MODELING WORK FOR COGNITIVE WORK SUPPORT SYSTEM DESIGN IN OPERATIONAL CONTROL CENTERS

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The design of cognitive work support systems for operational control centers is an emerging challenge for human factors practitioners. Ecological, task and cognitivist approaches individually do not provide the full insight required for CWSS design. Instead, work is presented as a 'mid-level abstraction' that captures many of the inherent structures and constraints of the ecology and context which can be captured by a set of complementary work models, and extended through the use of contextual control modes. This paper presents representative work models and insights from ethnographic observations of airline OCCs.

INTRODUCTION AND MOTIVATION

The general trend towards building large centralized installations observed by Rasmussen and colleagues in the late 1980s continues today (Rasmussen, 1988). The availability of low-cost and high-bandwidth data transmission has only amplified this centralization. As a result, centralized control centers, often called operational control centers (OCCs), are being built to control not just local facilities but remote facilities as well. Individuals working in OCCs are of great interest to the CEDM community as their work is both highly cognitive and often typifies naturalistic decision making. As a result of the complexity of the cognitive work required in OCCs, many are developing support systems to aid in 1) controlling the facilities under their management and 2) making more “optimal” decisions. The challenge for human factors practitioners is to effectively guide design of these cognitive work support systems (CWSSs).

OCCs may be observed and modeled from a number of viewpoints. An ecological approach provides insights regarding the work environment, i.e., a structural description of the OCC. Specifically, an ecological approach can concentrate on creating an understanding of the physical and cultural constraints that exist within the OCC (Vicente, 1999). A cognitivist approach might concentrate on the perceptual and attention limitations inherent to an OCC operator. A task-based approach would bring insights about the structure of the individual tasks which OCC operators use to accomplish their overall goals, such as an approach concentrating on a thorough hierarchical task analysis. However, no one approach alone can provide the full insight required for design of CWSS.

This paper will use airline OCCs to illustrate our experience in modeling the insights gained from ethnographic observations in complex, dynamic, collaborative environments in a manner suitable to drive the design of cognitive work support systems. Specific issues that we address include (1) viewing work as a 'mid-level abstraction' that captures many of the inherent structures and constraints of the ecology and (2) recognizing that a decision maker's approach to work is based not only on the ecology, but also on aspects of context such as information resources and perceived time available.

MODELING WORK

Work is defined here as purposeful activity. Work has a structure stemming from the physical, organizational, and social environment, the cognitive constraints of the work and the demands of the task which cannot be fully described by analyzing any of these elements in isolation.

To gain the insights necessary to design a CWSS, we have drawn on a series of complementary work models, as described by Beyer and Holtzblatt (1998). This set of work models captures a range of attributes that define work including the physical environment, the cultural context, the artifacts used during the work, the movement of information, and exemplar tasks of the work practice. They consist of the following types: information flow models, artifact models, cultural models, physical models, and sequence models. The number of each needed to describe a work environment will vary depending on the depth of understanding required.

The use of work models has three primary benefits. First, they facilitate the transfer of knowledge gathered during observations quickly, efficiently, and fully to others. Second, they provide a uniform and extensive understanding of work practices upon which a design can be based. These models are intended to provide a complete understanding of work because they include aspects from the cognitive, ecological, and task-based approaches. Third, they align any support system design with the fundamental work practices experienced by the user.

Contextual Inquiry

To gather the information necessary to create these models, a range of ethnographic methods could be used. We used a structured version of ethnography called Contextual Inquiry (Beyer and Holtzblatt, 1998; also Holtzblatt & Jones, 1995). Contextual inquiry allows an examination of how a system operates while taking into account not only the users but also others in the organization dependent upon the work.

It is centered on four guiding principles: context, partnership, interpretation, and focus. The first principle, context, implies that the interview must take place where the work is being conducted. Interviewing in context allows the interviewee’s actions and their answers to questions to be more accurate by being situated. The second principle, partnership, requires that the common role of interviewer-interviewee is
replaced with the role of mentor-mentee. This relationship enables the interviewee to take more control in the interview and thus impart the knowledge that they feel is important instead of simply answering questions. The third principle, interpretation, signifies that a shared understanding must be developed about all aspects of work. To accomplish this, the interviewer must not only abstract and describe their observations, but also share these interpretations with the interviewee for refinement and correction. The fourth principle of focus implies that, unlike pure observation, contextual inquiry allows the interviewer to steer the conversation gently to remain on task, while also capitalizing on unexpected insights.

