A Model of Enterprise Systems Engineering Contributions to Acquisition Success

Jill L. Drury, jldrury@mitre.org

Gary L. Klein

Mark S. Pfaff

Craig Bonaceto

19 May 2015

Presented at the 10th IEEE/INCOSE International Conference on Systems of Systems 2015, 17 – 20 May 2015, San Antonio, TX

Paper available in IEEE Xplore Digital Library

MITRE

Motivation

- **The factors leading to success or failure in the acquisition of complex systems are still unclear**
- **Enterprise Systems Engineering (ESE) takes a broad view but non-technical aspects are often inadequately addressed**
- **A model of success factors would help handle complex systems of systems**

An early 20th century engineering challenge: Hoover Dam (photo: J. Drury)

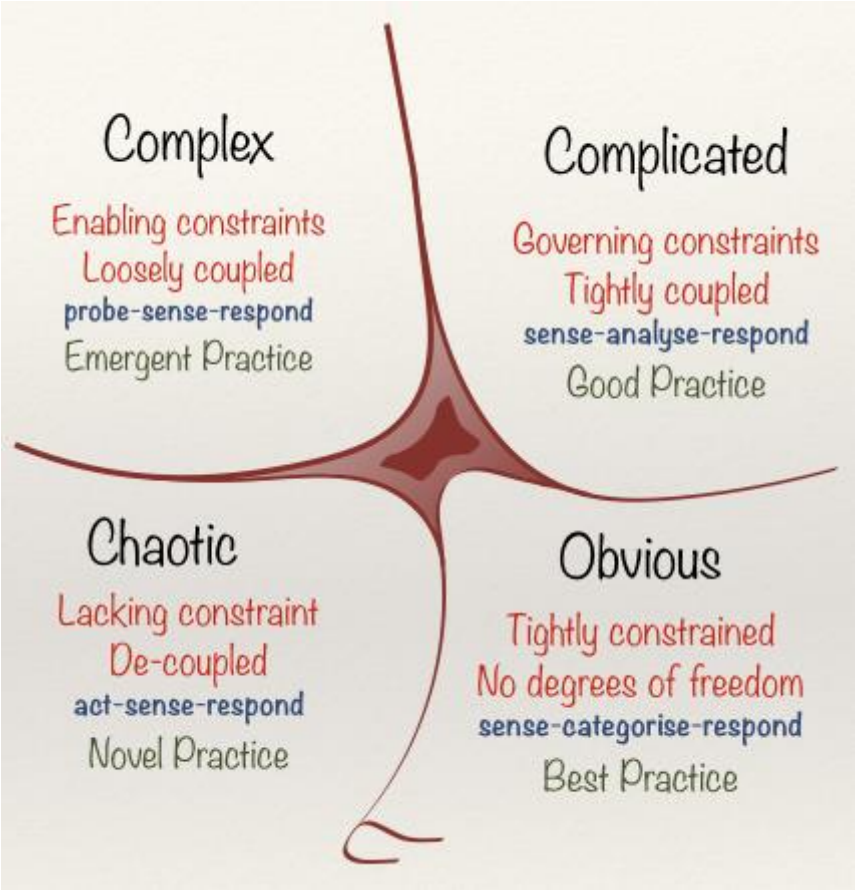
Engineering the Enterprise

- **In addition to engineering technological systems, ESE considers the effects of new technologies on stakeholder organization(s) such as:**
  - Business planning
  - Policy making
  - Redesigning workflows
  - Altering staff responsibilities

More great systems engineering: Discovery launch (NASA photo, in public domain)

Desired Model Characteristics

- **Applicable to systems that include direct user interaction**
- **Appropriate for *complex* systems**
- **General purpose**
- **Tailorable**
- **Sufficiently Detailed**
- **Causal**

