

## THE RESOURCE FOR APPLIED COGNITIVE AND SYSTEMS ENGINEERING (TRACE-SE): AN APPROACH TO UNDERSTANDING THE GAP

Heather A. Stoner<sup>1</sup>, Emily M. Stelzer<sup>1</sup>, Emily E. Wiese<sup>1</sup>, Michael Paley<sup>1</sup>, Adam Darowski<sup>1</sup>, Gilbert Mizrahi<sup>1</sup>, and Edward A. Martin<sup>2</sup>

<sup>1</sup>Aptima, Inc., Woburn, MA

<sup>2</sup>Air force Research Laboratory, Wright Patterson AFB, OH

Today's workplaces are complex organizations in which people connect to information, people, and the world through advanced technology. Accordingly, the nature of work evolves as the workplace adds technologies that challenge traditional skills and increase demands for highly specialized cognitive skills. Systems must therefore be designed to account for the cognitive strengths and limitations of users and support decision-based operations. Traditional systems engineering practices, however, frequently fail to expressly consider cognitive factors in design or consider them belatedly in the design cycle. As a result, systems are often designed that do not fully leverage the cognitive strengths of the human user or compensate for their limitations. Yet, embedding cognitive engineering methods into established systems engineering processes can be complex and expensive without tools to structure and support it. The Resource for Applied Cognitive Engineering and Systems Engineering (TRACE-SE) is a prototype web-based tool that can be used to begin bridging the gap that exists between cognitive and systems engineering. TRACE-SE provides the information needed to simultaneously support both cognitive and systems engineers in the design of user-centered systems that can produce superior decision making, improved safety, and greater operator productivity.

### INTRODUCTION

The integration of systems engineering with cognitive engineering is a broad concern within human-system integration (HSI) community. It is particularly relevant to the Department of Defense (DoD) acquisition process, as this process—which supports the acquisition of new, highly-complex, socio-technological weapon systems—does not include an explicit cognitive engineering component. Systems engineering practitioners experienced in large acquisition programs have reported in structured interviews that, with typical time and funding constraints, there is little motivation for considering cognitive engineering methods to complement the systems engineering activities within the systems acquisition process. Because systems engineers do not have access to the information or training that is needed to apply cognitive engineering methods to the design process, the cognitive aspects of HSI tend to be slighted. When designers focus upon the hardware and software components, but do not fully leverage the cognitive strengths of human users or fail to account for the weaknesses of human operators, the total system performance can be degraded in unexpected ways (Stephens, 2005).

While systems engineers do not have experience in implementing cognitive engineering methods, cognitive engineers also lack the contextual, system-specific knowledge that is needed to integrate human factors practices into the design cycle in a manner that is helpful to both the end user and the systems engineering practitioner. Cognitive engineering practitioners have the expertise in understanding the human user, but this community has less knowledge about or experience in extending this understanding to a set of design requirements. Cognitive engineers also have a limited understanding of the constraints under which systems

engineers must work and do not always have a full understanding of the key products that must be generated or milestones that must be passed during the acquisition process.

Obstacles that might inhibit a more tightly-coupled integration of systems engineering and cognitive engineering activities during system development include:

1. System engineers may be unaware of cognitive engineering and its benefits;
2. System engineers may know about cognitive engineering but do not know *how* to do it, *when* to do it, or *what* cognitive engineering methods to use;
3. System engineers and/or program managers may underestimate the value of cognitive engineering methods, leading to distorted judgments regarding the allocation of budget, time, and equipment to cognitive engineering activities;
4. Cognitive engineers may not know where they fit in during the system design process, and be less likely to provide critical design information at points when it can have maximum impact; and
5. Cognitive engineers may have difficulty in translating their findings into a format that system engineers can understand and use.

These factors contribute to the gap between the systems engineering and cognitive engineering disciplines. System design proceeds without a full consideration or understanding given the human user. Cognitive engineers fail to understand when and how to apply their methods within the acquisition process and why their methods and skills are underutilized during design.

Support is needed to bring systems engineering and cognitive engineering disciplines together, working in an interdisciplinary fashion. The systems engineering community can benefit from a resource that augments the

existing systems engineering process with cognitive engineering methods to improve overall system design, user performance, and human safety. Likewise, the cognitive engineering community can benefit from a tool that familiarizes them with systems engineering processes so that they can identify opportunities in the design process to embed cognitive engineering techniques, and tailor techniques to improve system development.

### A Prototype for Bridging the Gap

Given the challenges stated above, our goal was to begin the design and development of a tool that would begin to bridge this gap in knowledge and practice. Our objective during the first stage of development work was to develop *The Resource for Applied Cognitive Engineering and Systems Engineering* (TRACE-SE), a prototype web-based resource that can be used in conjunction with the current defense system acquisition process to embed cognitive engineering methods within the acquisition framework. Designed to be a *pragmatic* solution, it is our ongoing goal to develop a tool that provides both cognitive and systems engineers with education and the tools needed to appropriately consider and address the human factor.