**Work Models**

In the following sections, work models from the contextual inquiry of airline OCCs will be presented which illustrate 1) the usefulness of analyzing human behavior and cognition at a work-level abstraction and 2) the variation in work practice as a response to contextual (including, but not limited to the physical ecology) changes. The set of models described by the Contextual Design (Beyer & Holtzblatt, 1998) process facilitate modeling organizational and cultural aspects of work practice which are not captured well in other modeling paradigms such as cognitive work analysis.

**Artifact Models**

The purpose of the artifact models is to determine how artifacts help or hinder work. Annotations typically point out problems and explain usage. Often AOMs use multiple software tools concurrently, as shown in Figure 1, to visualize the airline schedule, draw attention to schedule deviations or potential deviations and obtain further information about the schedule. On the right monitor is a schedule visualization tool, used to monitor the state of the airline’s schedule and modify the schedule. On the left side, starting in the upper left corner and moving clockwise, are the shift log, out of service aircraft display and two text-based terminals which are provide information on aircraft, stations, and personnel.

**Figure 1: Artifact Model - Software Tools**

Figure 2 shows how a checklist used by AOMs serves as a physical reminder of remaining routine tasks. This artifact speaks to the repetitive nature of some aspects of the AOM’s work. However, this checklist neither prescribes nor describes the AOMs work fully.

**Figure 2: Artifact Model – AOM Checklist**

**Cultural Model**

The purpose of a cultural model is to understand the cultural forces which impact both the work environment and the work itself. In a cultural model the main influencers, including non-physical constraints, are represented. be they people, policies, values, preferences, or points of pride. In addition, the specific topic of influence and direction of that influence are shown. Cultural models are only able to capture a snapshot of the culture over a fixed period of time; however, the work culture itself is constantly evolving. Multiple cultural models can exist for the same airline as individuals performing different work will have different goals and experience different motivations and pressures.

Two cultural models (Figures 3 and 4) are included to illustrate the differences in culture which can be captured even between airline OCCs, despite their similar goals and organizational structures. For example, the models not only have different structures but also include different members. Figure 3 is much more disjointed, which captures the highly specialized nature of the work at this airline – one group focuses on problems that only effect a couple of flights and another group focuses on problems that effect entire stations or the entire fleet. As Airline 1 operated a fleet that was more than three times as large as the other airlines, they had the manpower necessary to allow this organizational structure. It is also interesting to notice the placement of the customers, customer service, and maintenance as all three were given significantly different priorities.

**Physical Models**

The purpose of the physical model is to depict the physical environment in which the work takes place and to illustrate physical barriers, constraints, and affordances. For example, Figure 5 depicts how the arrangement of an AOM’s physical workspace indicates the relative importance of objects: In this airline, monitor space is highly relied upon as this individual has five separate monitors. At other airlines, AOMs are less reliant on monitors, preferring paper print-outs.
Contextual Control Modes

Previous research using the contextual inquiry technique in the analysis of airline OCCs and the design of a cognitive work support system for airline operations managers (AOMs) has revealed a wide variation in the AOMs’s work practices (Feigh & Pritchett, 2005; Feigh, 2006a; Feigh, 2006b; Feigh, 2007). On a day with few disruptions the AOM may consider many possible alternatives to minimize flight delays, consult colleagues, generate several alternatives, and choose between them. Alternatively, on a busy travel day with major disruptions, the AOM may resort to broad measures such as operating the entire fleet an hour behind schedule.

The Contextual Control Model (COCOM) devised by Erik Hollnagel provides a useful framework to view these changes in cognitive work in response to contextual features such as time limit and information availability (Hollnagel, 1993), as it includes both a model of context and a model of control. COCOM allows many different ways of approaching a high level task which can be achieved by different patterns of behavior.

This breadth is necessary because of the wide variety of approaches to the AOM’s work we observed, including: which decisions to make; which methods of information seeking, communication, and coordination to employ; and when and how to apply these actions. We propose that analysis done at an appropriate level of abstraction should be able to capture the differences between the changes in cognitive work.

