Collaborative Systems Thinking:

Towards an understanding of team-level systems thinking

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Agenda

- Motivations
- Goals and Objectives
- Research Methodology
- Results and Ongoing Research

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Research Motivations

(from Rhodes et al)

Shortfalls in the systems engineering workforce

- Increasing demand for systems engineering skills in government and industry
- Erosion of engineering competency particularly in aerospace and defense
- Increased interdisciplinary emphasis as world becomes more connected
- Systems complexity demands more sophisticated systems architecting skills
- Nature of programs necessitates socio-technical rather than pure technical abilities

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Increasing Demand for Systems Engineering Skills

- Increases in schedule time and cost attributed to complexity
- Systems engineering skills valuable in low cost/high leverage early design
- Longer program 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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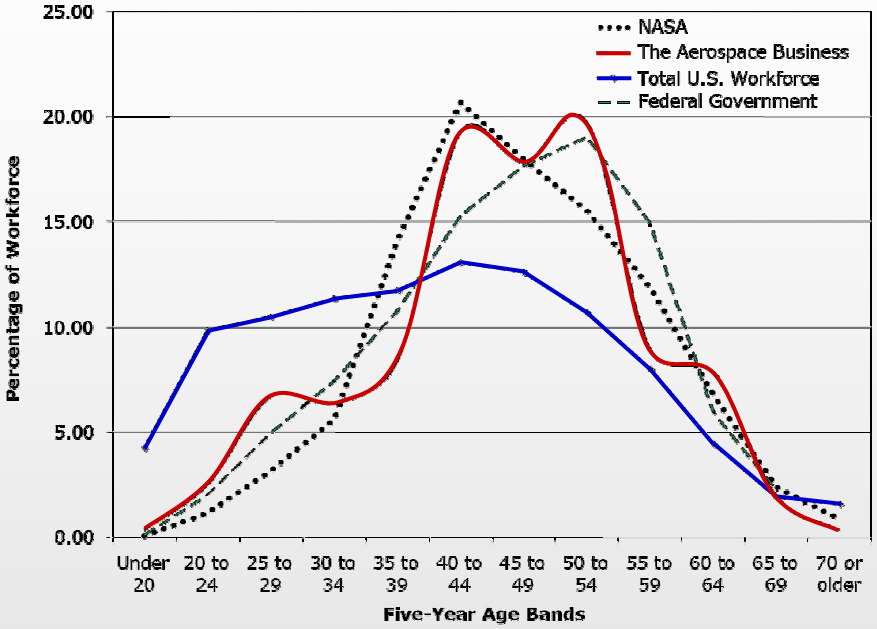
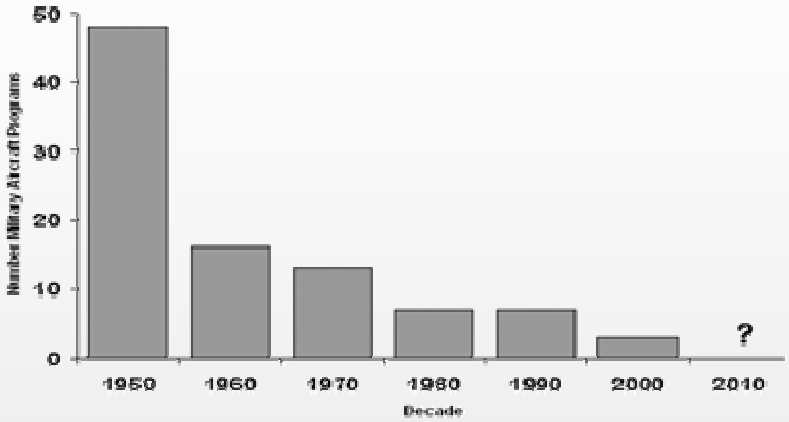
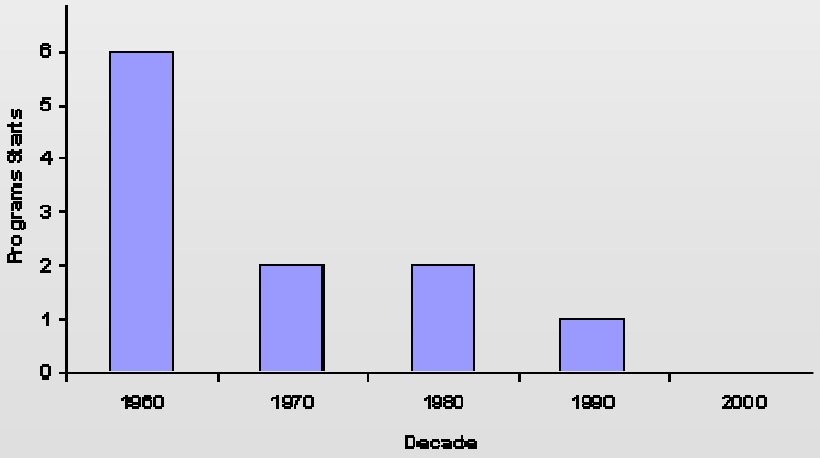
Erosion of Systems Engineering Competency



Engineering Demographics in the US
(Future US Space Workforce 2005)