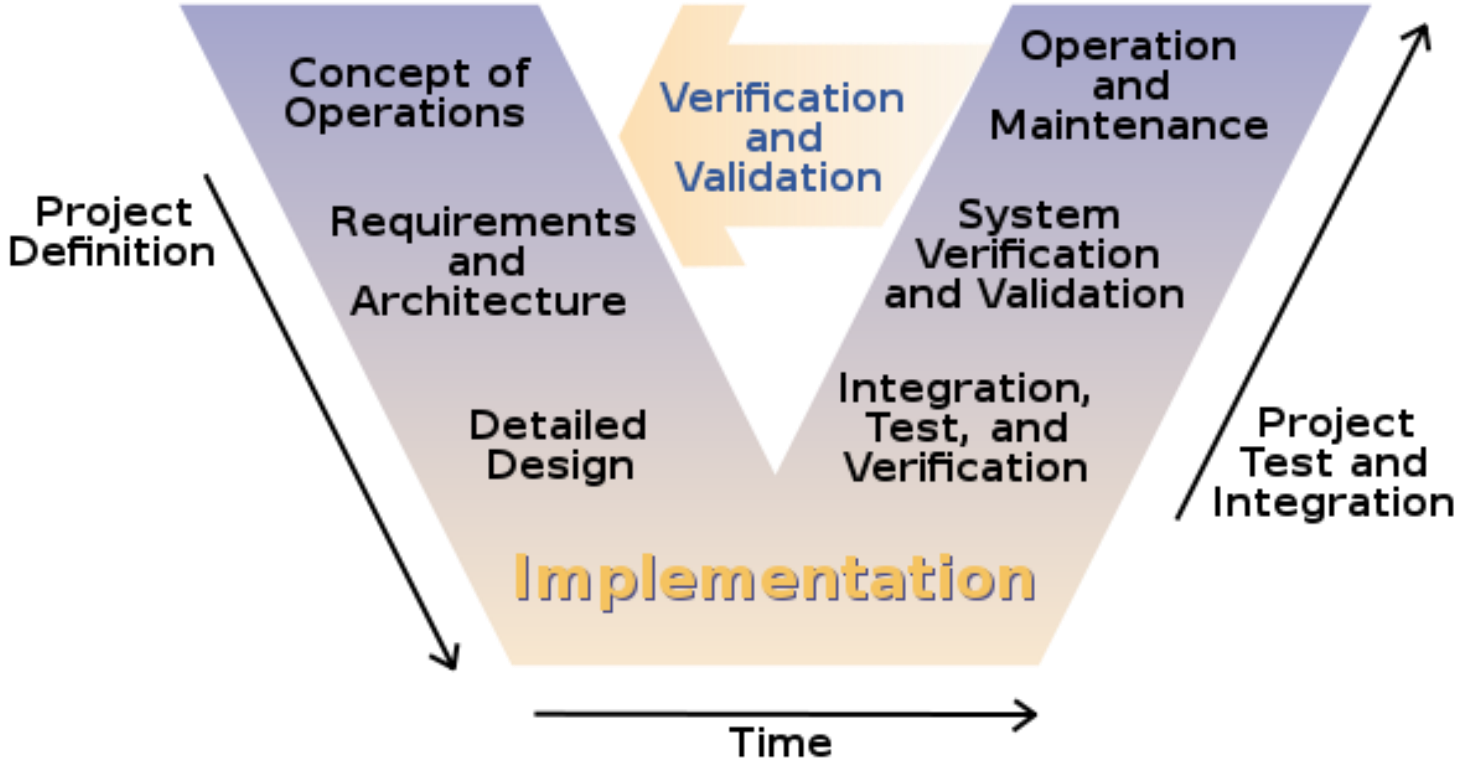


http://en.wikipedia.org/wiki/Cynefin
Creative Commons 3.0 license

MITRE

Existing SE Models: V-Model (INCOSE, 2007)

