SCENARIO DEVELOPMENT FOR DECISION SUPPORT SYSTEM EVALUATION

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This paper introduces a methodology for developing scenarios representative of the cognitive and collaborative challenges inherent in a domain of practice for evaluating Decision Support Systems (DSS). Explicit links are made between particular aspects of the DSS and specific cognitive and collaborative demands they are intended to support. The effectiveness of the DSS in supporting performance can then be systematically probed by creating scenarios that are informed by an understanding of individual and team cognitive processing factors, fundamental relationships within the domain, and known complicating factors that can arise in the domain to challenge cognitive and collaborative performance. This paper introduces a set of explicit artifacts to systematically create such scenarios to provide feedback on the viability of the DSS design concepts (e.g., are the hypothesized positive impacts of the DSS realized?), as well as feedback on additional unanticipated requirements for support.

INTRODUCTION

This paper introduces a methodology for developing cognitively challenging scenarios for evaluating Decision Support Systems (DSS). The evaluation of DSS is a fundamental element of the cognitive systems engineering (CSE) approach, which is intended to assist the cognitive and collaborative performance of domain practitioners. The visualization and DSS design concepts developed embody hypotheses about what constitutes effective support in the domain. For an evaluation to be useful, explicit links must be made between particular aspects of the DSS and specific cognitive and collaborative demands they are intended to support. Using cognitively informed scenarios as part of the process provides a means for assessing the viability of the DSS design concepts (e.g., are the hypothesized positive impacts of the DSS realized?), as well as feedback on additional unanticipated requirements for support.

WORK DOMAIN ANALYSIS

CSE utilizes the cognitive demands to be supported by the system or visualization as a starting point. Analysis of support requirements often begins with a work domain analysis, performed as part of a cognitive work analysis, which identifies the properties and constraints of the work domain (c.f., Vicente, 1999; Elm, Potter, Roth, Gualtieri & Easter, in press). This provides the basis for deriving the *cognitive work requirements* – the cognitive and collaborative demands placed on domain practitioners.

One of the consequences of this CSE approach is that it requires designers to be more explicit about the specific cognitive and collaborative activities that a given display/visualization/DSS is intended to support. Examples of cognitive and collaborative activities are: monitoring high level goal achievement, establishing course of action plans in the face of uncertainty and conflicting goals, and maintaining awareness of the goals and activities of other human or machine agents.

Explicit links are made between particular aspects of the DSS and specific cognitive and collaborative demands they are intended to support. The explicit links provide the basis for more informed and pointed testing of the effectiveness of the proposed aiding concepts. The visualization and DSS concepts embody hypotheses about what constitutes effective support. An empirical test can then be designed to answer the question, “Does the DSS support the particular cognitive and collaborative activities as hypothesized?”

The work domain analysis also reveals the types of complexities that can arise in the domain of practice that complicate cognitive and collaborative activities (e.g., missing or misleading information, goal conflicts, unanticipated events that prevent predefined courses of action from being executed). This supports the development of test scenarios that enable evaluation of the DSS under conditions that are representative of the range of situations and complicating factors that arise in the domain of practice.

Figure 1 provides a schematic overview of how the work domain analysis provides the basis for DSS requirements as well as the specification of test scenarios intended to evaluate the effectiveness of the DSS. The next sections describe the process of test scenario generation in more detail.

INDIVIDUAL AND TEAM COGNITIVE PROCESSING FACTORS

The cognitive work requirements to be supported should be probed using an understanding of individual and team cognitive processing factors, fundamental relationships within the domain, and known complicating factors that can arise in the domain to asses the impact of technology on decision-making performance.

While a domain analysis can be used to identify the fundamental relationships inherent in the domain and the cognitive and collaborative demands associated with them, the DSS developers also must consider the capabilities of the users of the system. Humans are capable of the processing of complex information, however, known cognitive processing factors can hamper the decision making process. For example, in information overload situations, decision-makers sometimes adopt mental strategies that simplify the problem, but which can lead to erroneous representations (Patterson, Roth, & Woods, 2001). The introduction of any technology into the decision-making process will have an impact – in some cases enhancing performance, and in others exacerbating performance problems.

