Function/discipline
4. Personality preferences
5. Individual systems thinking capability
6. Team stability
7. Team roles

B. Team Experience: Experience is an enabler of systems thinking (Davidz 2006). The ability to leverage a greater body of past experiences is one reason teams are a better decision making unit than individuals in safety critical situations (Salas and Fiore 2004).

1. Level of education
2. Tenure at company
3. Time in industry
4. Worked on past similar projects (#)
5. Time together as a team
6. Team training

C. Team Environment: The concept of creativity is closely linked with systems thinking (Thompson and Lordan 1999). Tangible and intangible components of the work environment contribute to creativity. Using multiple levels of abstraction to communicate within a team is linked with good engineering design thinking (Dym et at 2005). The tools and physical spaces available to a team will dictate with what means they communicate.

1. Co-location
2. Collaboration tools
3. Team spaces
4. Enabler/Barriers of creativity
5. Multiple design languages

D. Strong Team Cognition: Collaborative systems thinking is an instantiation of team thinking. Team-level cognition is a logical pre-requisite with a set of literature-identified traits (Salas and Fiore 2004). Testing for the presence of these traits will help in evaluating whether the observed behaviors are the result of team-level systems thinking or strong individual systems thinking.

1. Organization values teamwork
2. Strong sense of team (product focus)
3. Ability to engage in critical analysis of ideas.
4. Mutual respect and trust
5. Centrality-vs distribution of decision making
6. Mutual awareness
7. Situational awareness
8. Implicit vs explicit coordination

E. Well Design Technical Process: A concentration on analysis before evaluation enables better handling of complexity (Stemfle and Badke-Schaub 2002). Additional research suggests the act of discussing and agreeing upon additional communication processes within a team improves a team's odds of success (Dougherty 1990). Metrics such as CMMI© process maturity are an indicator of good process design, but not necessarily an indicator of good process implementation. Measures of actual process usage, process tailoring, and team-agreed upon practices round out the evaluation of technical process.

1. Analysis before evaluation
2. Understanding of role within systems/organization
3. Understanding of role within process
4. CMMI rating, or similar
5. Metrics of process usage
6. Extent to which team tailors process
7. Extent to which team chooses own process/tools/methods
8. Individual understanding of why process in place
9. Perception of Process

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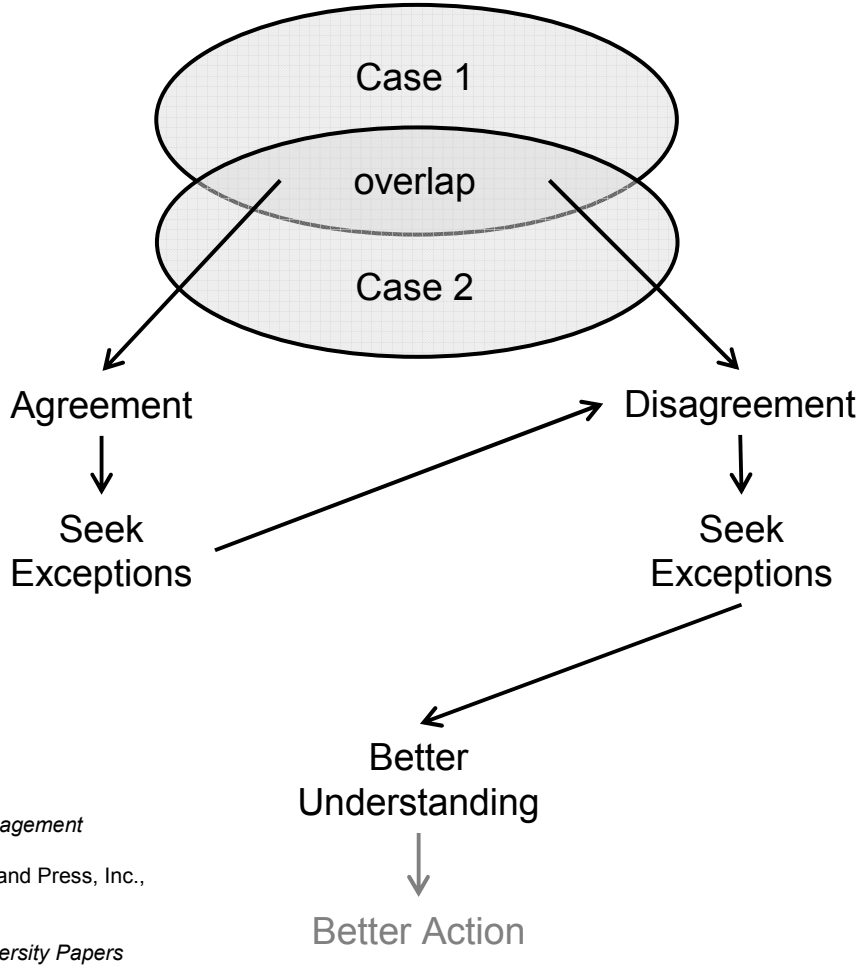
Phase 3: Data Analysis

- Coding
  - Definition: breakdown of textual data into central ideas with goal of creating relational structure for interpreting data and explaining observations
  - Open, axial, and selective coding
- Memo writing
  - Definition: record of researcher thoughts, data interpretations and questions
  - Code, theoretical, operation, diagrams



K. Eisenhardt. Building Theories from Case Study Research. *The Academy of Management Review*, 14(4):532{550, 1989.
D. Krathwohl, editor. *Methods of Educational and Social Science Research*. Waveland Press, Inc., Long Grove, IL, 1998.
C. Robson. *Real World Research*. Blackwell Publishing, Malden, MA, 2002.
R. Stebbins. *Exploratory Research in the Social Sciences*, volume 48 of *Sage University Papers Series on Qualitative Research Methods*. Sage Publications, Thousand Oaks, CA, 2003.

