Proceedings of the Human Factors and Ergonomics Society Annual Meeting
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Proceedings of the Human Factors and Ergonomics Society Annual Meeting 2006 50: 506
DOI: 10.1177/154193120605000362

THE SRK INVENTORY: A TOOL FOR STRUCTURING AND CAPTURING A WORKER COMPETENCIES ANALYSIS

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Worker Competencies Analysis (WCA) is the fifth and final phase of the Cognitive Work Analysis (CWA) framework. Unlike the earlier four phases, there is a dearth of published work illustrating how WCA is conducted within the context of CWA. The lack of concrete examples of the application of WCA has both practical and pedagogical ramifications, making it difficult to perform and understand this phase of analysis. This paper attempts to address this gap. Following a review of the CWA framework, WCA is introduced with the Skill, Rules, and Knowledge (SRK) taxonomy. Then, a methodological tool for structuring and capturing the execution of WCA—the SRK Inventory—is presented. Finally, a practical application of the SRK Inventory to a TRACON microworld is discussed. This paper is intended to serve as a resource to future CWA practitioners and researchers, and to stimulate discussion of methods and tools for better supporting WCA activities.

INTRODUCTION

The Cognitive Work Analysis framework (CWA; Rasmussen, Pejtersen, Goodstein, 1994; Vicente, 1999) is used for the analysis, design, and evaluation of interfaces for complex sociotechnical systems. CWA is a constraint-based approach consisting of five phases: Work Domain Analysis (WDA), Control Tasks Analysis (CTA), Strategies Analysis (SA), Social Organization and Cooperation Analysis (SOCA), and Worker Competencies Analysis (WCA). Constraints identified in each phase are inherited by subsequent phases, which can be conducted in any order (Vicente, 1999).

Most published applications of CWA have focused on its preliminary phases: WDA—mapping the constraints of a physical system's ecology—and CTA—describing navigation through this ecology's information processing steps. These phases have been well-defined, and refined, with numerous examples across multiple domains (see Vicente, 2002 and Burns & Hajdukiewicz, 2004). In contrast, while examples of methodologies and tools for completing SA and SOCA are provided by Vicente (1999), these phases have received significantly less attention in published literature.

Even less attention has been paid to the Worker Competencies Analysis phase, which focuses on psychological constraints regarding how operators perceive and act upon information. Although Vicente (1999) describes the Skill, Rules, and Knowledge taxonomy (SRK; Rasmussen, 1983) as a way of addressing worker competencies, WCA lacks well-defined tools and methodological examples. Not surprisingly, confusion regarding the nature and importance of this phase is often experienced by practitioners and researchers. This is compounded by the fact that few Cognitive Work Analysis applications have been followed to completion.

This paper describes experiences in performing a Worker Competencies Analysis. The WCA phase is first situated within the greater CWA framework. The SRK Inventory is then presented as a methodological tool for structuring Worker Competencies Analysis activities. Finally, an example of the SRK Inventory's application to an air traffic control microworld is provided. We hope this will shed light on this often-neglected phase of analysis and stimulate conversation regarding Worker Competencies Analysis in general, while supplementing the toolset available to CWA practitioners.

BACKGROUND

CWA Tools

Tools supporting many of the CWA activities already exist (Vicente, 1999). The Abstraction Hierarchy (AH; Rasmussen, 1985) facilitates WDA by identifying the functional structure of a system as well as constraints that must be respected to achieve the system's purposes. Similarly, the Decision Ladder (DL; Rasmussen, 1980) is used to support Control Task Analysis by modeling *what* actions are involved in completing different tasks. Information Flow Maps (IFM; Rasmussen, 1980, 1981) are used to perform Strategies Analysis by depicting *how* such information processing steps may be achieved. In Social Organization and Cooperation Analysis, all three tools (AH, DL and IFM) are used to express the distribution of information processing activities across actors (*who*). Finally, Worker Competencies Analysis identifies the competencies needed to achieve the activities outlined in previous analyses. While the SRK taxonomy forms the backbone of this analysis, no tool has been developed to support WCA activities.