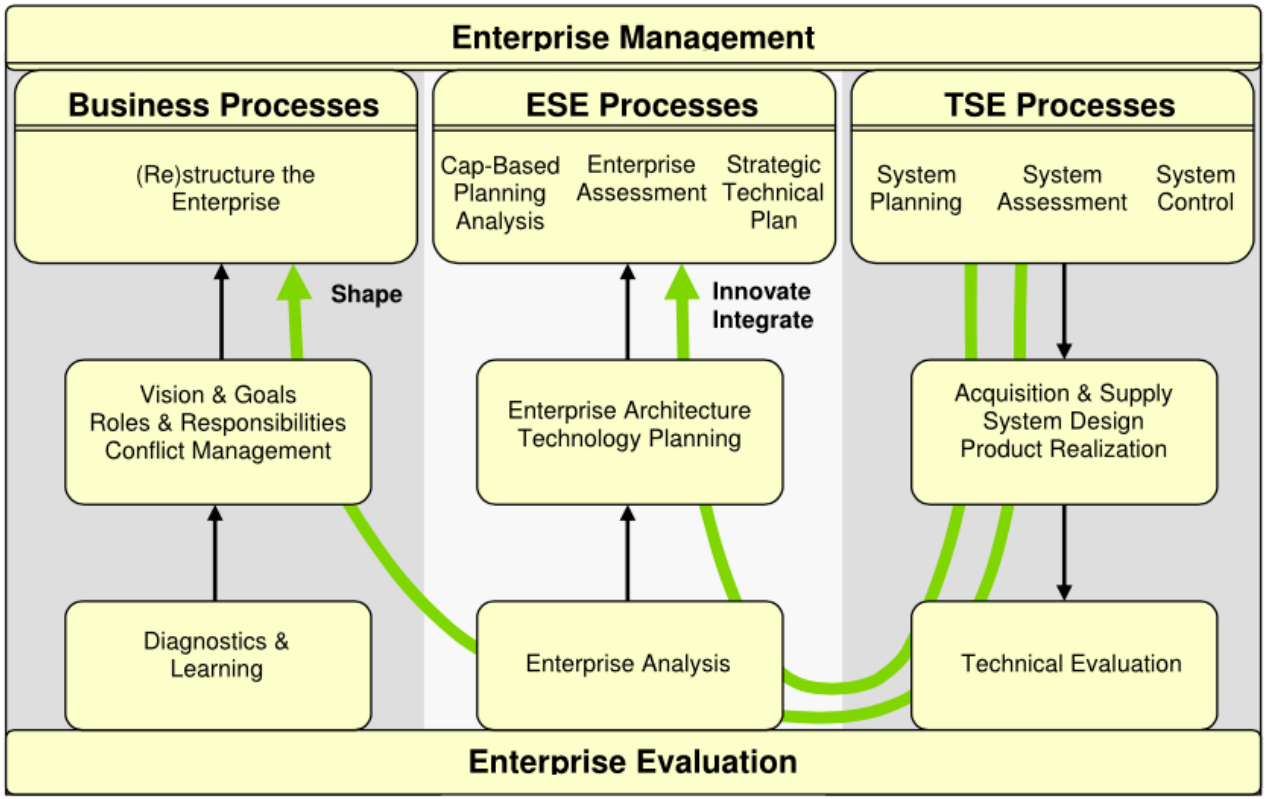
- **Describes categories of activities rather than the the techniques for executing those activities and their consequent outcomes**



http://en.wikipedia.org/wiki/V-Model; Public Domain Image

Existing SE Models: Enterprise Systems Engineering Model (DeRosa et al., 2006)

- **Purpose is to show relationships between traditional SE, traditional business practices, and ESE**



DeRosa et al. (2006)

Existing SE Models: Model Based Systems Engineering (MBSE)

- **Replaces documents specifying the system with functional, performance, component, and other models**
- **Not general purpose, but specific to a given system**

There is significant interest in MBE in the DoD for complex systems such as the Combat information center aboard the guided missile cruiser USS VINCENNES

(US Navy Photo in the public domain)

ESE Success Variables: Overview

- Techniques and methods that contribute to successful acquisitions of complex systems
- Based on evidence in the SE literature

  - SE Technique Application
    - Systems of Systems Engineering
    - Cognitive Systems Engineering
    - Participatory Design
    - Organizational Change Management
  - Collaboration
  - System Characteristics
  - Organizational Characteristics

ESE Success Variables:
System-of-Systems Engineering (SoSE)

- **An instance of a systems-of-systems is made up of elements that are, themselves, systems**
- **A type of "mega system"**
- **Major emphasis is on systems interoperability**
- **DoD defines SoSE as:**
  - … a process that deals with planning, analyzing, organizing, and integrating the capabilities of a mix of existing and new systems into an SoS capability greater than the sum of the capabilities of the constituent parts

Combined Air Operations Center in Qatar
(Photo: U.S. Air Force photo illustration by Senior Airman Brian Ferguson, www.usaf.mil/news)

ESE Success Variables:
Cognitive Systems Engineering (CSE)

- **Also known as Cognitive Ergonomics**
- **Major emphasis is on interaction between the system and end users**
- **Militello et al.'s (2010) definition:**
  - an approach to the design of technology, training, and processes intended to manage cognitive complexity in sociotechnical systems. In this context, 'cognitive complexity' refers to activities such as identifying, judging, attending, perceiving, remembering, reasoning, deciding, problem solving, and planning.