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



Manned Spacecraft Program Starts by Decade (Neal 1995)

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Importance of Teams for Systems Thinking

- Engineering is socio-technical activity
- Teams leverage breadth and depth of member experience
  - Portfolio approach
  - Multiple thinking styles
  - Experience on different programs
  - Different areas of expertise
- Teams regarded as better for safety-critical decisions (Salas and Fiore 2004)

Logistical Complexity	Physical Complexity	Design Space Complexity
– Social coordination – Maintaining awareness of 'whole' – Managing interfaces – Realizing opportunities at interfaces	– Large number of components – Static: component compatibility – Dynamic: emergence	– Exploration of design space – Requirements negotiation – Identification of 'sweet spots' within design space

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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Research Needs

(from Rhodes et al)

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
- Better understanding of systems contexts
- Factors underlying competency in workforce
- Identification of enablers, barriers, precursors
- Systems thinking at multiple levels – individual, **team**, enterprise

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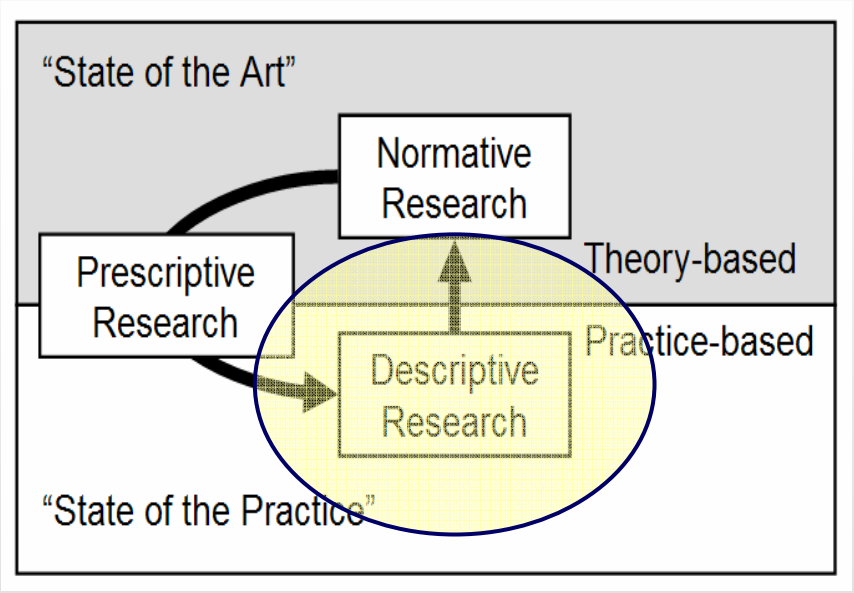
Leveraging Qualitative and Empirical Research Methods

- 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

SEAri Research Structure



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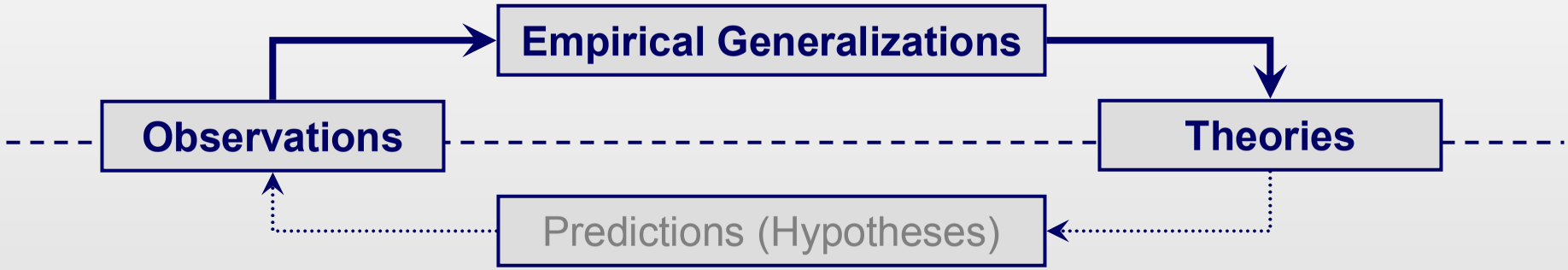
Grounded Theory Methods

- 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

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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: What is Systems Thinking?

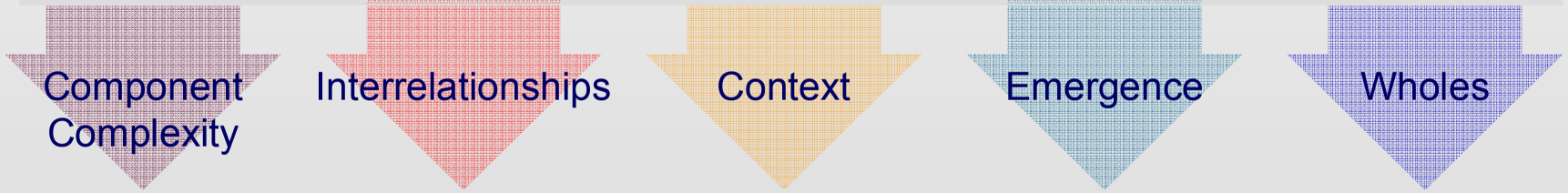
A framework for systems with four basic ideas: emergence, hierarchy, communication and control. Human activity concerns all four elements. Natural and designed systems are dominated by emergence. (Checkland 1999)