Worker Competencies Analysis

The goal of Worker Competencies Analysis is to identify psychological constraints applicable to systems design. As the final phase of the CWA framework, WCA inherits all requirements identified through the four previous phases. It is important to note that the output of WCA is *not* a finished design. Instead, the entire CWA process feeds constraints for developing information requirements used in subsequent interface design activities. These design activities must themselves satisfy the myriad constraints (physical, psychological, organizational, etc.) identified through *all* CWA phases. As such, it is critical that the final phase of the CWA framework structures all these nested constraints in a manner effectively supporting the development of system designs.

Several theories and models are relevant to identifying the implications of human characteristics in system design (e.g., manual control models, sampling theory, signal detection theory, etc.). However, each of these models focuses on specific, narrow psychological traits. Instead, an integrated model is needed to aid designers in deriving practical implications for system interfaces. Vicente (1999) proposes use of the SRK taxonomy to address this need.

Theoretical Foundations

The SRK taxonomy was developed to address requirements of the Worker Competencies Analysis identified in the previous section. The taxonomy outlines basic distinctions between three main psychological processes: Skill-Based Behavior (SBB), Rule-Based Behavior (RBB), and Knowledge-Based Behavior (KBB) (Rasmussen, 1983). SBB represents sensory-motor interactions consisting of smooth, automated, and integrated patterns that take place without conscious control. RBB represents the invoking of stored rules derived from procedures, past experiences, or operating instructions. KBB represents functional reasoning about the goals to be achieved, where operators rely upon internal knowledge of the system—or, mental models—to solve problems.

Information at the skill-based level is perceived as time-space signals, information at the rule-based level is typically perceived as signs, while information the knowledge-based level is perceived as symbols (Rasmussen,1983). Interfaces for complex socio-technical systems should encourage SBB and RBB, while allowing for operators' seamless transition to KBB during problem solving (Vicente, 1999). A well-known example of the application of the SRK taxonomy in systems design is the Ecological Interface Design framework (EID; Vicente and Rasmussen 1992). EID follows three design principles: (1) workers are able to act directly on the interface to support SBB and interaction via time-space signals; (2) there is a one-to-one mapping between the work domains constraints and the signs on the interface to support RBB; and (3) the work domains is represented in the form of an AH, serving as externalized symbols that support KBB. Vicente (1999) outlines the process of mapping the SRK taxonomy into an EID interface for DURESS II microworld. However, to the knowledge of the authors, few designers using the EID framework clearly establish this connection between the SRK taxonomy and their final designs. To this end, Worker Competencies Analysis activities must ensure that the forms of information relevant to these three levels are available to workers at all times. These requirements must also be inline with all constraints inherited from other CWA activities. Unfortunately, Vicente (1999) does not provide explicit methodologies to accomplish this.

THE SRK INVENTORY

The SRK Inventory was developed to facilitate the process of identifying informational design concepts that support SBB, RBB, and KBB control methods for a domain's myriad informational processing activities.

The SRK Inventory is a series of tables capturing analysts' concepts of behaviors that operators may invoke to complete information processing activities, with separate tables created for each of a domain's numerous control tasks. Cells within the first two columns of each table describe the information processing activities and resultant knowledge states comprising a given control task. The population and organization of the rows within these columns is informed directly by Decision Ladders generated during CTA activities, creating a direct link between the outputs of the Worker Competencies Analysis and previous CWA phases.

The remaining three columns of the SRK Inventory serve as placeholders to motivate the generation of design concepts. Descriptions of potential operator behaviors at each of these three levels of interaction are developed for each cell. These descriptions provide examples of how the resultant knowledge state of each information processing activity may be generated at each level of the SRK taxonomy. Empty cells within the SRK Inventory serve as indicators of information processing activities that may not be effectively supported by the interface. For example, an empty cell in the Knowledge column indicates the interface may not provide an operator with sufficient resources to engage in effective troubleshooting or problem solving for a particular information processing step. Completed cells in the SRK Inventory can also be used to generate profiles of competencies that operators must possess to adequately perform control tasks. In this manner, the SRK Inventory can be used to inform worker selection and training.