Space vehicle and space suit controls were designed to be comprehended and manipulated by highly trained astronauts (NASA photo, in the public domain)

ESE Success Variables:
Participatory Design (PD)

- **Arose from the Scandinavian workplace democracy movement**
- **Major emphasis is on working with the end users during system design**
- **Muller and Druin's (2012) definition:**
  - a set of theories, practices, and studies related to end-users as full participants in activities leading to software and hardware computer products and computer-based activities. ... Researchers and practitioners are brought together ... by a pervasive concern for the knowledges, voices, and/or rights of end users

Involving factory workers at a stainless steel ecodesign company in Rio de Janeiro
(Photo by Alex Rio Brazil; free to use under CC BY-SA 3.0 license)

ESE Success Variables:
Organizational Change Management (OCM)

- **Not always viewed as a SE method**
- **Major emphasis is on helping end users handle organizational changes brought about by technology**
- **Technopedia's (undated) definition:**
  - a framework structured around the changing needs and capabilities of an organization. OCM is used to prepare, adopt and implement fundamental and radical organizational changes, including its culture, policies, procedures and physical environment, as well as employee roles, skills and responsibilities.

The largest nuclear power plant in the world, the Bruce Nuclear Power Generating Station (Photo: Chuck Szmurlo; permission to use granted under GNU Free Documentation License)

