Design of Multi-mode Support Systems for Airline Operations

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ABSTRACT

This paper discusses designing support systems for cognitive work environments, focusing specifically on airline operations. Previous studies found that cognitive work, which includes activities such as judgment and decision making, varies with context such that a single method of supporting cognitive work would not apply in many situations. For example, time constraints have been found to be a major factor in the both the decision strategies adopted by individuals and in the contextual control mode individuals operate in. In order to best support multiple modes of cognitive work, a multiple mode support system design is proposed. The Contextual Control Model is used as the basis for the multiple mode support system as its model of control provides a useful framework upon which different patterns of behavior observed due to varying context can be aggregated into four distinct modes.

Keywords

Support Systems, Airline Operations, Contextual Control Modes

INTRODUCTION

The availability of computer based systems for information exchange and for e-commerce has huge implications for Air Traffic Management (ATM) and Airline Operations (AO). As current ATM and AO modernization efforts attempt to further increase productivity and efficiency, support systems are increasingly being devised, designed, and implemented in these environments. Traditionally these support systems have been specifically designed to support a single activity, decision making, and have consequently been labeled Decision Support Systems (DSS).

This paper argues that, instead of focusing on supporting the decision making activity in isolation, a broader set of activities which include decision making, judgment, coordination, information gathering, solution generation and decision execution should be supported concurrently. The broader set of activities will be defined here as cognitive work and the emphasis of a cognitive work support system in airline operations will be to support individuals with selecting and prioritizing their activities so as to accomplish the tasks required to maintain the airline's published schedule.

US airlines play a large role in the efficient operation of the national air transportation system, not only due to strategic scheduling decisions made by airlines, but also on the daily implementation of these strategic decisions [2,11]. The safe and efficient management of an airline is a complex cognitive task involving many individuals working in close coordination. Of note are the Airline Operation Managers (AOMs) of typical major U.S. airlines who are responsible for the daily operation of large regions or fleets of aircraft, often with 40-50 flights departing every hour. They oversee daily operations that are often disrupted by weather, ATC delays and unscheduled maintenance, and are responsible for implementing flight delays, cancellations, "aircraft swaps" and the use of reserve crews to minimize the impact of such disruptions.

Previous research by the authors has employed an ethnographic technique, called contextual inquiry as described by Beyer & Hotzblatt [1], to model the work performed by AOMs [2]. The contextual inquiry revealed that AOMs' approaches to their work can vary wildly. On a day with few disruptions the AOM may consider many possible alternatives to minimize flight delays. He may consult his 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. These variations lead the authors to hypothesize that any tool intended to support AOM's work process would need to be capable of accommodating the range of behaviors observed in the contextual inquiry.

The AO work environment can be characterized as:

- regulating a dynamic system;
- requiring a series of activities to reach/maintain the overall goal;
- having activities that are dependent on the outcome of previous activities;
- having task parameters which are continuously changing in response to changes; and
- requiring tasks be accomplished in real time.

Unlike other domains in which decision support systems have been fielded, the cognitive work of airline operations presents a distinct set of challenges for any support system, which primarily stemming from the dynamic nature of the work environment. These challenges include: supporting a variety of activities concurrently, supporting activities over a range of time horizons for task completion [8], and supporting multiple activities with varying amounts of information.

Additionally, in the field of airline operations, there has been much interest in the operations research (OR) community on using mathematical programming to improve airline recovery from irregular operations [8]. The aim of these algorithms is to generate a set of feasible solutions which optimize some aspect of the operation, be it aircraft utilization, the number of passengers stranded or a composite function of revenue generation based on the problem description that it is given. The algorithms developed must be housed within a larger support system, and their effectiveness will be limited by the effectiveness of the overall design of the support system and its ability to fully support the work of AOMs.

Traditionally, DSS have been developed to aid in the comparison of multiple decision alternatives based on a set of attributes. Presently, there has been much interest in creating DSS to support AO where the emphasis is on not only choosing between options, but also on generating feasible or "optimal" options [8], where the step of choosing between options is eliminated and the "best" solution is presented to the user to approve and implement. As DSS are currently designed, this takes time, suitably formatted information and expertise. Unfortunately, time and suitably formatted information are not always available in the AO environment. Often information that is necessary to "optimally" solve a problem is not known, not known precisely enough, or known in a form difficult to enter in a DSS. In summary, the current design method is not appropriate for dynamic decision making environments such as AO.

This paper proposes that the challenges created by the dynamic nature of the AO work cannot be met through the use of traditional DSS systems where a single user interface is created for the support system functions regardless of the work context. Instead, this paper hypothesizes that there is a need to create support systems with multiple operational modes, with distinct functionality, and correspondingly, interfaces to support the distinct modes observed during the contextual inquiry.