DISCUSSION

This section provides an example of the SRK Inventory being used to perform a Worker Competencies Analysis as part of a five-phase Cognitive Work Analysis of a Terminal Radar Approach Control (TRACON) microworld.

The Work Domain

TRACON for Windows (TFW, 1991) is an air traffic control (ATC) simulation. The main component of the TFW microworld is a computerized radar system, tracking aircraft local to a given airport. Aircraft parameters—including flight number, altitude and destination—and other domain components, such as airports, airways, radio beacons, intersection fixes, instrument landing systems, significant terrain markings and weather patterns, are provided via the simulator's viewport. While the TFW microworld captures many of the complexities found in real-world ATC environments, its overall scope is significantly reduced, accommodating control by a single operator.

Completed SRK Inventory

In analyzing the TFW domain, a SRK Inventory was completed for one control task identified during previous CTA activities. In this control task—designated as *Rerouting*—an operator detects multiple aircraft with potentially conflicting flight paths and then determines and relays flight instructions to these aircraft to better avoid future collision. This task was selected for analysis for its relative complexity and because it had been analyzed across all four previous CWA phases. A complete Worker Competencies Analysis—and thus a complete SRK Inventory—would include analyses of *all* control tasks identified for the TFW domain, but this was prohibited by project scope.

The completed SRK Inventory for *Rerouting* is shown in Table 1 on the following page. The first two columns of the table describe the information processing activities and knowledge states of this control task. The remainder of the table presents conceptualized behaviors for each level of the SRK taxonomy. These cells were populated with reference to constraints generated through the previous four phases of Cognitive Work Analysis.

The following design insights were captured through this SRK Inventory:

Skill-Based Behavior. SBB can be supported by providing signals to operators in the form of time-based spatial representations of aircraft flight. Any operator engaging in SBB must be able to perceive aircraft headings, time-to-collision, potential overlap zones, and boundaries of minimal separation. It is crucial that the interface provide adequate support for such competencies in light of known perceptual limitations. For example, to predict the future locations for converging aircraft (Step 5, in Table 1) using SBB, operators must perceive a potential a loss of separation between two aircraft—a product of their individual flight headings, altitude, and travelling speeds—as a signal. Slow visual update and poor resolution of the traditional TFW interface make this task difficult. SBB may be better supported by augmenting the interface with accelerated, hi-resolution depictions of aircraft locomotion through the flight space.

Rule-Based Behavior. To support RBB, signs should be presented to operators via isomorphic mapping between display geometries and system states (Vicente & Rasmussen, 1990). Operators must have the necessary competencies to use these signs to trigger stereotypical control rules, as outlined in part by Table 1. Such signs include indications of: the presence of multiple aircraft, the convergence/divergence of particular aircraft routes, and whether future proximities of converging aircraft may necessitate intervention. Additionally, control concepts captured through the SRK Inventory suggest that operators should be trained to recognize and address some predefined set of generic loss-of-separation scenarios.

Knowledge-Based Behavior. To support KBB, the interface must facilitate operators' integration of multiple pieces of information to predict future system states and develop rerouting strategies. Table 1 highlights information requirements for effective problem solving during rerouting, including geospatial knowledge of aircraft origins and destinations, as well as performance characteristics, airspeeds, headings, altitudes, and scheduling criteria, among others. To support problem solving across multiple levels of system abstraction, these informational requirements must be conveyed in a manner that reflects the underlying relationships and constraints uncovered through WDA activities. Finally, the SRK Inventory highlights necessary worker competencies, including the ability to integrate relevant flight parameters to calculate future aircraft locations and determine suitable rerouting procedures.