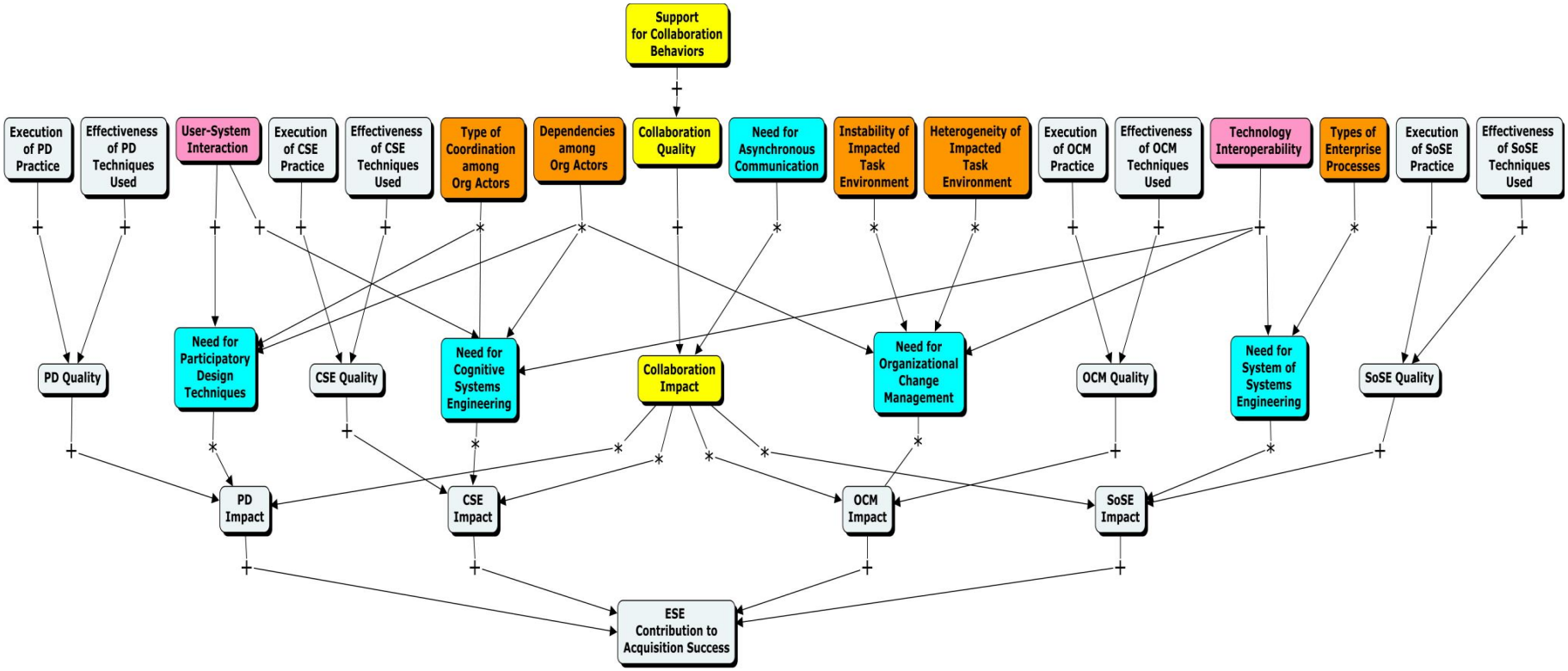
Additional Success Variables

- **Collaboration**
  - Geographically-diverse teams require collaborative methods and tools to work across time and space
- **System Characteristics**
  - Complexity
  - Size
  - Performance demands
  - Degree of maturity
- **Organizational Characteristics**
  - Degree to which users are dependent upon each other to accomplish tasks

The Chemelot "Chemical Innovation Community" in Geleen, The Netherlands
(Photo: Koen Brouwer; reuse allowed with attribution)

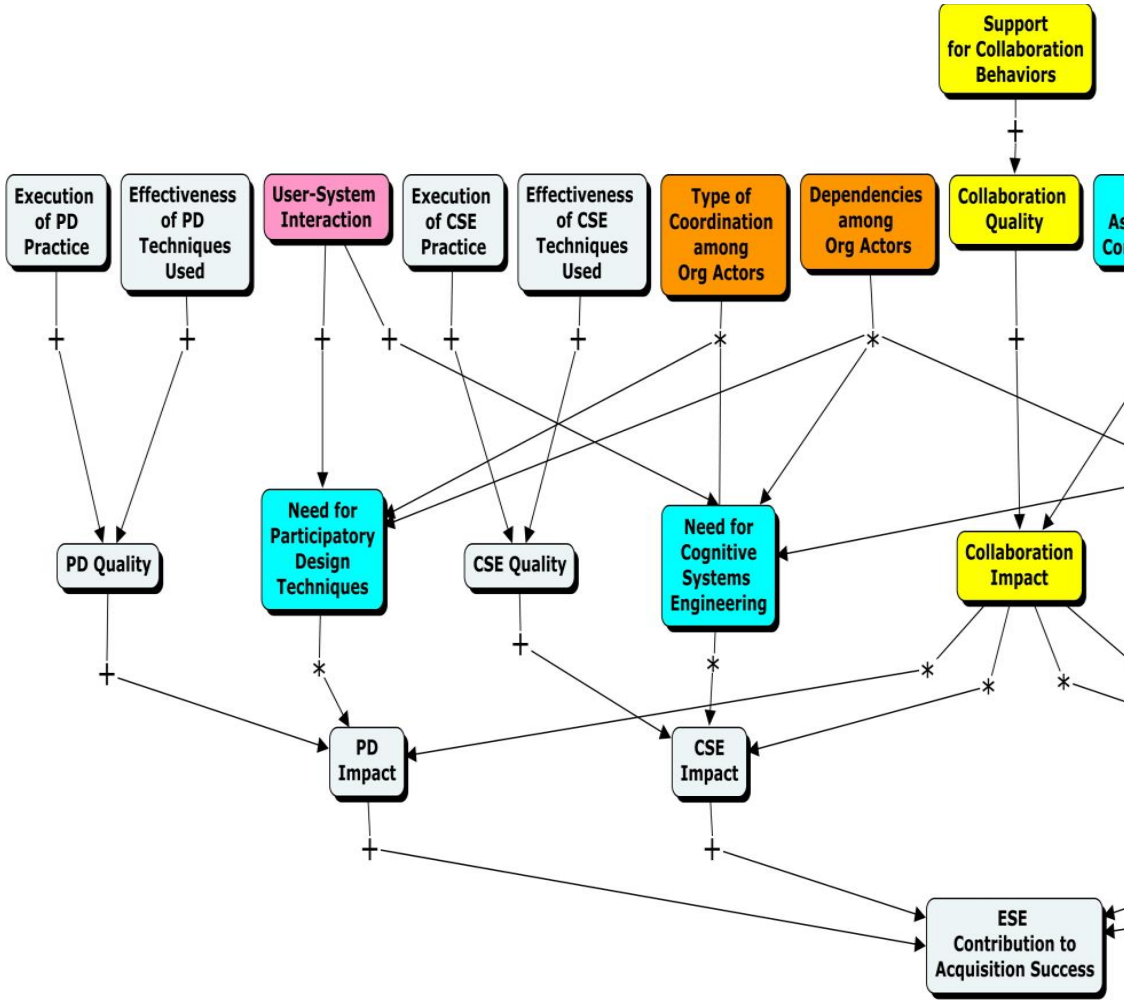
Model Structure

- **Blue**: ***Need*** **for a technique category**
- **Pink**: **System characteristics**
- **Orange**: **Organizational characteristics**
- **Yellow**: **Collaboration support**