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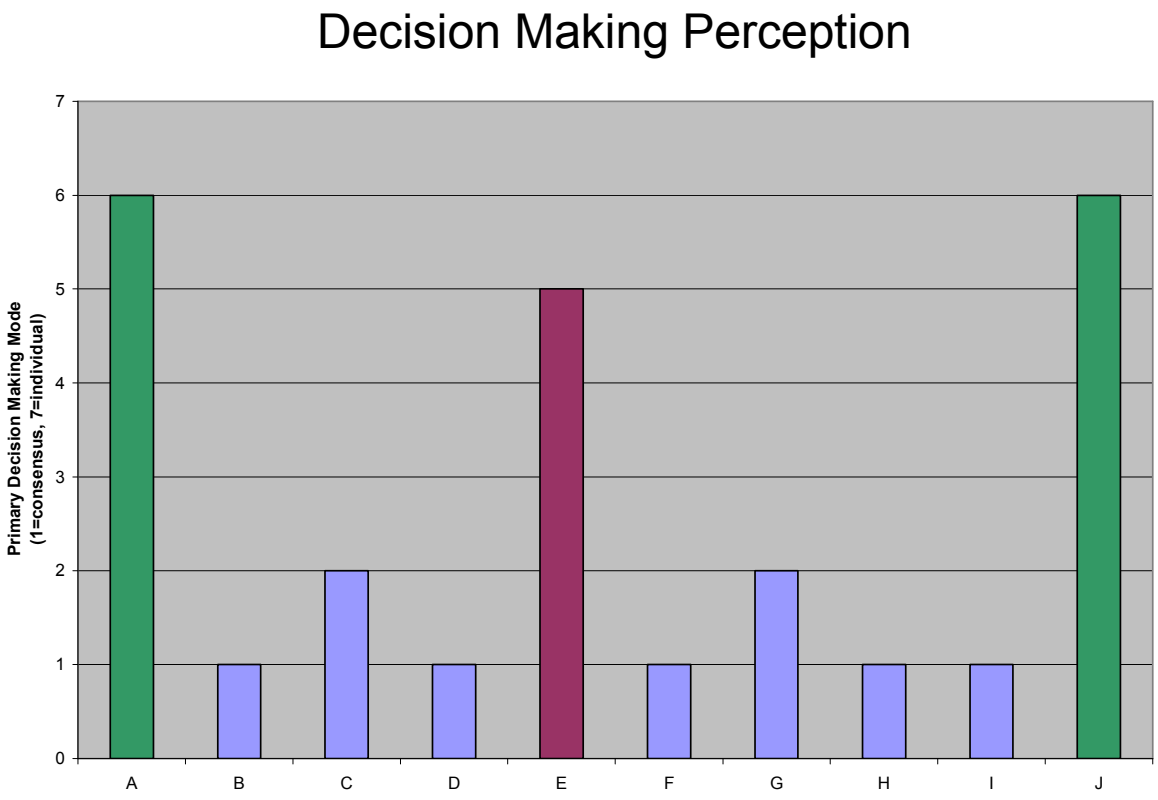
Phase 3: Examples

Question:

- Are design decisions within the team more often made by an individual or team consensus? (1-decision by team consensus, 7-decision by individual)

Response:

- Most team members perceived decisions were made primarily through team consensus
- Individuals A and J were offsite members
- Individual E collocated but identified with introvert preferences in contrast to the rest of the team



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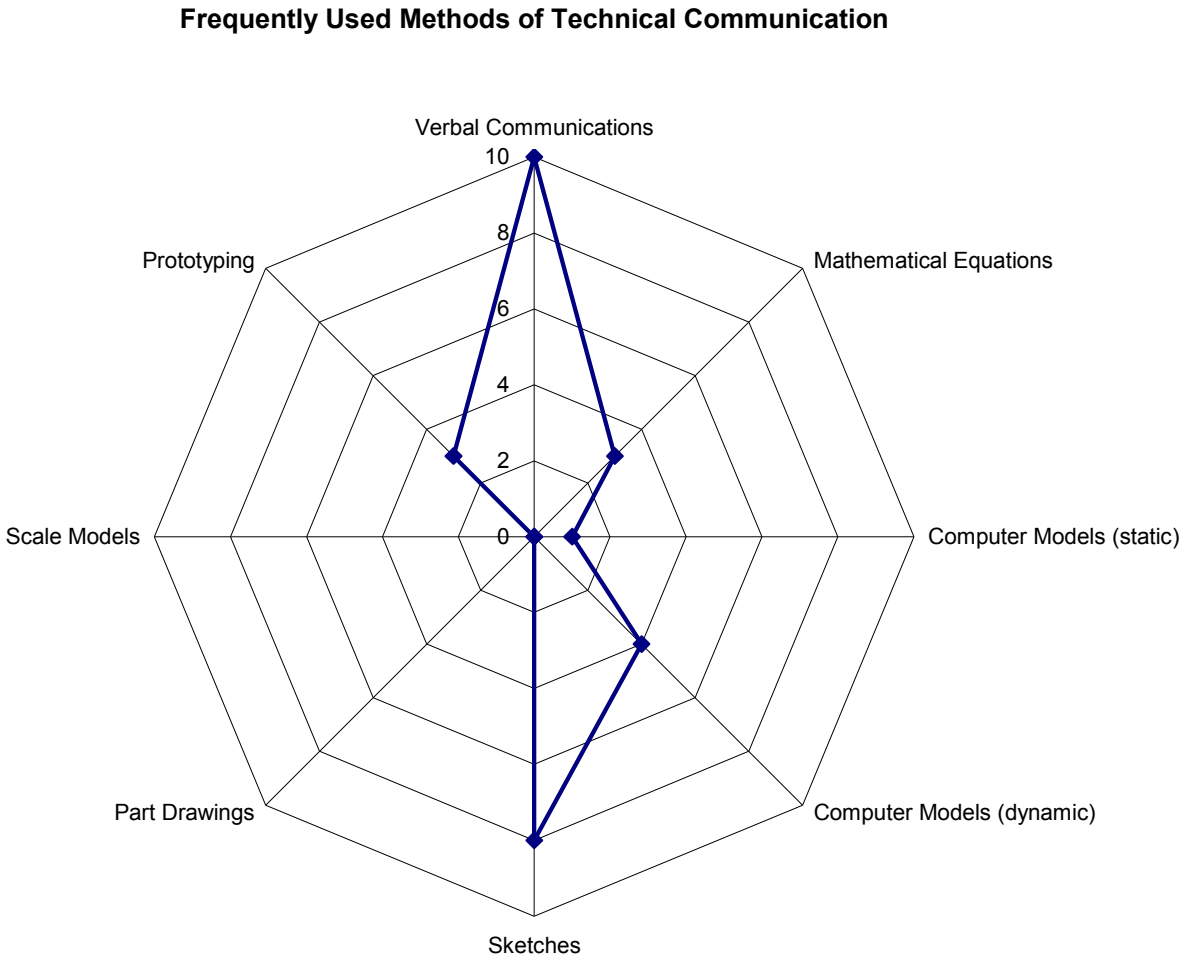
Phase 3: Examples