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)



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Phase 1: Systems Thinking within 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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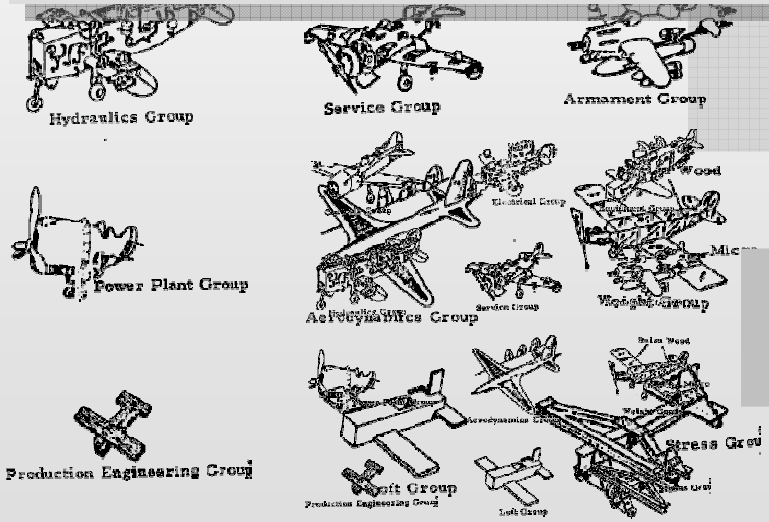
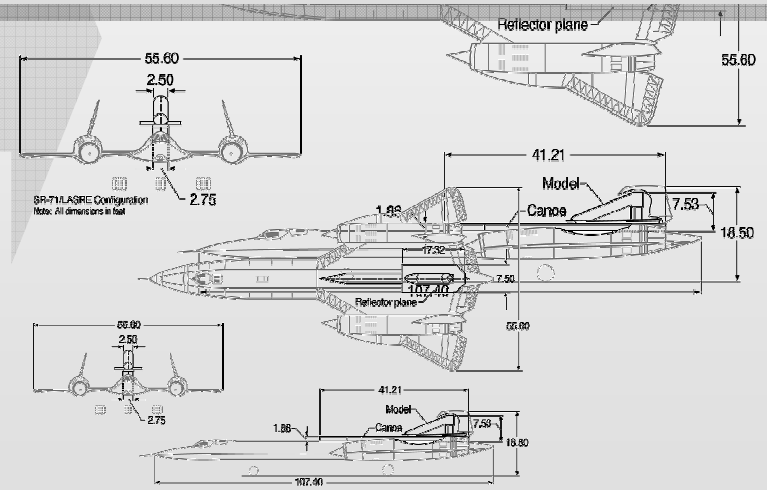
Phase 1: Collaborative Systems Thinking

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)





"Dream Airplanes" by C. W. Miller

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

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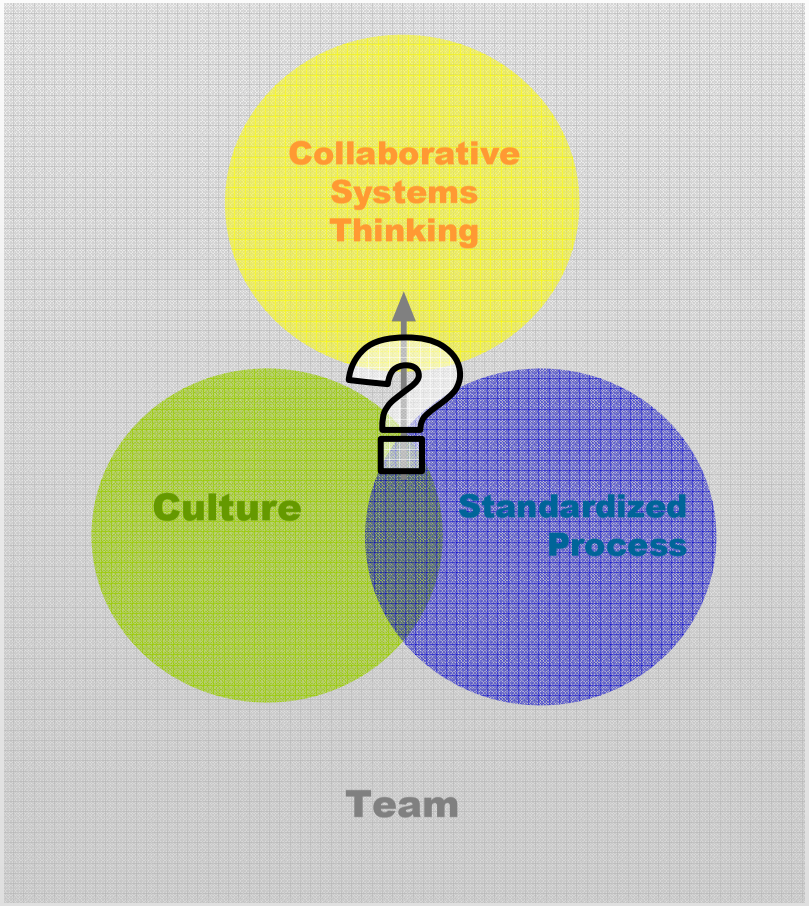
Phase 1: Conceptual Framework