## METHODOLOGY AND DEVELOPMENT

In its initial design framework, the TRACE-SE tool has been designed to be aligned with the DoD 5000 series requirements and guidance. The *Defense Acquisition Guidebook* (<http://akss.dau.mil/dag/>) describes the five acquisition phases of the Defense Acquisition Management Framework. These phases are Concept Refinement, Technology Development, System Development and Demonstration, Production and Deployment, and Operations and Support. The guidebook provides specific procedures and protocols involved in creating the products that must be delivered within each phase of the acquisition process, as well as the key milestones in the acquisition process that must be achieved to advance to the next acquisition phase.

Several benefits accrue from using this integrated approach. First, by aligning TRACE-SE with the DoD documentation, systems engineering practitioners can use the TRACE-SE prototype to identify and research cognitive engineering methods that can be most efficiently applied to the phase of acquisition on which they are currently working. Second, because the TRACE-SE prototype provides information about each of the acquisition phases, cognitive engineering practitioners can develop an improved understanding of the acquisition process and the points where cognitive engineering techniques can be most effectively applied. By aligning the tool with the acquisition phases, TRACE-SE can be used to ensure that cognitive engineering methods and approaches are implemented within the systems acquisition phase where these methods can deliver the largest and most cost-effective impact on the overall design

### Defense Acquisition Analysis

Our research team began TRACE-SE development by first understanding systems engineering as it occurs within the Defense Acquisition System and is described within the DoD acquisition documentation. Our focus was to identify “*worry points*” that serve as gates within the acquisition process where cognitive engineering practices can be effectively applied to systems engineering in order to improve the integrated performance of the human user and the designed system. Worry points were designed to represent key factors that should be considered when establishing a user-centered, advanced system. These worry points were organized into a larger framework of “*themes*.” This framework was used to identify the human-system design issues to be considered during specific acquisition phases in order to yield the greatest benefit to human-system performance.

For example, *Assessing Algorithm Fidelity* is a worry point when considering new system technological constraints affecting (among other things) the perceived reliability of the system and a user’s trust in that system. Research has widely documented the influence of algorithm fidelity on the reliability and validity of advanced systems, the resulting performance of the human-automation team (Parasuraman, Sheridan, & Wickens, 2000), the trust of the user in the automated system (Muir, 1994, 1996), and the effects of automation performance on the operator’s use of that system (Parasuraman & Riley, 1997; Wickens & Hollands, 2000).

Table 1 shows a subset of the themes and worry points identified and mapped to the primary systems acquisition phase where that theme and worry point has relevancy. In general, several themes were identified, and multiple worry points were organized within each of these themes. After identifying these worry points and themes, cognitive engineering methods were investigated with regard to their applicability to the worry points.

### Identification of Cognitive Engineering Methods

We then analyzed and reviewed cognitive engineering methods in the context of the defined themes and worry points. Specific cognitive engineering techniques were selected as key approaches for addressing each worry point during each of the acquisition phases based on a set of evaluative criteria. These criteria included the ease with which the technique can be applied within time and resource constraints, the quality of the information yielded from these techniques, the applicability of the technique to the individual worry point, and past research that has been done to reflect the reliability and validity of the technique. In total, over 115 cognitive engineering methods were initially identified. Of those, six methods were chosen to populate the TRACE-SE prototype and address the prototype worry point, *Identify User Needs*. Samples of the types of methods identified to date include:

1. Conducting and interviewing a *focus group* (Kitzinger, 1994)

- 2. Conducting a *field observation* (Millen, 2000; Patterson, Woods, Sarter, & Watts-Perotti, 1998)
- 3. Establishing a *cognitive function model* (Chrenka, Hutton, Klinger, & Anastasi, 2001).

Table 1. Depictions of themes, associated worry points, and the phases for which the themes can be applied. CR = Concept Refinement, TD = Technology Development, SDD = System Development and Demonstration, PD = Production and Deployment, and OS = Operations and Support. Legend: ● = Most relevant theme and or worry point, ○ = Less relevant theme and or worry point.

THEME	WORRY POINT	CR	TD	SDD	PD	OS
Identify and Satisfy User Needs	Identify User Needs	●	●			
	Translate User Needs to Requirements	●	●	●		
Consider Constraints: Human Constraints	Consider Interface Legibility and Usability		●	●		
	Consider Control Design		●	●		
Consider Constraints: Technological Constraints	Assess Algorithm Fidelity		●	●	●	
	Estimate Development and Maintenance Costs	●	●	●	●	●

Table 2. TRACE-SE Summary Use Case.