Question:

- Which of the following are most commonly used to communicate technical information within the team?

Response:

- Group primarily relies on verbal communication and sketching.
- Prototyping, mathematical equations and computer models also used
- Scale models, part drawings, and static computer models not relevant to group's task



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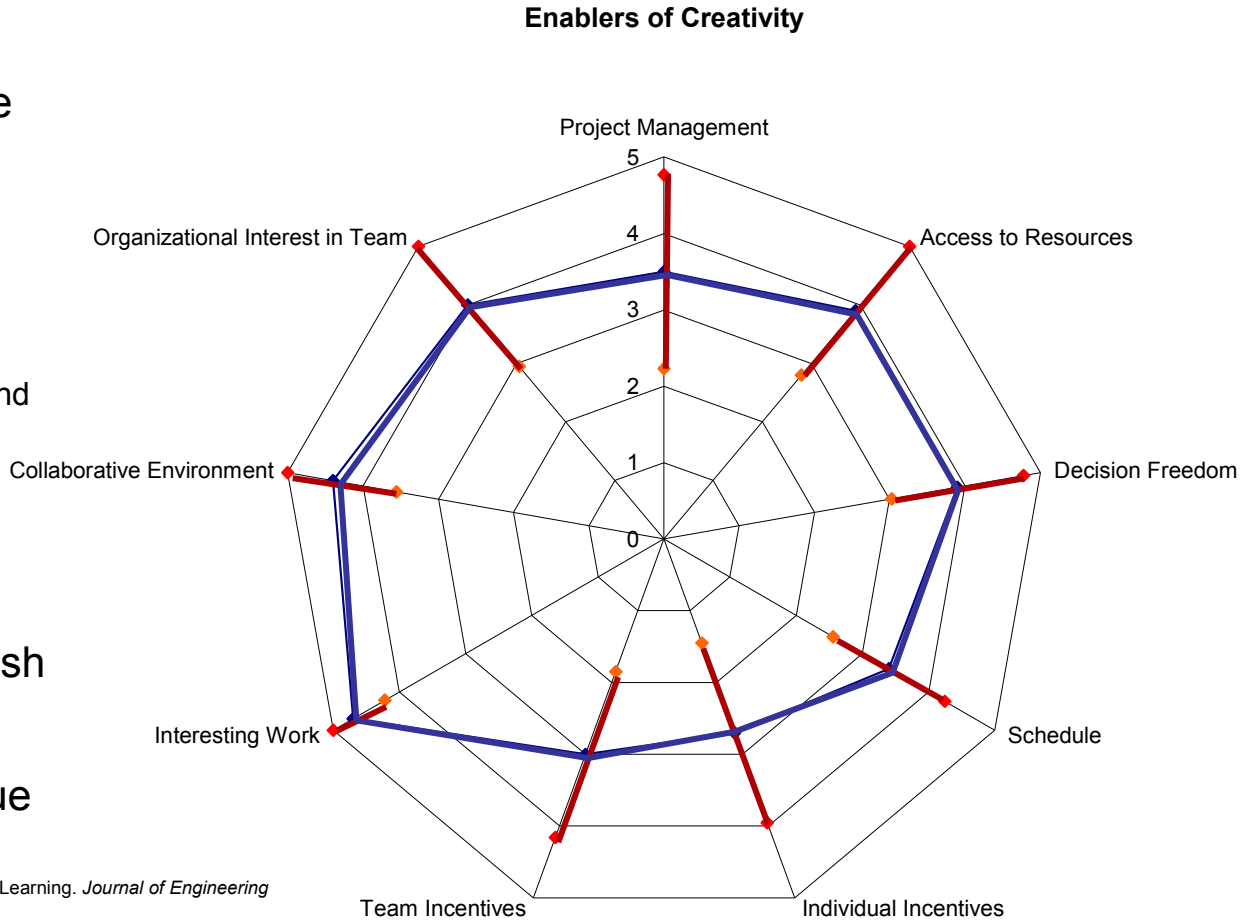
Phase 3: Examples