MITRE

Close up of structure: Participatory Design



- **The right PD techniques done well will increase quality and positively impact ESE success**
- **The degree and type of user-system interaction, the type of coordination, and the dependencies among users will affect the need for PD**
- **If PD is not needed, then PD will have no impact on ESE success**
- **How well collaboration behaviors are supported will affect collaboration quality, which will affect both collaboration impact and PD impact**

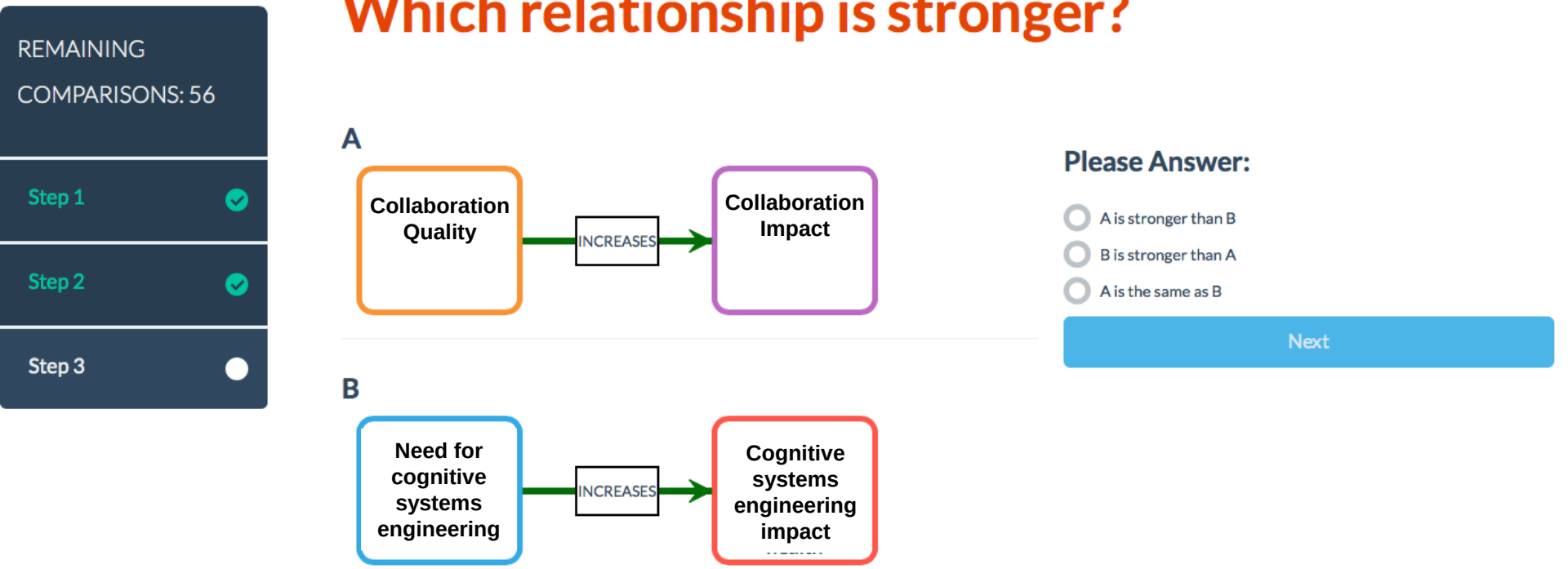
MITRE

Model Validation

- **Initial phase**
  - Peer review with seven senior systems engineers
  - Resulted in a revised model used for formal validation
- **Formal phase**
  - Descriptive to Simulation Modeling (DESIM, patent pending)
  - Converts causal descriptive model to executable simulation model
  - Crowdsourcing approach elicits edge weights for the model from large population of SMEs

Methods

- **Used Analytic Hierarchy Process (Saaty, 1990)**
  - Causal descriptive model is decomposed into a set of pairwise comparisons of relationships in the model
  - Experts rate which relationship is stronger, and by how much