CONCLUSIONS

This paper has introduced the SRK Inventory, a methodological tool for systematizing and executing Worker Competencies Analysis activities within the context of Cognitive Work Analysis. The SRK Inventory was used to perform a Worker Competencies Analysis of one control task within an air traffic control microworld. This resulted in several key design concepts for supporting operators engaged in skill-, rule-, and knowledge-based control within the work domain. It is our hope that this example will aid others in understanding and performing WCA activities.

Table 1. Completed SRK Inventory for the *Rerouting* control task within the TFW domain

WORKER COMPETENCIES ANALYSIS SRK Inventory				SRK 2.7
Rerouting Task (Control Task 2.7) Related Documents Abstraction Hierarchies: AH0, AH0.2, AH2.1 Decision Ladders: DL2.7.1, DL2.7.2, DL2.7.3, DLSUM2.7.1, DLSUM 2.7.2, DLSUM 2.7.3 Information Flow Maps: IF2.7.1., IF2.7.1.1, IF2.7.2, IF2.7.2.1, IF2.7.3, IF2.7.3.1				
Information Processing Step	Resultant Knowledge State	Skill-Based Behavior	Rule-Based Behavior	Knowledge-Based Behavior
1. Scan for aircraft presence in area of responsibility	2. Whether multiple aircraft are within area of responsibility	Monitoring of time-based spatial representation of aircraft in area of responsibility	Perceive explicit indication multiple aircraft are currently within area of responsibility	Reason, based on proposed flight plans, that multiple aircraft may be present in area of responsibility within similar time frames
3. Determine future flight vector for each aircraft	4. Whether multiple aircraft within area of responsibility have intersecting flight paths	Perceive headings of related aircraft as convergent, divergent, or parallel	Use heuristics to determine whether flight paths are intersecting (e.g. flight paths A→B and C→D are convergent paths; flight paths A→C and B→D are divergent)	Reason, based on geospatial knowledge of to/from points for each flight, that aircraft are on convergent or divergent paths
5. Predict future, time-based location states for aircraft on convergent paths	6. Whether converging aircraft will arrive at point of convergence within a similar time frame	Perceive time-to-collision (tau) of each aircraft with the convergence point, based on spatial representations of heading and speed	Use heuristics to estimate whether aircraft will arrive at convergence point within a similar time frame (e.g. if distance A ≈ distance B AND airspeed A ≈ airspeed B, aircraft will arrive at approximately same time)	Calculate, using airspeed, heading, and location of each aircraft, the time at which each aircraft will arrive at the convergence point
7. Determine the criticality of a pending convergence	8. Whether future distances between converging aircraft will constitute a 'loss of separation' event	Perceive whether the zones of safe travel surrounding each aircraft will overlap at or near their closest point	Use heuristics to determine proximity as being greater or less than the minimum required envelope of separation	Calculate distance between each aircraft at their closest future states and compare with the minimum value of separation required for safe travel.
9. Choose to modify aircraft flight path(s) to address future problem	10. Which aircraft flight path(s) must be modified to eliminate potential 'loss of separation' event	Directly perceive that one or more aircraft must be redirected	Apply doctrine: (e.g. If loss of separation will occur, MUST reroute one or more aircraft)	Reason from knowledge of proposed flight paths, current locations, and expected future behavior that aircraft must be rerouted
11. Select specific method for accomplishing rerouting of aircraft	12. Air Traffic Controller's awareness of new flight path(s)	Respond automatically to perception of loss of separation by directly manipulating a representation of aircraft flight path(s)	Classify loss of separation within a set of generalized scenarios and select appropriate stereotypical control rule	Develop new, optimized flight path(s) based on weighted criteria including urgency, flight priority, passenger convenience, efficiency etc.
13. Convey flight modifications to aircraft for execution	14. Aircraft's awareness of new flight path(s)	Direct, simultaneous interaction with communication equipment through control interface through input of rerouting information (step 11)	Apply stereotypical control rules to select method/sequencing for conveying proposed flight path (e.g. if one aircraft involved, contact that aircraft; if two, contact both)	Reason using knowledge of aircraft systems, priorities, urgency, etc., the best means and order for contacting each aircraft to convey proposed flight path(s)

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