The cognitive processing factors are important to consider when developing scenarios for system evaluation, because inclusion of event sequences meant to elicit these cognitive processing factors provide a more stringent test of the DSS.

Table 1 lists a sample of the types of individual and team cognitive factors that can affect decision quality, as well as ways technology can mitigate or exacerbate the impact. Consideration of these factors can lead to testable hypotheses about the potential impact, both positive and negative, of new displays and decision-aiding concepts on the decision-making process.

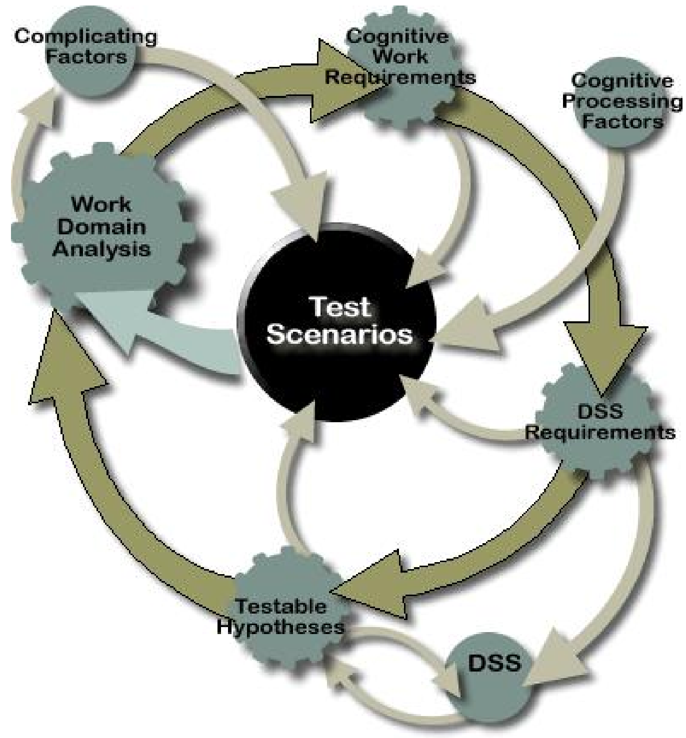

Figure 1. A Work Domain Analysis reveals cognitive work requirements as well as complicating factors that can increase cognitive and collaborative demands. It provides the starting point for the specification of DSS requirements as well as the basis for design of test scenarios to evaluate the effectiveness of the DSS.

Cognitive Processing Factors (CPF)	Description of CPF	How Technology Can Mitigate CPF	How Technology Can Exacerbate CPF
Availability Bias (Tversky & Kahneman, 1973)	The ease with which humans can recall specific incidents affects judgements of frequency	Utilize context sensitive cues to determine the likelihood of an incident to aid in categorization	Present the incident history which will reinforce the likelihood that prior incidents will be more heavily weighted when making a decision
Primacy Effect (Anderson, 1981)	Information presented first is weighted more heavily than information presented later	Manipulate salience to ensure equal visibility of all information being utilized to make a decision	List information in the order which it was received, keeping the first piece of information at the top of the list
Confirmation Bias (Watson, 1960)	The tendency to seek information consistent with an opinion	Monitoring agents that alert user when the value for a particular cue falls outside of a pre-specified range	System architectures that allow for user to "drill-down" into the data, but no facilities for lateral movement
Frequency Bias (Eihorn & Hogarth, 1978)	Relationship between two variables focus on the absolute frequency of events	Dynamic process instrumented to represent function relationship between variables rather than the value of individual variables	Displays that provide informational values out of context
Concrete Information Bias (Nisbett & Ross, 1980)	Information that is based on personal experience tends to dominate statistical base rates	Displays that provide context dependent cue to help focus attention and alert user when conditions deviate from normal.	Self-organizing displays that morph to match the user's mental model of the domain
Shared Mental Models (Cannon-Bowers & Salas, 1998)	Smooth communication and coordination depend on shared mental models of team members.	Displays that foster a common understanding of the current situation facilitate effective communication.	The absence of a common picture for team members can exacerbate communication problems among team members

Table 1. Example of individual and team Cognitive Processing Factors that can be impacted by technology

ISSUES MATRIX

The Issues Matrix (IM) provides a means to capture cognitive processing difficulties. The IM links individual and team cognitive factors with the set of domain specific cognitive demands and decisions derived from the Cognitive Work Analysis on which the DSS design is based to generate a matrix of potential experimental issues to be addressed.