Question:

- Please rate each of the following aspects of team environment.(1-Poor to 5-Excellent)
- Grounded in link between creativity and systems thinking
  (Dym et al 2005; Thompson and Lordan 1999; Volger 2002)

Response:

- Overall, a creative environment
- Constrained design space necessitated fresh thinking
- Need points of comparison to draw true conclusions



C. Dym et.al. Engineering Design Thinking, Teaching, and Learning. *Journal of Engineering Education*, 94(1). pp. 103-120, 2005.
G. Thompson and M. Lordan. A Review of Creativity Principles Applied to Engineering Design. *Journal of Process Mechanical Engineering*, 213(1). pp. 17-31, 1999.
A. Volger. The Munich Model: Creating an environment for space architecture development. In *Proc. AIAA Space Architecture Symposium*, Houston, TX, October 2002. AIAA.

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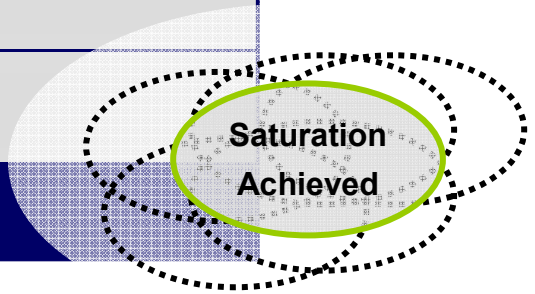
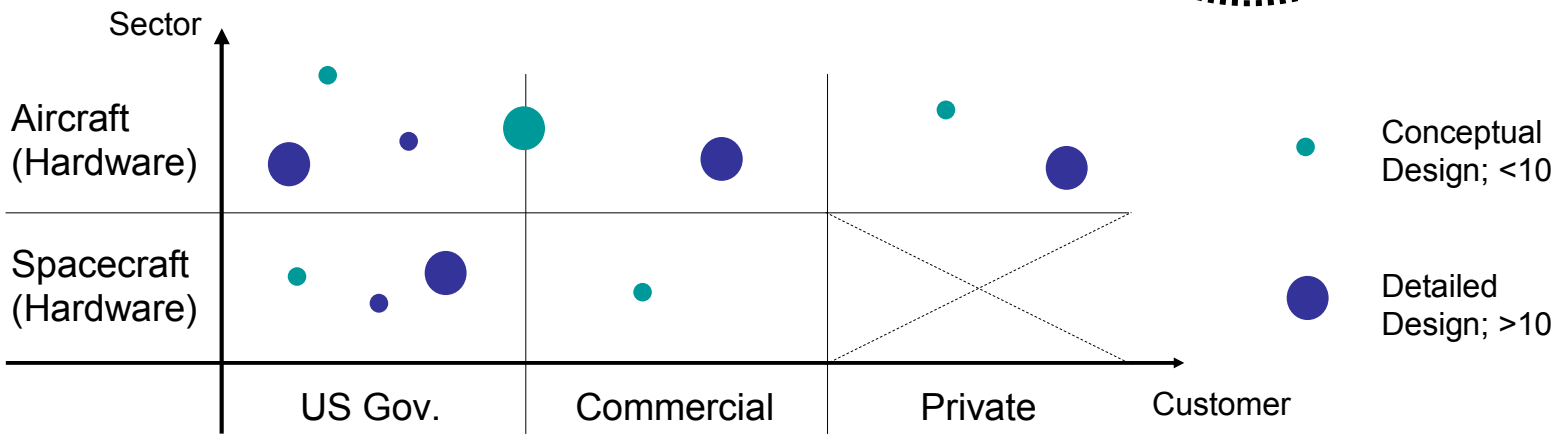
Phase 3: Next Steps
Continuing Case Work

Independent Variables				Dependent Variable
Customer	Industry Sector	Program Lifecycle	Team Size	Collaborative Systems Thinking
US Gov.	Aircraft (Hardware)	Conceptual Design	<10	Strong
Commercial	Spacecraft (Hardware)	Detail Design	>10	Weak
Private				





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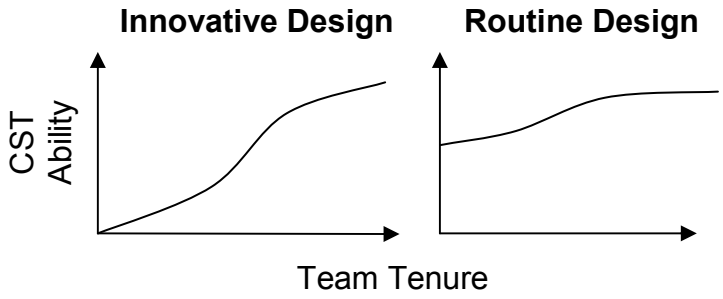
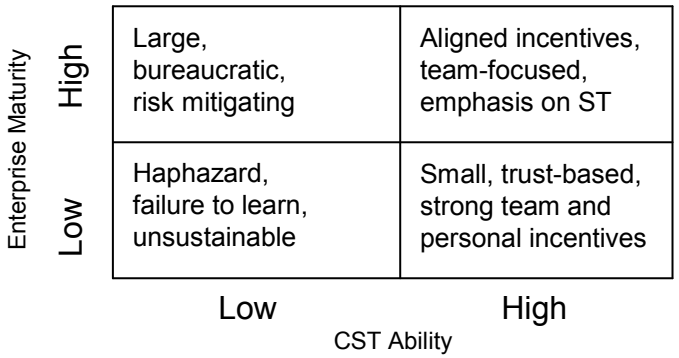
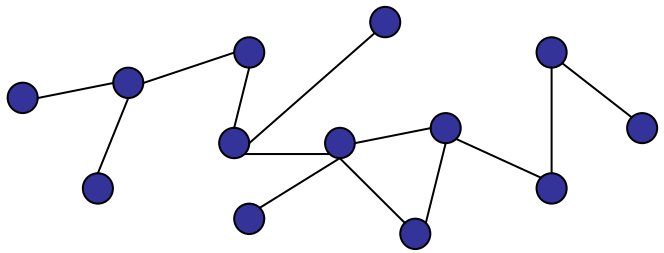
Future Directions