MITRE

Methods

- **Random assignment to one of two scenarios**
  - Airborne Command and Control System (ACCS)
    - Many subsystems and interfaces to numerous other systems
    - Requiring a wide variety of tasks by a large number of operators
  - Translator Document Feed (TDF) subsystem
    - Embedded component of a translation management system
    - Manages documents assigned to translators
- **Additional data collected**
  - Impacts of four main ESE variables (SoSE, CSE, PD, OCM)
  - Self-rated expertise in the human, technology, and organizational domains

Results – Domain Expertise

- **85 SME participants (68 male, 17 female)**
- **Expected to see correlations between self-rated domain expertise and corresponding ratings of the four impact variables**
  - Only for the ACCS scenario: Technology domain expertise rating was correlated with the SoSE impact variable (r_s = .33, p = .03)
- **Expected to see domain expertise correlate with the edge weights leading to each of the four impact variables, but was not**

Boeing 777 aircraft cockpit
(Photo use permission granted under GNU Free Documentation License)

Results – ESE Impact Variables

- **Friedman's ANOVA found significant differences in ESE impact ratings across both scenarios ($\chi^2(3) = 40.27$, $p < .001$)**

- **Split by scenario, SoSE had more impact on success in the ACCS scenario (*Mdn* = 10) than the TDF scenario (*Mdn* = 8.5), *U* = 604.00, *z* = 2.90, *p* = .004.**
- **Other three impacts had no significant differences between scenarios**

MITRE

Results – Agreement with the Model

- **Edge weights close to zero indicate disagreement with that relationship between nodes in the model**
- **Lowest mean edge weight was .08**
  - From a bi-model distribution, with clusters at 0 (no relationship) and .15 (small relationship)
- **Non-zero edge weights confirm expert agreement with the model**

Burj Khalifa, the tallest building in the world
(Photo use permission granted under GNU Free Documentation License)

Discussion

- **SoSE was found to have more impact on the ACCS scenario**
  - ACCS clearly included systems of systems, while TDF did not
- **Due to ACCS system's greater degree of interaction with users, expected other three ESE techniques to show significant differences, but did not**
- **Did not find significant differences in impact ratings based on domain expertise**
  - The need for different ESE techniques apparently was not biased by the experts' background