The IM allows the scenario designer to identify those cognitive demands that are most likely to be vulnerable to individual and team cognitive processing demand limitations. Testable issues include exploration of the impact of proposed new visualizations, and decision-aids on known human decision-making characteristics, as well as the evaluation of hypotheses regarding the impact of particular visualizations or aiding concepts on overall decision effectiveness. Table 2 provides an example of an Issues Matrix. The IM informs the experimental design as well as the development of test scenarios.

Cognitive Demands \ CPF	Concrete Information Bias	Confirm Bias	Primacy Effect	Frequency Bias	Availability Bias
Compare relative combat power (D1)	X	X			X
Select path that will max combat power (D2)		X			X
Combine resources to max combat power (D3)				X	X
Monitor combat power coverage over time (D4)			X		

Table 2. Issues Matrix – Impact of potential biases and errors on a sample of Cognitive Demands associated with military power projection

COMPLICATING FACTORS MATRIX

A second issue to consider when developing scenarios for system evaluation is the inclusion of a range of complicating factors. Scenarios should include not only routine or textbook cases, but also cases that challenge both individual cognition, as well as collaborative processes and reflect the real complexities that may arise in the domain. Complicating factors can be thought of as the types of conditions that can arise in a domain to create opportunities for potential human biases and errors to emerge.

There has been a growing body of research that has attempted to capture and catalogue the types of complicating factors that arise in dynamic high risk domains which can impact the decision-making and collaborative processes of domain practitioners (Mumaw & Roth, 1992; Woods, Johannesen, Cook & Sarter, 1994; Roth, Mumaw & Lewis, 1994; Woods & Patterson, in press). Complicating factors can be found across domains and provide challenging decision-making and collaborative demands, which in turn provides a principled way to generate test scenarios that systematically probes the DSS design. Table 3 provides a list of typical complicating factors that arise in dynamic, high-risk worlds.

Like the Issues Matrix, the Complicating Factors Matrix (CFM) cross-references domain specific cognitive demands with complicating factors that may impact the difficulty of those cognitive demands. Likewise, the CFM is based on observable behaviors in the work domain. This matrix and the IM provide the skeletal structure for scenarios that is then instantiated with mission specific details that arise in the domain and truly test the DSS's decision-aiding effectiveness. Because the scenario occurs within a naturalistic context and the experiment addresses critical cognitive issues within the domain a true test of improved decision effectiveness of the DSS can be achieved. Table 4 provides an example of a CFM.

Complicating Factors	Cognitive Processing Factors	Scenario Characteristics
Garden path problems	Confirmation Bias	Initially scenario appears to be a simple problem (based on strong but incorrect evidence). However, later symptoms appear, which are not noticed until it is too late.
Missing information	Availability Bias	Key indicators may be missing due to failed sensors, lack of sensors, or lack of informants on the ground.
Misleading information	Primacy Effect	Misleading information may be provided due to inherent limitations of reports (e.g., stale information) or explicit intent to deceive through misinformation.
Masking activities	Frequency Bias	Activities of other agents, or automated systems may cover up or explain away key evidence.
Multiple lines of reasoning	Availability Bias	Situations can occur where different explanations or response strategies, all of which seem valid at the time, but which may be in conflict (or a source of debate and disagreement by team).
Side effects	Failure to Consider Side Effects	Situations can arise where the effects of human or automated system actions, or effects of the initial failure, have side effects, which are not expected or understood.
Late changes in the plan	Failure to Revise Plan	Changes to a prepared plan are required, decision-makers can become confused as to next steps; flaws are inserted into plan, and the whole "big picture" gets lost.
Impasses	Failure to Develop Alt. Plan to Achieve Goals	Scenario contains features which make it very difficult to move forward, such as when the COA no longer matches the conditions, or assumed available personnel or resources are not available.
Goal trade-offs	Failure to evaluate risk/benefit tradeoffs	Decision-makers must balance multiple-conflicting goals in deciding on a course of action

Table 3. Example of typical Complicating Factors

Complicating Factor	Compare CP (D1)	Select CP (D2)	Combine CP (D3)	Monitor CP (D4)
Garden path problems	X			
Missing information			X	
Misleading information		X		
Masking activities			X	
Multiple lines of reasoning				
Side effects				X
Late changes in the plan				X
Impasses		X		
Goal trade-offs	X			

Table 4. Complicating Factors Matrix

MISSION SPACE

Along with the IM and CFM a comprehensive understanding of the domain or Mission Space is necessary for constructing scenarios. This is because cognitively challenging scenarios are not enough; if the scenarios are not credible and engaging to the participants, the system evaluation will be suspect.