- Stages of Teams/Evolution of Collaborative System Thinking (CST)
  - Evolution of CST with team development
  - Which team stages most benefit from CST?
- Impact of Enterprise Maturity on CST
  - Is a high level of enterprise maturity an enabler or inhibitor of CST?
  - Startup companies vs. large companies
- Impact on Knowledge Transfer
  - Do strong CST teams have better knowledge transfer mechanisms?
  - Mentoring, tacit knowledge sharing







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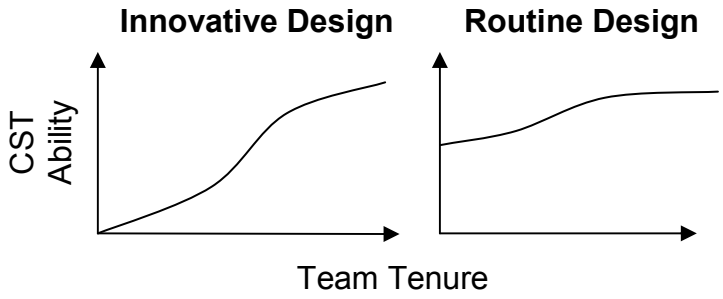

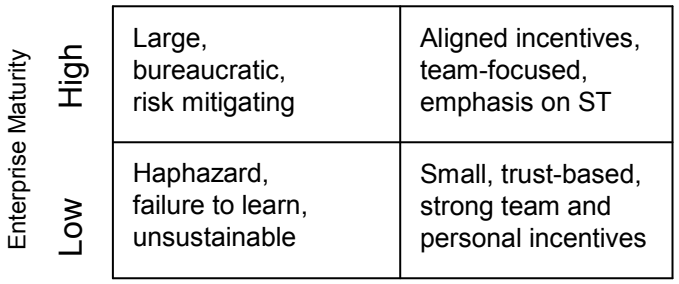

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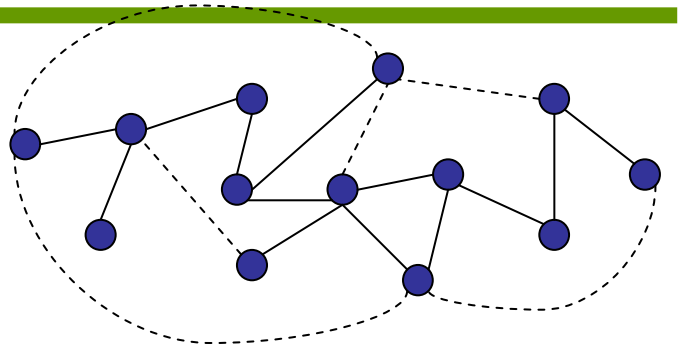
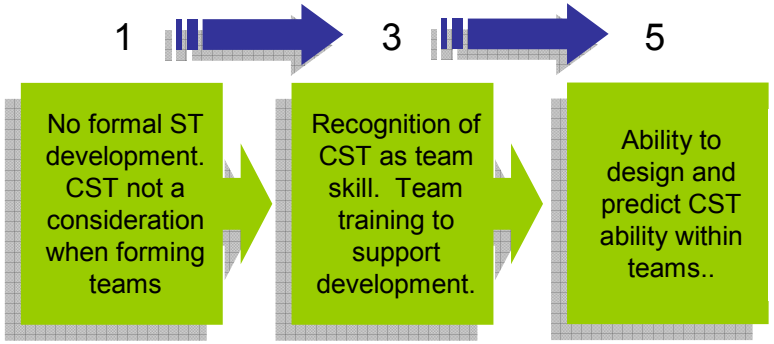
Future Directions

- CST in the Distributed Enterprise
  - Continuation of (Utter 2007)
  - Is CST more or less likely to occur in distributed teams?
- CST in Context of Domain and Type
  - How does the expression of CST differ between domains?
  - Are the enablers and barriers of CST domain specific?
- Integration of CST in Competency Models
  - Development of a CST competency model towards enabling development





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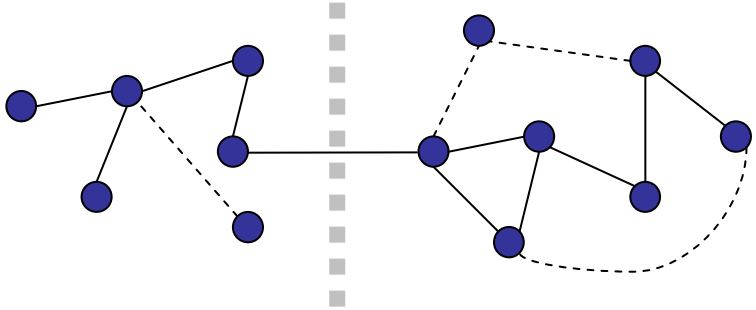