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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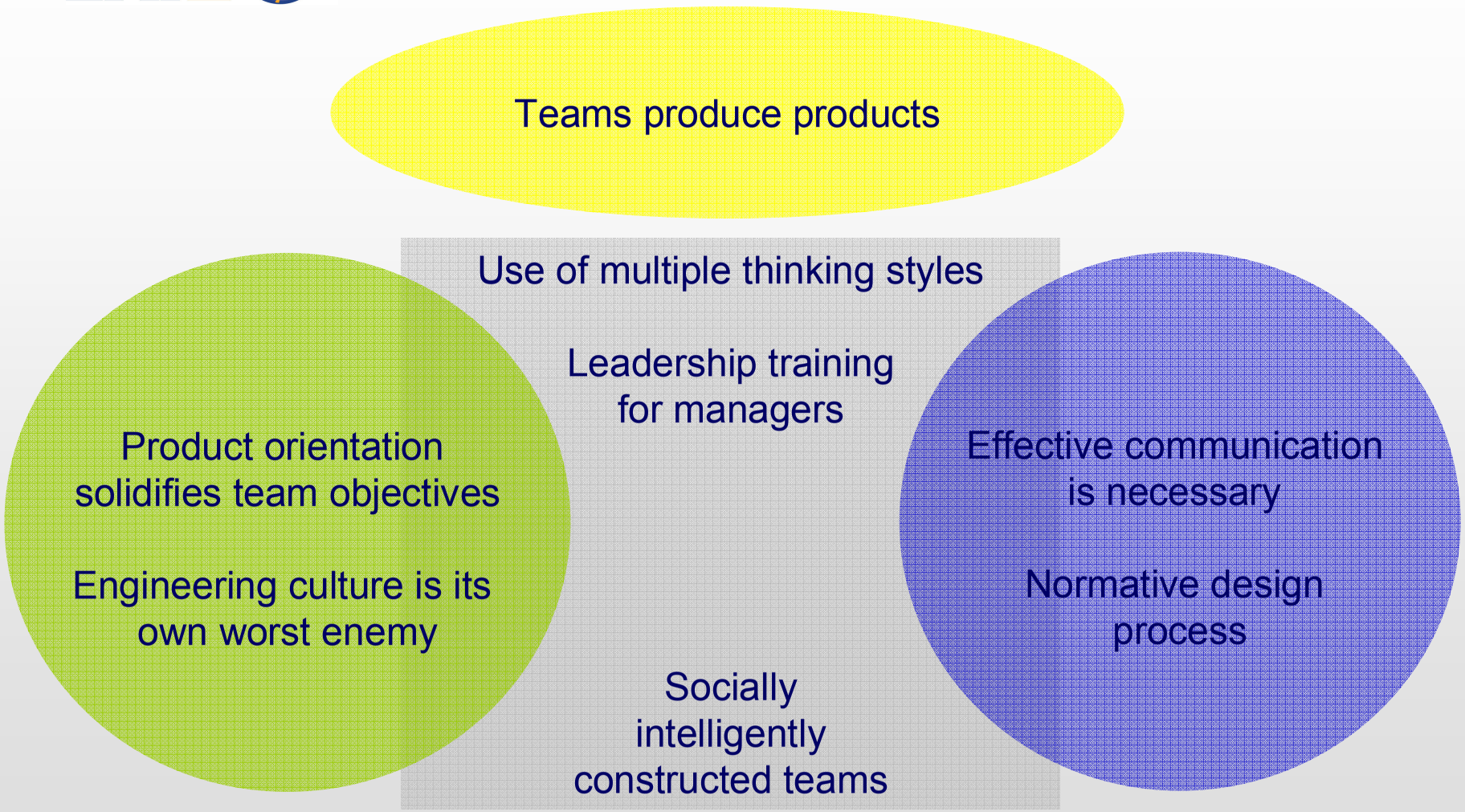
Phase 2: Pilot Interviews