<b>TRACE-SE Use Case: Unmanned Vehicle Platform Development</b>	
<b>Step 1: Initial Capabilities Document (ICD) Generation</b>	
System Acquisition Process (SAP) Activity Description:	An approved ICD results from the analysis of potential concepts across DoD Components identifying an initial concept for an Unmanned Vehicle (UV). An approved plan for conducting an analysis of alternatives (AoA) is included in the ICD.
TRACE-SE User Activity:	No TRACE-SE activity needed.
<b>Step 2: UV ICD is entered into Concept Refinement</b>	
SAP Activity Description:	An AoA assesses the critical technologies and feeds development of a Technology Development Strategy (TDS) that focuses on the development, maturation, and evaluation of the technologies needed.
TRACE-SE User Activity:	No TRACE-SE activity needed.
<b>Step 3: Concept Refinement Identification of HSI Requirements</b>	
SAP Activity Description:	Subsuming the TDS as a basis, an acquisition program strategy is developed leading into Milestone A. Among other things, the acquisition strategy identifies HSI responsibilities, describes the approach for meeting HSI requirements, and summarizes major elements of the training system required.
TRACE-SE User Activity:	Using TRACE-SE, the systems engineer (SE) is faced with supporting the the program strategy development by identifying specific HSI requirements. Worry Points should be considered.
<b>Step 4: Identify Relevant Themes</b>	
SAP Activity Description:	The SE identifies a theme: Identify and Satisfy User Needs.
TRACE-SE User Activity:	The SE selects the content button at the intersection of the Concept Refinement systems acquisition phase and the User Needs theme and is taken to the first worry point for that theme.
<b>Step 5: Identify Relevant Worry Points</b>	
SAP Activity Description:	One of the first worry points identified by the SE is Identifying User Needs.
TRACE-SE User Activity:	After selecting the worry point, a description and a set of cognitive engineering (CE) methods to aid in the identification of the user needs are listed.
<b>Step 6: Investigate and Apply Relevant Cognitive Engineering Methods</b>	
SAP Activity Description:	After selecting a given worry point, the SE is given a set of relevant CE methods.
TRACE-SE User Activity:	A brief description of the method and links to relevant references are show after selecting any of the methods listed.

## Developing the Use Case

The development of the TRACE-SE prototype was further refined by defining an initial use case for TRACE-SE. Using data that were collected through interviews with system developers at an Air Force Intelligence, Surveillance, and Reconnaissance Special Programs Office, a prototypical example was developed that formally outlines the interaction that a system engineering practitioner might have with TRACE-SE in applying cognitive engineering methods during the system design process, as it might be used specifically within the concept refinement phase. A summary of the use case is shown in Table 2.

## Prototype Development

Using the defined use case, we developed a prototype of TRACE-SE, first through storyboarding and subsequently through development of a preliminary operational website. The preliminary site, which is shown in storyboard form in Figure 1, was developed as a community-based web site. The community approach was chosen because it not only encourages repeat visitors to the tool, but also provides users a sense of ownership of the site and encourages them to contribute their own content. The prototype features a weblog on the home page that presents content categorized by theme. Once content begins flowing into the framework that we developed, it will be updated on a constant basis. The site will also maintain an archive of articles, tutorials, and interviews with industry experts. Users will be able to stay up-to-date with the site using technologies like RSS (i.e., Really Simple Syndication, a form of web syndication used by news websites and weblogs).

The initial prototype of TRACE-SE was demonstrated to system developers at the Air Force Intelligence, Surveillance, and Reconnaissance Special Programs Office. During this demonstration, the developers provided feedback and were encouraged to specifically focus on identifying disconnects between the proposed vision of TRACE-SE, how system engineers were expected to actually use the tool, and the validity and utility of the processes and methods of systems engineering and cognitive engineering. The feedback received indicated that the continued development of TRACE-SE could provide a valuable tool for both cognitive engineering and system engineering practitioners. Most importantly, the pragmatic approach taken by TRACE-SE was seen as a valuable contribution to the system development process. Additional feedback from both cognitive engineers and system engineers will assist in refining the TRACE-SE structure and in continuing to identify relevant content.

## Future Development

Further development on the TRACE-SE prototype is needed to make this a versatile and useful tool for both systems and cognitive engineers. Specifically, additional content must be identified and added to support users in all phases of the acquisition process. This content will be evaluated by experts from both disciplines with respect to validity, usefulness, and presentation format to ensure that there is a community of practice that both systems engineers and cognitive engineers can use with confidence. Additionally, formal evaluations of the functionality and usability of the site will take place. These evaluations will occur throughout the development and will use both structured and unstructured interviews, as well as formal usability studies. When TRACE-SE is available for public use, we will collect site use statistics in order to better refine TRACE-SE in its content and structure. Finally, we will continue to explore additional approaches to continue to bridge the gap between system engineering and cognitive engineering, including the Navy's SEAPRINT and Air Force's AIRPRINT efforts to cultivate human-systems integration, and investigate the possibilities of collaboration.