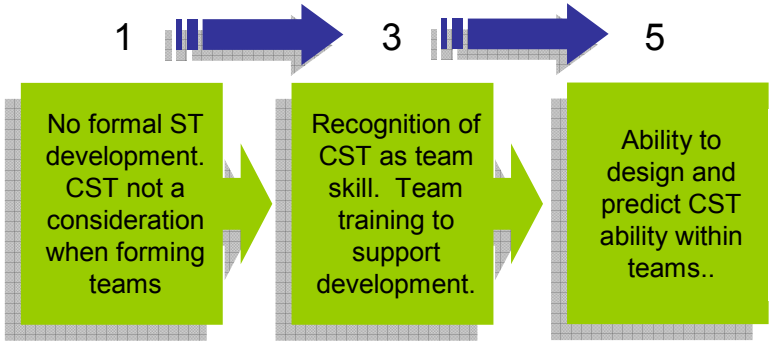

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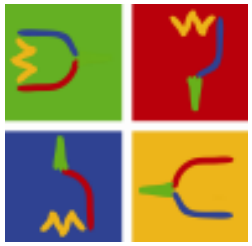

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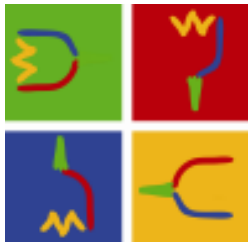

Backup Slides

Sources

Motivation

N. Augustine and The Committee on Prospering in the Global Economy of the 21st Century. Rising Above the Gathering Storm. Technical report, National Academies, 2005.

D. Black, D. Hastings, and the Committee on Meeting the Workforce Needs for the National Vision for Space Exploration. Issues Affecting the Future of the U.S. Space Science and Engineering Workforce: Interim report, 2006.

E. Murman et.al. *Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative*. Palgrave, New York, NY, 2002.

V. Neal, C. Lewis, and F. Winter. *Spaceflight*. Macmillan, New York, NY, 1995.

R. Stephens. Ensuring Aerospace Skills of the Future. In *Proc. AIAA/ICAS International Air and Space Symposium and Exposition: The Next 100 Years*, Dayton, OH, August 2003.

Systems Thinking

R. Ackoff. Transforming the Systems Movement. Opening Speech at 3rd International Conference on Systems Thinking in Management, May 2004. Philadelphia, PA.

P. Checkland. *Systems Thinking, Systems Practice, Soft Systems Methodology: A 30-year retrospective*. John Wiley and Sons, West Sussex, England, 1999.

H. Davidz. *Enabling Systems Thinking to Accelerate the Development of Senior Systems Engineers*. PhD thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, 2006.

J. Gharajedaghi. *Systems Thinking: Managing chaos and complexity*. Butterworth-Heinemann, Burlington, MA, 1999.

C. Lamb Systems Thinking as an Emergent Team Property: Ongoing research into the enablers and barriers of team-level systems thinking. IEEE Systems Conference, Toronto, Canada, April 2008 (forthcoming)

P. Senge. *The Fifth Discipline*. Doubleday, New York, NY, 2006.

J. Sterman. *Business Dynamics: Systems thinking and modeling for a complex world*. McGraw-Hill, New York, NY, 2000.

Research Methods

H. Davidz. *Enabling Systems Thinking to Accelerate the Development of Senior Systems Engineers*. PhD thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, 2006.

A. Edmondson. Psychological Safety and Learning Behavior in Work Teams. *Administrative Science Quarterly*, 44(2):350-383, 1999.

K. Eisenhardt. Building Theories from Case Study Research. *The Academy of Management Review*, 14(4):532{550, 1989.

B. Glaser and A. Strauss. *The Discovery of Grounded Theory: Strategies for qualitative research*. Aldine Publishing Company, Chicago, IL, 1967.

D. Krathwohl, editor. *Methods of Educational and Social Science Research*. Waveland Press, Inc., Long Grove, IL, 1998.

C. Robson. *Real World Research*. Blackwell Publishing, Malden, MA, 2002.

R. Singleton and B. Straits. *Approaches to Social Research*. Oxford University Press, Oxford, 3rd edition, 1999.

R. Stebbins. *Exploratory Research in the Social Sciences*, volume 48 of *Sage University Papers Series on Qualitative Research Methods*. Sage Publications, Thousand Oaks, CA, 2003.

A. Strauss and J. Corbin. *Basics of Qualitative Research: Techniques and procedures for developing grounded theory*. Sage Publications, Thousand Oaks, CA, 1998.

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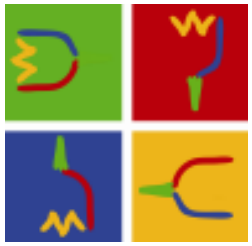

Backup—Team

- Team: a co-acting group of individuals
  - Bring greater breadth of knowledge to problem
  - Teams are more reliable for making safety critical decisions (Salas and Fiore 2004)
- Benefits to bringing functions together early in design
  - Two-thirds lifecycle cost determined in conceptual design
  - Concurrent engineering and Integrated Product Teams (IPTs) reduce failures due to poor communication (Newman 1999)
- Many theories of team structures
  - X-Teams (Ancona 2002)
  - Team roles
    - Functional
    - Basic (Belbin 1993)

D. Ancona, H. Bresman, and K. Kaeufer. The Comparative Advantage of X-Teams. *MIT Sloan Management Review*, 43(3):33-39, 2002.
R. Belbin. *Team Roles at Work*. Elsevier, London, 1993.
R. Newman. Issues in Defining Human Roles and Interactions in Systems. *Systems Engineering*, 2(3):143-155, 1999.
E. Salas and S. Fiore. Why *team* Cognition? An overview. In E. Salas and S. Fiore, editors, *Team Cognition*, chapter 1, pages 11-32. American Psychological Association, Washington, DC, 2004.