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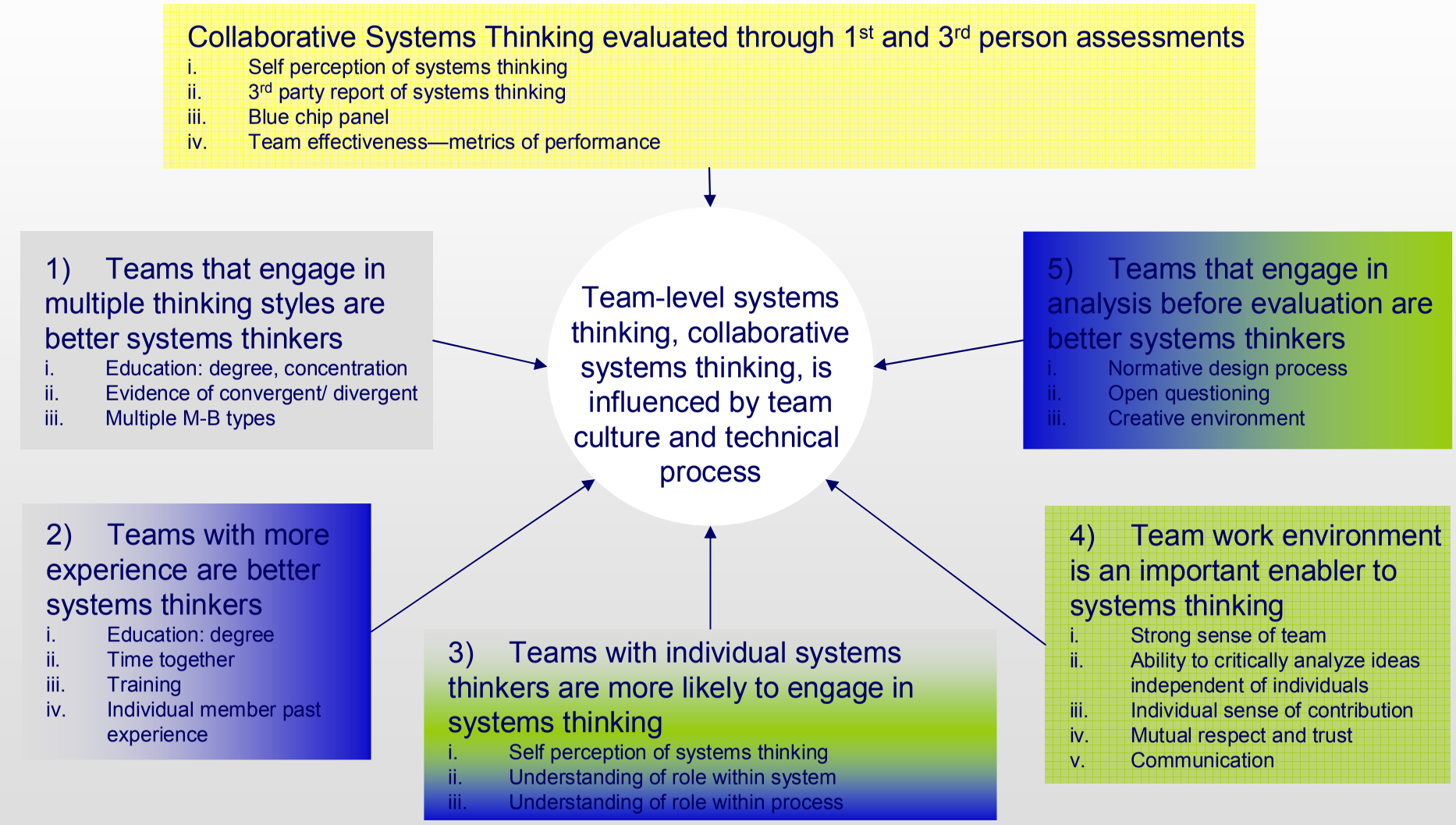
Phase 3: Case Studies



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Phase 3: Multiple Thinking Styles

1) Teams that engage in multiple thinking styles are better systems thinkers
   i. Education: degree, concentration
   ii. Evidence of convergent/ divergent
   iii. Multiple personality types

→ Team-level systems thinking, collaborative systems thinking, is influenced by team culture and technical process

Theoretical Background

- Team Diversity
  - Degree (O'Brien et al 1998)
  - Personality (Varvel et al 2004)
- Capture diversity in systems thinking definitions and attributes (Davidz 2006)

Questions or Metrics

- Degree / concentration
- Indicators for common engineering personality types
  - Introvert/Extrovert
- Comfort with divergent and convergent thinking styles
- Self-identification with 'big picture' thinking vs. detail orientation

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Phase 3: Team Base of Experience

2) Teams with more experience are better systems thinkers

i. Education: degree
ii. Time together
iii. Training
iv. Individual member past experience

→ Team-level systems thinking, collaborative systems thinking, is influenced by team culture and technical process

Theoretical Background

- Role of experience learning in systems thinking development (Davidz 2006)
- Team development stages (Tuckman et al 1977)
- Role of training in developing effective team norms (Hackman 2002)

Questions or Metrics

- Number and type of past program experience on team
- Maturity of team
- Participation in (and impression of) team training
- Total years of team experience

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Phase 3: Team Composition

3) Teams with individual systems thinkers are more likely to engage in systems thinking

i. Self perception of systems thinking
ii. Understanding of role within system
iii. Understanding of role within process

→ Team-level systems thinking, collaborative systems thinking, is influenced by team culture and technical process

Theoretical Background

- Diverging professional opinions on necessity of individual systems thinking as prerequisite for team systems thinking
- Ability to understand and innovate past limitations in process (Dougherty 1990)

Questions or Metrics

- Self perception of individual systems thinking
- Job title
- Manager assessment
- Ability to explain context within process
- Ability to explain context within system

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Phase 3: Work Environment

4) Team work environment is an important enabler to systems thinking
   i. Strong sense of team
   ii. Ability to critically analyze ideas independent of individuals
   iii. Individual sense of contribution
   iv. Mutual respect and trust
   v. Communication

→ Team-level systems thinking, collaborative systems thinking, is influenced by team culture and technical process