## CONCLUSIONS

The current effort represents the first year of a three year development effort. To date, we successfully identified problems and potential solutions to bridge the gap between system and cognitive engineers within the Air Force development cycle.

Initial feedback from subject matter experts in the DoD acquisition community within the Air Force have been positive and provide guidance for future development. The end state for TRACE-SE will provide systems engineers with a "one button" approach to structuring a system design within a user-centered framework and guide them through established systems engineering processes. The tool will provide a vehicle to bring traditional systems engineering and

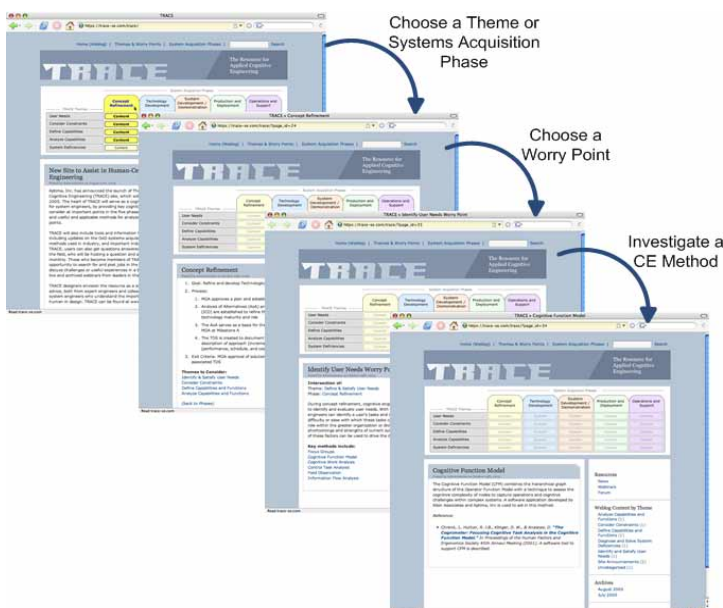


Figure 1. Prototype TRACE-SE design

cognitive engineering together to design systems in an interdisciplinary manner, guiding both disciplines through their own processes and allowing them to learn how they can tailor their methods to include the strengths of both approaches and identify positive opportunities to influence the system development process as a whole. TRACE-SE, when fully operational, will serve as a community of practice for both disciplines and include web-based seminars and discussion forums that aim to facilitate coordination between them.

### ACKNOWLEDGEMENTS

This work was funded under contract FA8650-05-C6892 through AFRL/Wright-Patterson. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of AFRL. Special thanks to Dr. Emilie Roth's contributions to this work.

### REFERENCES

- Chrenka, J., Hutton, R. J. B., Klinger, D. W., & Anastasi, D. (2001). The cognimeter: Focusing cognitive task analysis in the cognitive function model. In *Proceedings of the Human Factors and Ergonomic Society 45<sup>th</sup> Annual Meeting*.
- Kitzinger J. (1994). The methodology of focus groups: The importance of interaction between research participants. *Sociology of Health, 16*, 103-121.
- Millen, D. R. (2000). Rapid ethnography: Time deepening strategies for HCI field research. In *Proceedings on Designing Interactive Systems: Processes, Practices, Methods, and Techniques*.
- Muir, B. M. (1994). Trust in automation, part I: Theoretical issues in the study of trust and human intervention in automated systems. *Ergonomics, 37*, 1905-1922.
- Muir, B. M. (1996). Trust in automation, part II: Experimental studies of trust and human intervention in a process control simulation. *Ergonomics, 39*, 429-460.
- Parasuraman, R., & Riley, V. A. (1997). Humans and automation: Use, misuse, disuse, and abuse. *Human Factors, 39*, 230-253.
- Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A model for types and levels of human interaction with automation. *IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems and Humans, 30*, 286-297.
- Patterson, E. S., Woods, D. D., Sarter, N. B., & Watts-Perotti, J. (1998). Patterns in cooperative cognition. In *Proceedings of the COOP '98, Third International Conference on the Design of Cooperative Systems*. Cannes, France, 26-29 May.
- Stephens, E. (2005). Factor in the human to enhance capabilities. *Wright-Patterson AFB Skywrighter, 46* (36).
- Wickens, C. D., & Hollands, J. G. (2000). *Engineering Psychology and Human Performance* (3<sup>rd</sup> Ed.). Upper Saddle River, NJ: Prentice Hall.