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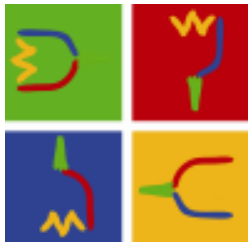

Backup—Process

- Process: a logical sequence of tasks towards achieving an objective
  - Way to decompose a large task into smaller subtasks (Martin 1997)
  - Standardization way to reduce ambiguity, improve repeatability
- Concerned with technical processes
  - May be standardized at many levels
  - Facilitate collaboration (Rhodes 1994)
- Several theories of process design (Stempfle and Badke-Schaub 2002)
  - Normative design theory
    - Divergent-convergent
  - Natural (empirical) design theory
    - Convergent

J. Martin. *Systems Engineering Guidebook*. CRC Press, Boca Raton, FL, 1997.
D. Rhodes. Frequently Asked Questions on Systems Engineering Process. In *Proc. 4th INCOSE International Symposium*, San Jose, CA, 1994.
J. Stempfle and P. Badke-Schaub. Thinking in Design Teams: An analysis of team communication. *Design Studies*, 23(1):473-496, 2002.

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Backup—Culture

- Culture: an abstraction for explaining group behavior (Schein 2004)
  - Artifacts and behavioral norms
  - Espoused Beliefs
  - Underlying Assumptions
- Culture can be a barrier to introduction of new methods, tools and processes (Belie 2002)
- Culture exists at several levels
  - Organizational culture
    - Beliefs and values held by an organization and its employees
    - Team variations in behaviors result in subcultures
  - Engineering culture
    - Beliefs and behaviors linked to profession
    - Consistent across organizations

R. Belie. Non-Technical Barriers to Multidisciplinary Optimization in the Aerospace Community. In *Proc. 9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and Optimization*, Atlanta, GA, September 2002.
E. Schein. *Organizational Culture and Leadership*. Jossey-Bass, San Francisco, CA, 2004.

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Team, Standard Process & Culture

Team

D. Ancona, H. Bresman, and K. Kaeufer. The Comparative Advantage of X-Teams. *MIT Sloan Management Review*, 43(3):33-39, 2002.

R. Belbin. *Team Roles at Work*. Elsevier, London, 1993.

R. Newman. Issues in Defining Human Roles and Interactions in Systems. *Systems Engineering*, 2(3):143-155, 1999.

E. Salas and S. Fiore. Why *team* Cognition? An overview. In E. Salas and S. Fiore, editors, *Team Cognition*, chapter 1, pages 11-32. American Psychological Association, Washington, DC, 2004.

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R. Belie. Non-Technical Barriers to Multidisciplinary Optimization in the Aerospace Community. In *Proc. 9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and Optimization*, Atlanta, GA, September 2002.

E. Schein. *Organizational Culture and Leadership*. Jossey-Bass, San Francisco, CA, 2004.

Process

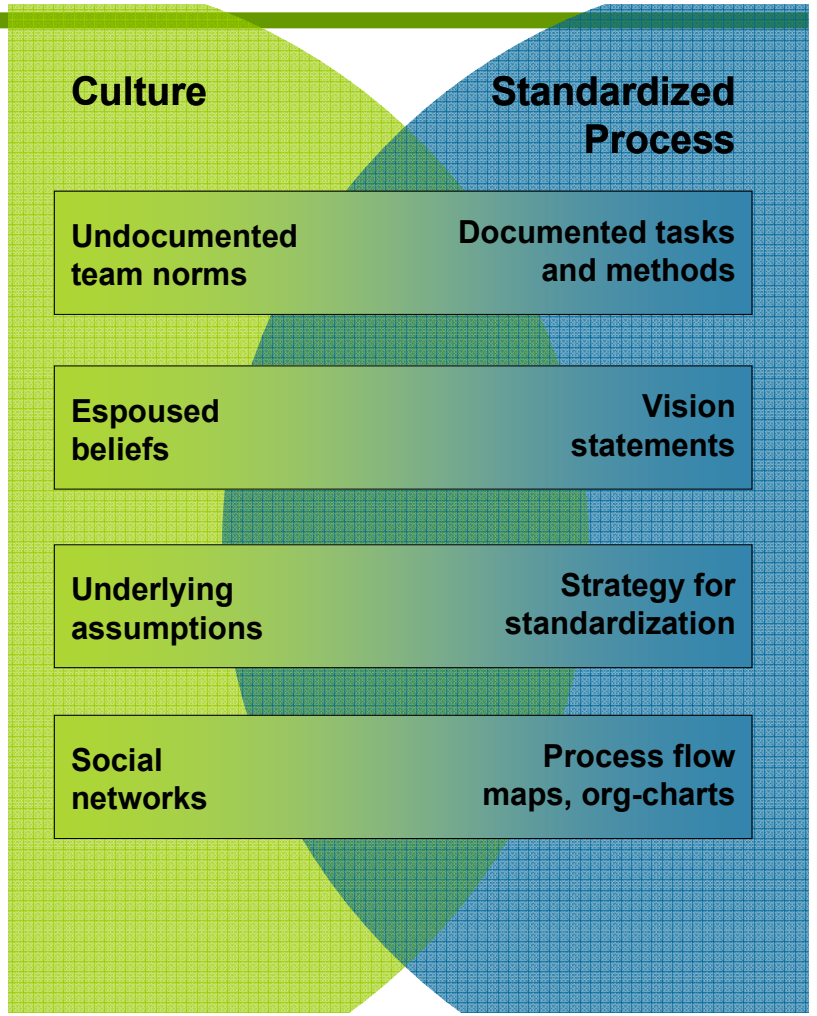
J. Martin. *Systems Engineering Guidebook*. CRC Press, Boca Raton, FL, 1997.