Theoretical Background

- Team Cognition (Salas and Fiore 2004)
- Avoidance of groupthink (Janis 1972)
- Establishment of trust (Cross 2004)
- Designed team environment

Questions or Metrics

- Team/task awareness
- Response to critical questioning
- Perceptions of team member competence and reliability
- Tools, spaces, co-location or distribution of team members

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Phase 3: Design Process

5) Teams that engage in analysis before evaluation are better systems thinkers
i. Normative design process
ii. Open questioning
iii. Creative environment

→ Team-level systems thinking, collaborative systems thinking, is influenced by team culture and technical process

Theoretical Background

- Normative design process (Stempfle and Badke-Schaub 2002)
- Creative environment as enabler for systems thinking traits (Thompson and Lordan 1999; Dym et al 2005)

Questions or Metrics

- Analysis of design process steps
- Interview: Relative emphasis on analysis and evaluation
- Survey: Test for creativity enablers and barriers

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Phase 3: Collaborative Systems Thinking

Collaborative Systems Thinking to be evaluated through 1st and 3rd person assessments

i. Self perception of systems thinking
ii. 3rd party report of systems thinking
iii. Blue chip panel
iv. Team effectiveness—metrics of performance

Theoretical Background

- No agreed upon metrics for systems thinking at individual level
- Collaborative systems thinking
  - New construct
  - Complete absence of metrics

Metrics

- Team self perception
- Supervisor perception
- HR perception
- Expert Panel
- Performance metrics
  - Long-term planning efforts
  - Ability to meet deadlines and requirements

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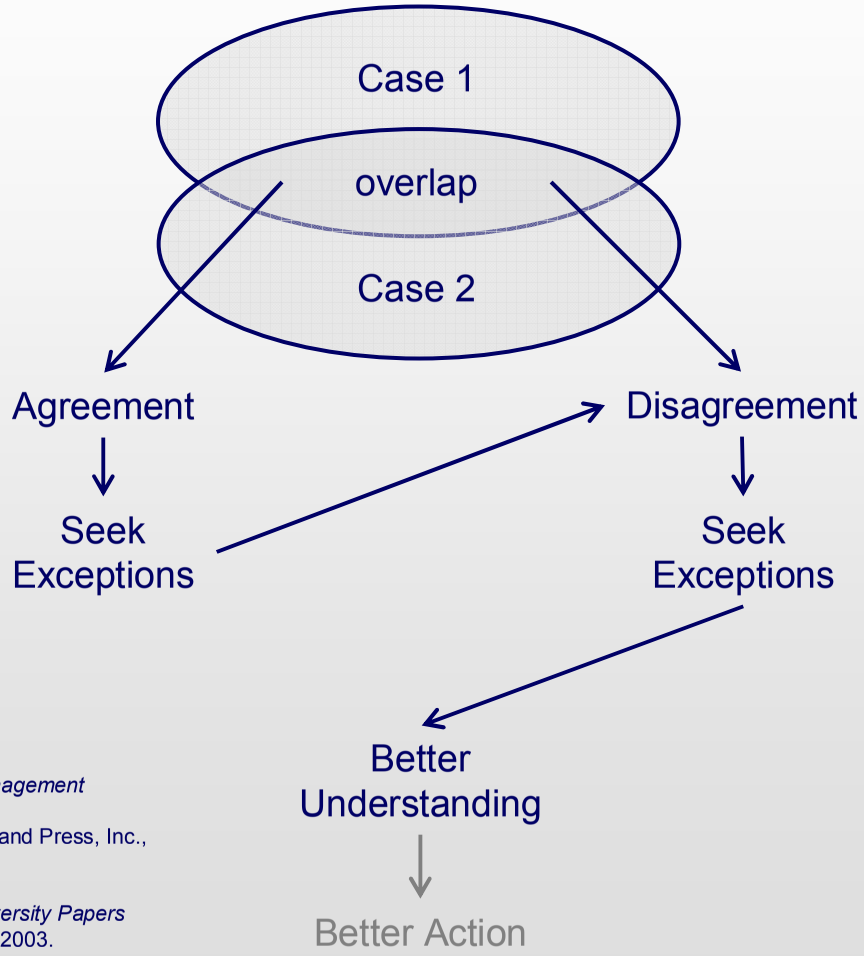
Phase 3: Data Analysis