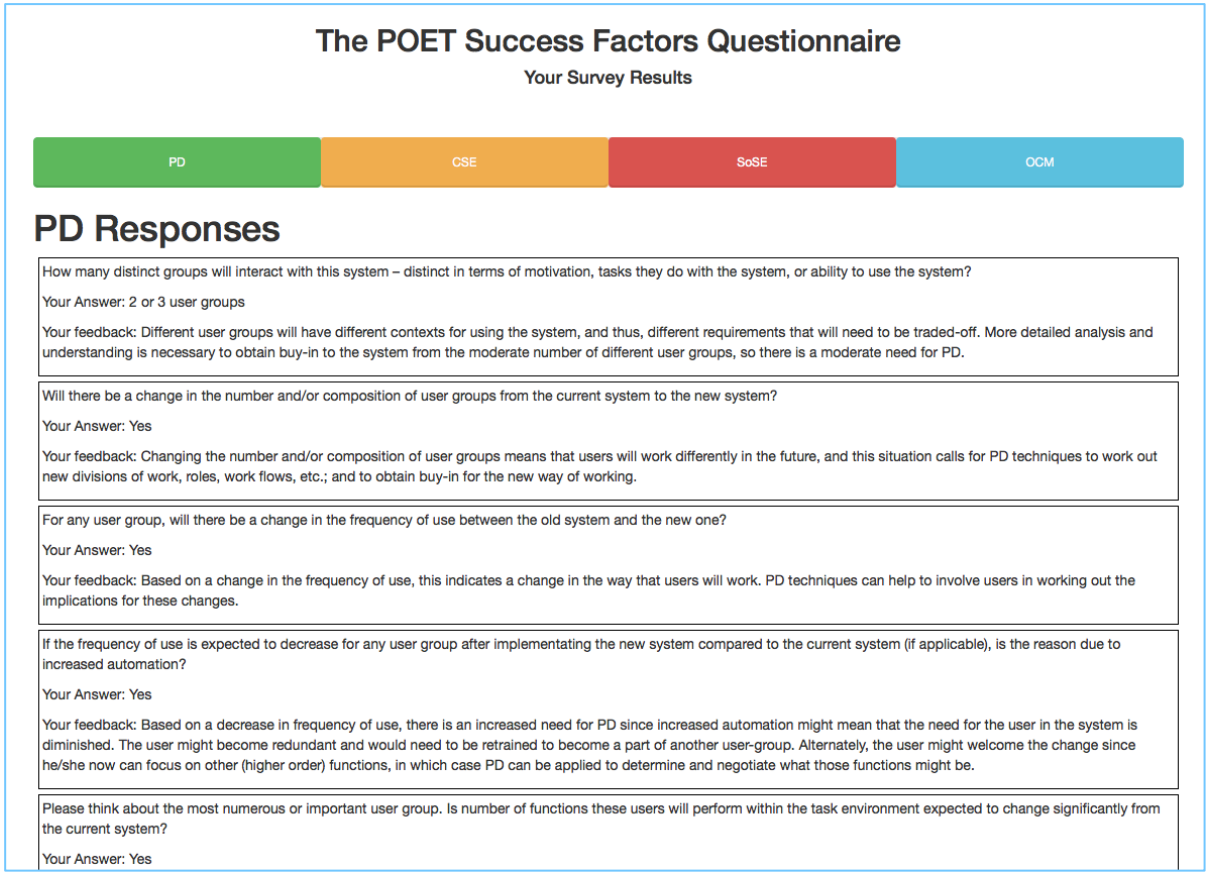
Limitations and Future Work

- **Model was compared to combined opinions of experts, rather than ground truth**
- **Future work**
  - Provide the model to real-world SE teams and assess the resulting activities to acquisition success
  - Controlled experiment with only one group given the model's recommendations, to assess the quality of SE products generated
  - Use of model with actual SE efforts

Predator Unmanned Aerial System Cockpit
(Photo: www.mitre.org)

Developed Success Factors Automated Tool

- **Customized Lime Survey instance**
- **Displays report info immediately upon completion**
- **Estimated at 30 – 45 minutes**



The POET Success Factors Questionnaire

Your Survey Results

PD | CSE | SoSE | OCM

PD Responses

How many distinct groups will interact with this system – distinct in terms of motivation, tasks they do with the system, or ability to use the system?

Your Answer: 2 or 3 user groups

Your feedback: Different user groups will have different contexts for using the system, and thus, different requirements that will need to be traded-off. More detailed analysis and understanding is necessary to obtain buy-in to the system from the moderate number of different user groups, so there is a moderate need for PD.

Will there be a change in the number and/or composition of user groups from the current system to the new system?

Your Answer: Yes

Your feedback: Changing the number and/or composition of user groups means that users will work differently in the future, and this situation calls for PD techniques to work out new divisions of work, roles, work flows, etc.; and to obtain buy-in for the new way of working.

For any user group, will there be a change in the frequency of use between the old system and the new one?

Your Answer: Yes

Your feedback: Based on a change in the frequency of use, this indicates a change in the way that users will work. PD techniques can help to involve users in working out the implications for these changes.

If the frequency of use is expected to decrease for any user group after implementating the new system compared to the current system (if applicable), is the reason due to increased automation?

Your Answer: Yes

Your feedback: Based on a decrease in frequency of use, there is an increased need for PD since increased automation might mean that the need for the user in the system is diminished. The user might become redundant and would need to be retrained to become a part of another user-group. Alternately, the user might welcome the change since he/she now can focus on other (higher order) functions, in which case PD can be applied to determine and negotiate what those functions might be.

Please think about the most numerous or important user group. Is number of functions these users will perform within the task environment expected to change significantly from the current system?

Your Answer: Yes

MITRE

Created guidance summary (example)

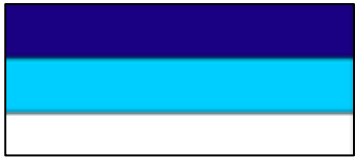
Characteristic	PD	CSE	SoSE	OCM
No. of user groups				
Frequency of use				
No. of functions				
Training				
Interaction of org. units				
Complexity				
Criticality				
Technical interoperability				
SoS interdependency				
SoS interoperability				

Legend

High emphasis

Medium emphasis

Low or no emphasis



MITRE

Looking for Government partners

- **Please contact me if you would like to pilot the use of the success factors survey tool in your organization**
- **Jill Drury, jldrury@mitre.org**