D. Rhodes. Frequently Asked Questions on Systems Engineering Process. In *Proc. 4th INCOSE International Symposium*, San Jose, CA, 1994.

J. Stempfle and P. Badke-Schaub. Thinking in Design Teams: An analysis of team communication. *Design Studies*, 23(1):473-496, 2002.

Team

- Social systems
- Group of individuals
- Task interdependency
- Represent multiple backgrounds
  - Disciplines
  - Experience
- Great breadth of knowledge
- More reliable for safety critical decisions (Salas and Fiore 2004)



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Research Framework

- Four constructs to frame inquiry
  - Team
  - Standard Technical Process
  - Culture
    - Organizational culture
    - Engineering culture
    - Team norms and behavior
  - Collaborative systems thinking

Map to enablers from past research on systems thinking
- Individual Characteristics
- Experiential Learning
- Supportive Environment
- Systems thinking

- Use of Mixed Qualitative/Quantitative Research Methods
  - Techniques and tools borrowed from social science
  - Similar to past LAI, Aero-Astro, and ESD theses
  - Uses qualitative and quantitative data types to describe systems thinking within teams

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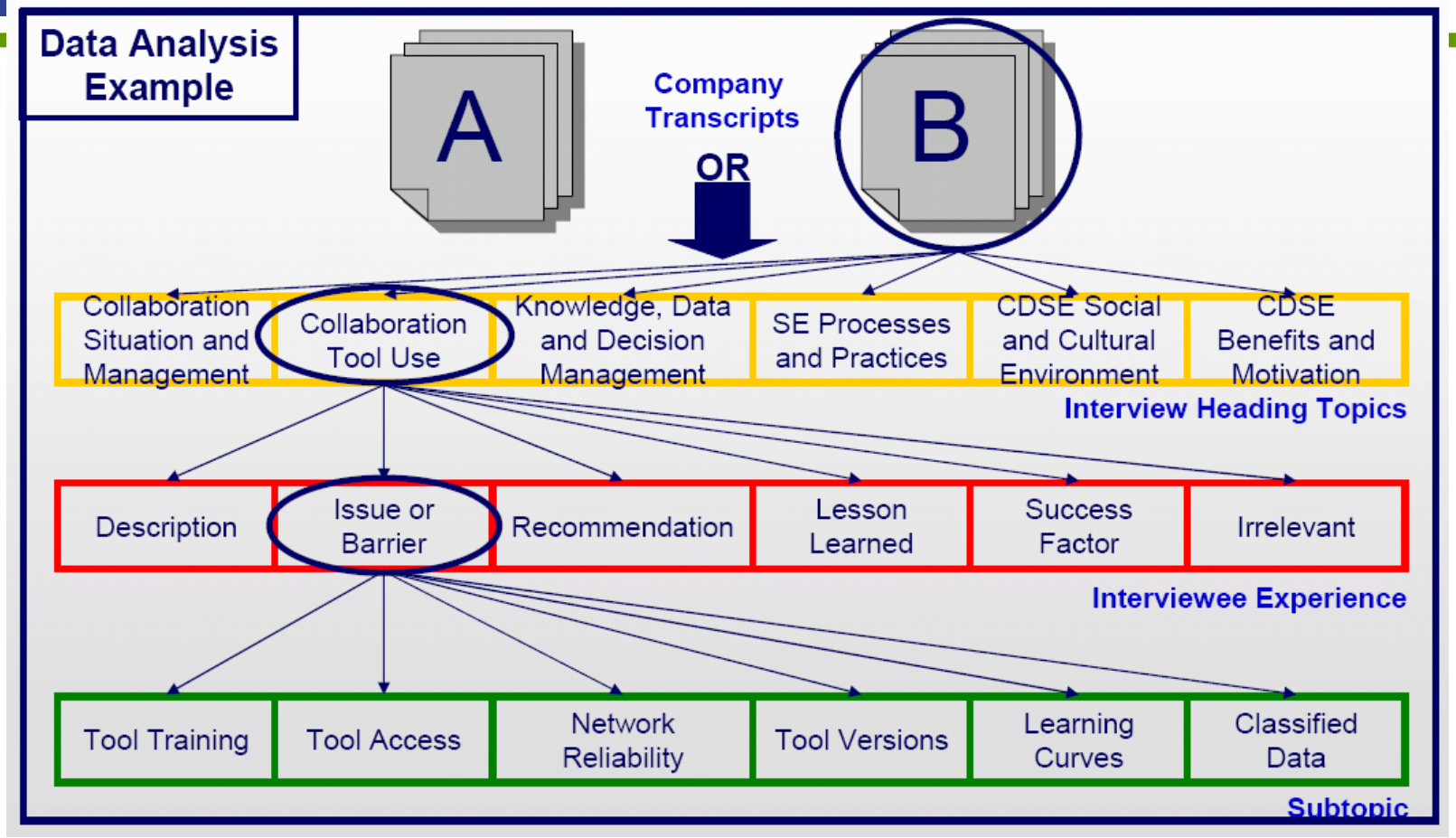
Qualitative Data Analysis: An Illustrative Example



Example of data coding and code hierarchy from similar research

D. Utter. *Collaborative Distributed Systems Engineering*, Master of Science Thesis, Engineering Systems Division, MIT, January 2007.

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