The different decision strategies seen in the contextual inquiry of AOMs appear to correspond to the decision maker's perception of the variable time constraints and other contextual features such as knowledge of situation. This paper postulates that the same variability in time constraint perception and other contextual changes which have been found to cause decision makers to utilize different decision making strategies will also have an effect on the successful implementation of support systems in the AO work domain.

MODEL OF CONTROL AS A DESIGN FRAMEWORK

Designing a support system with multiple operational modes to support a variety of patterns of activity is a challenge. What is needed first is a model of these patterns of activity and how they manifest themselves in response to specific contextual features such as time pressure and information uncertainty.

The Contextual Control Model (COCOM) devised by Erik Hollnagel provides a useful framework to view the changes in cognitive work in response to contextual features such as time limit and information availability [4], as it includes both a model of context and a model of control.

Control in this model is conceptualized as planning what to do in the short-term and within the time horizon of the system with which the human is interacting [5]. The model of control envisions the degree of control an individual would have over a situation 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" [4].

To better describe this continuum of control, Hollnagel has developed a classification of four contextual control modes (CCMs) [4]:

- 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 means that the person is using a wider event horizon and looking ahead at higher level goals..." (p170).

Importantly, COCOM includes the idea that individuals will transition between CCM to maintain control over a changing situation [6,12]. Hollnagel states that "The change between control modes is determined by a combination of situational and person (or internal) conditions, – in other words by the existing context…" [4] (p194). Thus, the control mode must be appropriate for the context. Several factors are thought to influence transitions between CCMs, including expertise, knowledge, and system interface (ease of information access).

COCOM allows many different ways of approaching a high level task and many different patterns of behavior. This breadth is necessary because of the wide variety of approaches AOMs use in accomplishing their goal of schedule adherence, including which decisions to make, which methods of information seeking, communication, and coordination to employ, and when and how to apply these actions. Using the framework provided by the COCOM suggests that support systems (SS) could be tailored for specific CCMs [3,7,9].

This paper seeks to begin discussion on how to design SS for different CCMs so that the SS is appropriate for the context of the environment for which it will be used. The paper will discuss the different features of the CCMs and suggest implications of each of these features on the design of the SS.

DESIGNING FOR CONTEXTUAL CONTROL MODES

Using the framework provided by the CCMs we can begin to think about how activities might change under different contexts. For example, it can be imagined that an AOM working in an opportunistic mode, where the choice of next action is primarily influenced by the salient features of the environment, may need the support system to highlight the most relevant information available about the problem and then facilitate task execution (perhaps identifying the flight that is in the most 'trouble' and providing 'one-click' mechanisms to delay or cancel it). However, an AOM operating in a tactical mode may need a support system to facilitate following a standard operating procedure for planning and double checking their task solution. On the other hand, an AOM operating in a strategic mode may need a support system to facilitate solution generation and comparison along a number of objective function lines (such as the number of passengers disrupted, number of aircraft disrupted, or overall economic impact) in addition to facilitating task execution and solution checking.

Strategic Control Mode

The Strategic CCM is the highest level of control, and is often the mode to which SS have traditionally been designed. It has long a resolution time horizon (RTH)[1] and thus a more than adequate subjectively available time limit. In this CCM the AOM has time to fully assess the situation, without the need for much information filtering. Consequently, in the strategic mode the amount of information sought and coordination required between individuals are also expected to be extensive, as the AOM seeks to integrate information from a large number of sources and individuals.

In this mode AOMs can develop multiple feasible solutions either manually or in conjunction with the SS. AOMs will also be able to compare multiple feasible solutions and iterate several times to make the "best" decision possible. Further, the AOM should have the time and information available to ask the SS to compute "optimal" solutions for the current problem along many different dimensions. For example, the support system may compute "optimal" solutions to minimize passenger delay, maximize aircraft usage, etc as directed by the AOM. In addition, AOMs are able to create high level abstractions about the information they gather from their environment. For example, AOMs may determine that the situation calls for a `thinning' of the schedule in advance of a convective weather event. This abstraction of `thinning' will consequently affect subsequent actions.

In the strategic mode the time for iteration and the desire to find the absolutely best alternative will be high, leading to a large number of iterations with the support system. Further, the solution alternatives will be compared more thoroughly than in any other mode. Strategies which describe how an individual chooses between alternatives are often referred to as decision strategies. It is hypothesized that the decision strategies which best describe the alternative comparison used in the Strategic CCM are a set of rational decision making strategies which range from weighted additive derived strategies to the equal weight strategy [10].