Control is conceptualized as planning what to do in the short-term and within the subjectively available time horizon (Hollnagel, 2002). The degree of control an individual has over a situation is modeled as a “continuous dimension where at one end there will be a high degree of control and at the other there will be little or no control” (Hollnagel, 1993). To better describe this continuum of control, Hollnagel (Hollnagel, 1993) has developed a classification of four contextual control modes (CCMs):

- Scrambled control “denotes the case where the choice of next action is completely unpredictable or random. This type of performance is thus, paradoxically, characterized by the lack or absence of any control” (p168).
- “Opportunistic control corresponds to the case when the next action is chosen from the current context alone, and mainly based on the salient features rather than durable goals or intentions” (p169).
- Tactical control is characteristic of situations where “the person's event horizon goes beyond the dominant needs of the present, but the possible actions considered are still very much related to the immediate extrapolations from the context” (p170).
- “Strategic control … is using a wider event horizon and looking ahead at higher level goals...” (p170).

Extending Work Models to Describe CCMs

All of the work models may change to reflect the difference between different cognitive control modes. Information flow models are included below as a representative example of the variations which work models can depict.

**Information Flow Model**

This model shows the flow of information and artifacts between individuals, and notes any breakdowns in this flow.
The flow model for the AOMs involves both individuals and computer systems. Individuals are represented by ovals. Artifacts (physical entities used to convey information) are represented by small rectangular boxes, and areas of information storage are represented by shaded boxes. The flow of information between these elements is illustrated by arrows. Breakdowns are represented by lightning bolts.

Using the contextual control modes as a framework to view the variation in work practices observed at the airline operation control centers, three distinct information flow models have been included in this paper. Each represents the work practices as a result of a combination of different contexts and the human reaction to that context.

In the Strategic mode, Figure 6, the contextual features of the OCC include a fairly long resolution time horizon (30+ minutes), a single problem whose impact is so large to require the attention of most of the OCC personnel, an intention to optimize their cancellations and delays, increased coordination between the AOMs and the airline operations manager, and a preemptory approach to addressing schedule disruptions. Correspondingly, the AOMs limit the amount of coordination between themselves and the crew schedulers, maintenance control, and the ramp managers. They increasingly rely on their computer systems to gather information and to optimize their response, to the extent that they may use a separate computer system designed specifically to optimize the cancellation portion of the response plan.

In the Tactical mode, Figure 7, the contextual features of the OCC include a fairly short resolution time horizon (10-20 minutes), an intention to catch problems before they become schedule disruptions where possible, and, when not possible, to minimize the ripple effect of these disruptions. It is typified by manageable number of schedule disruptions at the level of individual flights or aircraft, a goal to minimize the impact of disruptions not only on passengers, but also on crew and maintenance schedules, and a preemptory approach to addressing schedule disruptions. Correspondingly, the AOMs engage in high levels of coordination with the crew schedulers, maintenance schedulers, and ramp managers, but virtually no coordination with the AOM. They address one problem at a time, but are often juggling multiple problems simultaneously as they wait for answers to queries.

In the Opportunistic mode, Figure 8, the contextual features of the OCC include an extremely short resolution time horizon (0-5 minutes), an intention to correct problems (but not necessarily in a way that is optimal), a seemingly unmanageable number of schedule disruptions, and a ‘fire-fighting’ approach to addressing schedule disruptions. The AOMs engage in very little coordination activities, beyond asking direct questions and giving orders. These behaviors are generally those addressed by naturalistic decision making (Orasanu, 1993; Klein, 1997).

INSIGHTS FROM WORK MODELS

After reviewing the work models from these airlines, many insights with significant design implications can be identified. First, as was illustrated in the information flow models, work practices vary with context. Changes in context identified during the contextual inquiry include: 1) the amount of schedule disruption across the entire air transportation network, especially those locations where the airline bases its operations, e.g. hub stations; 2) the resources available to the AOM including spare
airlines with larger fleets tended to use small pieces of software to automatically monitor the schedule and to present potential and on-going schedule disruptions to the AOMs in a list.

CONCLUSION

In conclusion, this paper has sought capture all of the aspects of OCC work necessary for CWSS design by modeling work as of a series of complementary work models. We believe the work models have successfully captured not only the ecological aspects of the work, i.e. the aspects which are the physical and cultural constraints outside of the individual worker that remain fairly fixed over time, but also the contextual aspects of work, i.e. the aspects which include the immediate resources and demands as perceived by the worker, which can change rapidly.

In addition, in order to capture the different patterns of behavior observed during the contextual interviews, we have extended the work models to account for CCMs as different patterns of work within a given ecology. While the CCMs represent discrete instantiations on what is otherwise a continuum, three identifiable modes appear to be sufficient to describe our observations. We felt it was important to include the CCMs; as a descriptor of the worker’s response to the environment, they can provide insights not possible from modeling the environment alone.

REFERENCES