- 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



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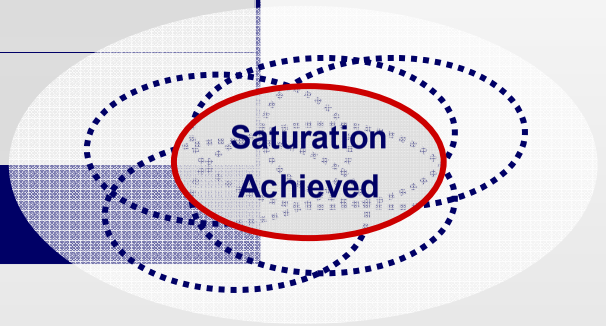
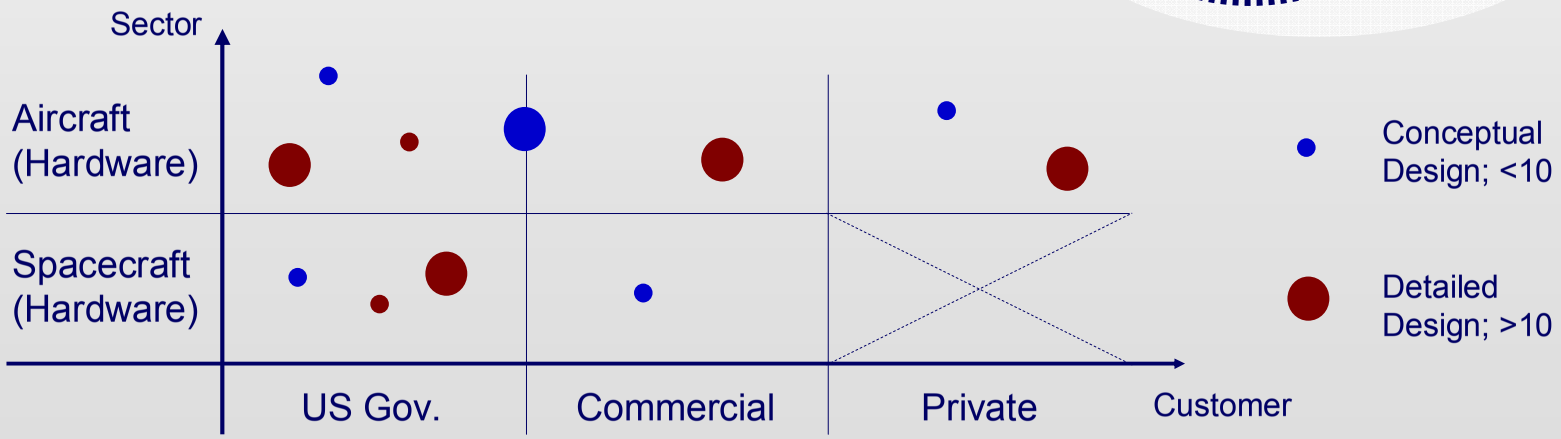
Phase 3: Next Steps

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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Summary

- Collaborative systems thinking to address skill shortage
- Literature and practitioner agreement on importance of culture and process
- Case study research ongoing
- Expected Contributions (Early 2009)
  1. Definition for Collaborative Systems Thinking (CST)
  2. Identified enablers and barriers to CST
  3. Heuristics for process tailoring and workforce development towards enabling CST

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Questions/Comments?

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Backup Slides

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)

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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

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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

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Team, Standard Process & Culture

Team

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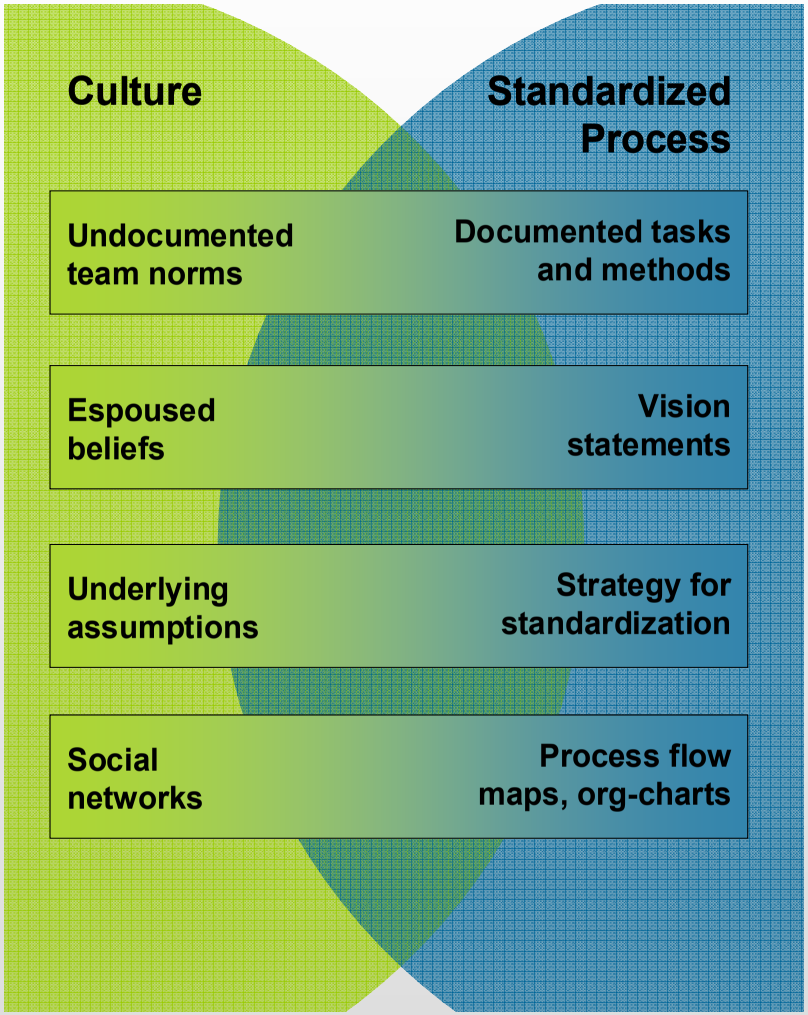
Team