The scenario defines the context of the experiment, as well as the sequence of decision events that are going to be used to test the effectiveness of the DSS design. The scenario should be carefully crafted to include relevant domain events and have sufficient realism to help draw participants in the experiment into the situation. Scenarios must be designed to test essential features or functions of the DSS, with a sequence of events that imposes a series of challenges to the joint system evaluation experiments. This approach ensures that the joint cognitive team (human operator and DSS) are exposed to a representative of the range of complexities.

Table 5 provides an example of such a scenario event list that has been created to stress specific cognitive demands and whose sequence has been informed by the IM and CFM.

Typically, a number of scenario events are created that relate to each of the cognitive demands (Oser, Gualtieri, Cannon-Bowers & Salas, 1999). These events vary in difficulty and occur at different points in the scenario. This allows for a principled evaluation of the proficiencies and deficiencies of the DSS.

By incorporating cognitive processing and complicating factors into scenario development, it is possible to go beyond 'textbook' descriptions of the task or routine cases or canonical versions of abnormal scenarios. A CSE-based scenario provides the ability to gain insight and dissect

Event Description	Compare CP (D1)	Select CP (D2)	Combine CP (D3)	Monitor CP (D4)
Corp directed fires on MLRS TAI MONTANA		X	X	
Red counter-battery fires	X			
SEAD mission				
TACAIR interdiction			X	
Mass fires on TAI TOM		X		
Withdrawal of TF 2-7 across Leon River				X
11th Mech Division enters TAI DICK				X
Red formations massed north of Gatesville	X			
17th Brigade repositioned				X
Red 2nd Brigade crosses Leon River at Linton	X			
1-9 struck by missile attack				X
Red TACAIR attack 2-18	X			
Report of chemical attack on 1-17				
48th Infantry Brigade move through 101st				X

Table 5. Mapping cognitive work requirements onto the scenario event list

influences at the intersection of domain demands, decision-maker capabilities and DSS representation. Examples of well documented cases where a CSE-based system evaluation approach was employed as part of the development process include design of an advanced alarm system for a process control application (Carrera, Easter & Roth, 1996), design of a large wall-mounted group view display intended to support individual and team situation awareness (Roth, Lin, Kerch, Kenney, and Sugibayashi, 2001), and the evaluation of cockpit displays in long-haul flight operations (Woods & Sarter, 1991; 1993).

CONCLUSION

In CSE-based testing it is important to ask one self:

- What is the model of support embodied in the aiding concept being tested? Are the test conditions focused enough to evaluate this model of support?
- Have the human performance issues (e.g., potential vulnerabilities, biases, and errors) that can impact the decisions and related cognitive and collaborative activities of interest been identified? Do the test scenarios create opportunities to assess the impact of the aiding concepts on these potential performance deficiencies?

- Do the test scenarios capture the range of complicating factors that arise in the actual operational environment so as to assess extent and boundaries of effectiveness of the aiding concept?
- Are the dependent measures of performance sufficiently diagnostic to pinpoint the effect of the aiding concept on the decision making process so as to guide future design direction?
- Does the test serve as a tool for discovery -- providing a vehicle to uncover additional domain demands, and unanticipated requirements for support, to propel design innovation?

By utilizing a CSE-based approach to evaluate DSS effectiveness it is possible to develop scenarios that extend the analysts understanding of the domain. By taking into consideration domain demands, cognitive processing factors, and complicating factors, the developed scenarios provide a richer test bed for DSS evaluation than is currently practiced. This richer context is necessary if the hypothesized positive impacts of the DSS are to be realized. Only by fully exercising DSS designs will revolutionary improvements in decision effectiveness be realized.

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