The Strategic SS mode should, therefore, support rational decision making strategies by providing a comparison tool which is capable of comparing a large number of alternatives and attributes, as well as enabling each attribute to be independently weighted. Similarly, AOMs in a strategic mode will need to supplement their short term memories by storing information in a computer or on paper, as they can generate lists of resources, options, ideas etc. In a strategic CCM AOMs will also be able to deliberately configure their work environments, e.g. organizing their computer screens for a specific task. Consequently the SS interface should support reconfigurability.

Tactical Control Mode

The Tactical CCM is the intermediate level of control characterized by actions being determined according to some general established pattern of behavior, such as a procedure. It has a RTH and subjectively available time limit which are "adequate". In this CCM the AOM has time to assess the situation and use a procedure to solve the disruption, possibly generating multiple feasible solutions along the way.

The amount of information sought in a tactical control mode is expected to be beyond what is immediately observable, but may be limited to what routine procedure requires. Coordination is expected to be formulaic as the AOM restricts information seeking to a limited set of preferred sources and individuals. It is expected that the time spent on individual activities such as communication, coordination, judgment, etc. will be lower than in strategic as time constraints will not allow the AOM to spend large amounts of time on more than a few activities. Further the AOM may not need to spend much time on any one activity because, by following a procedure, they are not required to evaluate the outcome from the previous activity prior to determining which activity to undertake next.

The procedure followed in the tactical mode may incorporate the use of a support system. The AOM, while having enough time and information in this CCM to allow the support system to compute "optimal" decision alternatives along some predetermined dimensions as a part of the procedure, but may not have adequate time to fully evaluate the resultant alternatives for several reasons. First, the large number of attributes that are evaluated by the SS to generate a solution is likely to be larger than the small number of attributes that the AOM will be able to consider, which may lead the AOM to dismiss any solutions that she does not understand. Second, the AOM may not have time to iterate with the support system to create an appropriate solution for the small number of attributes that the AOM is interested in satisfying. This does not mean that solutions generated by the support system are valueless, just that their utility may be limited in this CCM, and that perhaps less optimal, but more transparent, solutions may be preferred.

To support the Tactical CCM, then, the support system must support the procedure that the AOM is attempting to follow. For example, the support system may be able to alert the AOM as to the procedure's boundaries, i.e. when the procedure is no longer applicable. It may also need to direct the AOM to create more than one solution when procedure will lead to multiple valid solutions. Finally the support system should be capable of double checking the AOM's

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[1] The amount of time allowable to resolve the problem, which is independent of the time required to resolve the problem.

solution as derived from a procedure, and provide feed back to the AOM on a set of evaluation criteria.

Opportunistic Control Mode

Finally we should examine the Opportunistic CCM, which is the lowest level of control that can be supported by a support system. It has a RTH which is tight, and subjectively available time characterized by Hollnagel as “just adequate”. In this CCM, the AOM is not able to fully assess the situation, often having difficulty finding and assessing relevant aspects of the environment.

The Opportunistic CCM is characterized by a person's actions revolving around the most salient cues. Correspondingly both information seeking and coordination are limited to necessary and salient information. In an opportunistic mode iteration will be limited to cases in which solutions generated by the AOM fail to meet minimum criteria.

Unlike the Strategic CCM, AOMs in the Opportunistic CCM will not have the time required to specify the situation thoroughly enough to enter it into the SS, nor will they have the time necessary to double check that any SS-generated solutions resolve the schedule disruption appropriately. As both time and information are scarce in the Opportunistic CCM, the aspects of the task which are appropriate for automation are those which are well defined, such as solution evaluation and execution.

To support this CCM a SS should be able to evaluate the solution generated by the AOM by making a small number of important attributes salient to the AOM. This evaluation is especially important if any of the attribute's pre-set minimums were not met by the solution (which may be the case). The SS should also aid the execution of decisions.

Research Outline

In order to test the hypotheses set forth in this paper, a prototype SS for airline operations with multiple modes corresponding to the three CCMs described above is being designed. The design method we are using is Contextual Design [1] because of its emphasis on understanding the work first and better redesigning the work, thereby fully integrating the automation into the work. The authors are planning on implementing and testing the resultant prototype with actual AOMs. Previous work by the authors has not found any observable CCM indicators which would enable the SS to automatically adapt to a user’s CCM. However, individuals have been able to self-assess their CCM to some degree [3]. We are therefore planning to allow the SS users to determine which of the SS modes they use and when they switch between them. We plan to use an experiment with AOM as participants to evaluate the effect of matching the SS with the AOM’s CCM on performance and workload.

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