- 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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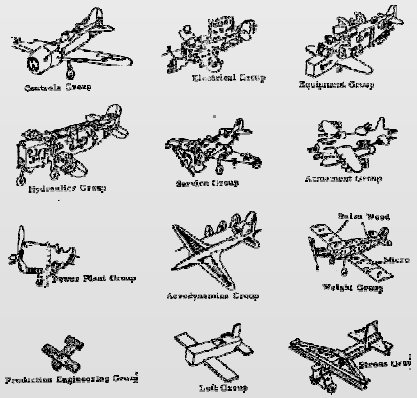
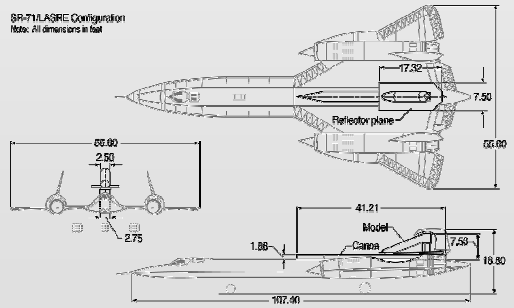
Phase 1: Collaborative Systems Thinking

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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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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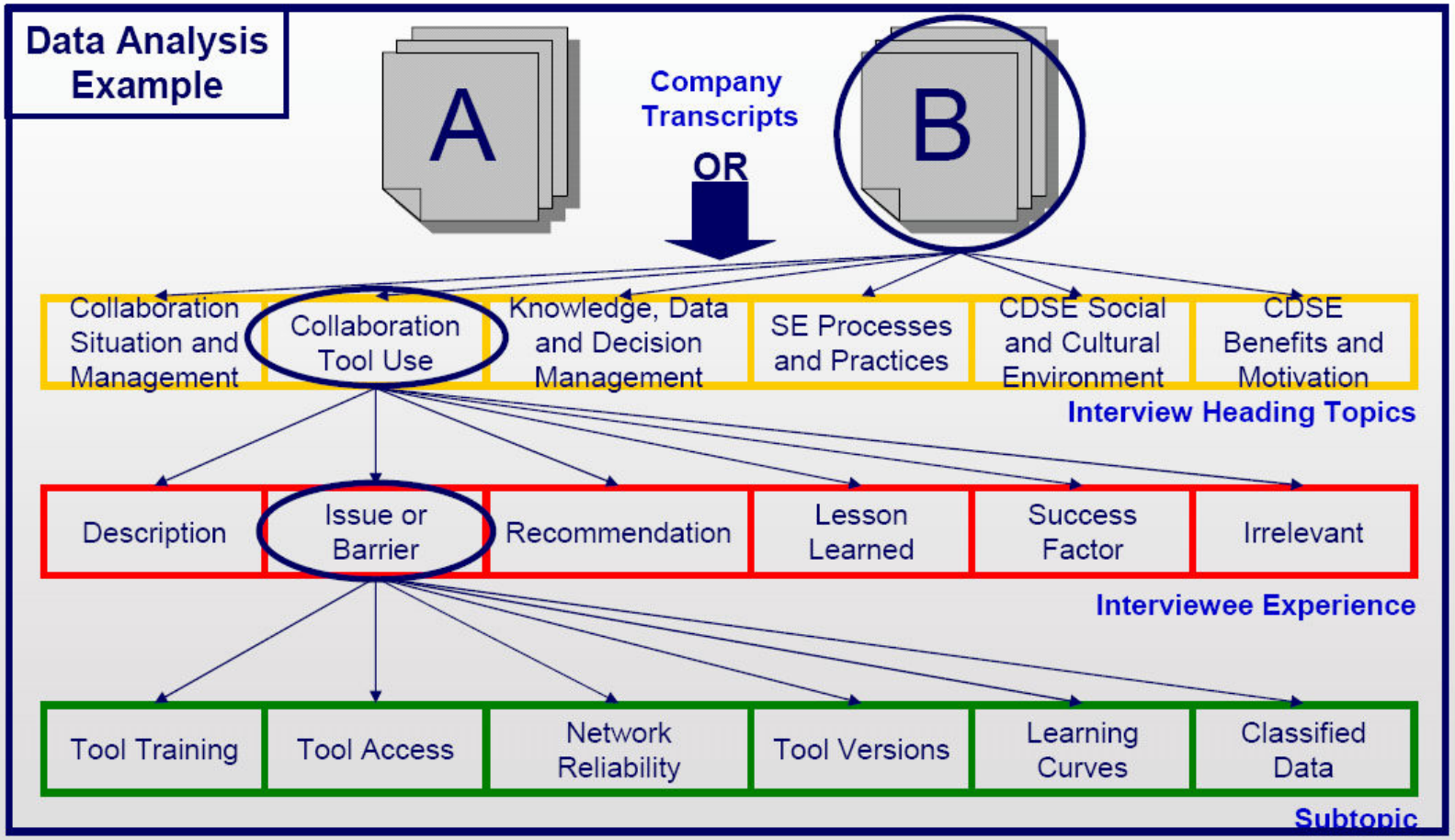
Qualitative Data Analysis: An Illustrative Example



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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