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Design of Support Systems for Dynamic Decision Making in Airline Operations

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Abstract— **To date, there has been very little research conducted on the design of support systems for dynamic decisions environments, such as airline operations. The paper discusses the idea that the regulation of dynamic systems has implications for both"internal" and "external" dynamic systems with respect to the human operator. Hollnagel's Contextual Control Modes are suggested as a framework for designing such support systems, noting that they can identify requirements specific to different contextual control modes.**

I. Introduction and Motivation

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) 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, cancelations, 'aircraft swaps' and the use of reserve crews to minimize the impact of such disruptions.

Airline operations strives to regulate the schedule of the aircraft, flight crew, and cabin crew within the airline. AOMs operate within an environment in which:

- The overall goal is to regulate a dynamic system
- A series of activities are required to reach and maintain the overall goal
- Individual activities are dependent on the outcome of previous activities
- Task parameters are continuously changing in response to changes in the environment
- Tasks must be accomplished in real time

The AOM work domain is particularly interesting as a dynamic system because of the current interest in expanding the use of optimization techniques in airlines to operations. Specifically, there has been much interest in the operations research (OR) community on using mathematical programming to improve airline recovery from irregular operations [1]. The aim of these algorithms is, first, to generate a set of feasible solutions, and, second, select the solution that optimizes 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. With over 10% of daily operations considered to be irregular, even small performance improvements in the work of AOMs could potentially translate into significant revenue. What is lacking is a coherent support system in which to implement these algorithms.

To date most support systems have been fielded in static or slowly evolving dynamic environments. In these environments the challenges facing support system designers include how to deal with uncertainty in situation assessments. Dynamic environments add to these challenges a wide range of time constraints within which actions must be taken, as well as interdependence between subsequent decisions.

Thus, airline operations typify dynamic systems, defined here as those requiring a series of actions, including decisions, judgments, etc, to reach or maintain the overall goal, being dependent on the previous action outcomes, having an environment, which is continuously changing, and requiring that actions be made in real time [2].

In addition to the challenges posed to the design of support systems by the dynamic nature of the work environment, there are further questions imposed by human operator, which include:

- Which activities should the support system aim to support?
- Which aspects of human performance should the system aim to support?
- How should the work be split between the human operator and the support system?
- How should the human and the support system interact?

Traditionally, support systems have been developed to aid in the comparison of multiple decision alternatives based on a set of attributes. These systems have focused on aiding the operator to make the best decision possible based on a model of rational decision making, and were thus dubbed Decision Support Systems. Sophisticated DSS can allow for the weighting of attributes and the automatic calculation of the "best" rational choice according to these weightings.

In the field of airline operations, there has been much interest in creating a DSS where the emphasis is on not only choosing between options, but also on generating feasible or "optimal" options [3] 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 in a form difficult to enter in a DSS. In the case of traditional DSS, the designer has chosen to primarily support the activities of decision making and information gathering. The designer has used a rational model of decision making, split the work such that the human serves as an automation translator and monitor, and limited interaction between the two to a minimum.

Previous research has employed an ethnographic technique, 'contextual inquiry' as described by Beyer & Hotzblatt [4], to model the work performed by AOMs [5]. The contextual inquiry revealed that AOMs' approaches to their work can vary widely. On a day with few disruptions the AOM may consider many possible alternatives to minimize flight delays. He or she 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 AOMs' work processes would need to be capable of accommodating the range of behaviors observed in the contextual inquiry. Unfortunately, traditional support systems do not allow for the different patterns of behavior observed.

In summary, the current models and assumptions upon which support systems are designed are not appropriate for dynamic work environments, and are not consistent with the activities observed there. For example, present AOM support systems focus on supporting decision making behavior alone. Further, DSS design is based on a model of rational decision making, where the required decision making strategy is compensatory decision making [3].

II. Expanding the System Boundaries

A new way to approach the questions present in the design of support systems for dynamic systems is to expand the boundaries of the system to include the human operator. In this way, we can then view the human's work as the regulation of two dynamic systems simultaneously, i.e., the internal system (themselves) and the external system, e.g., the flight schedule. Adopting this approach allows us to confront the challenges which affects both the human and the system simultaneously by examining the contextual aspects which are hypothesized to be an underlying determinant of the choice of control mode.

Over the past few decades, there has been a steady shift in the study of human cognition away from the notion of cognition as a process control system towards a view of cognitive control [6], [7]. In the former, actions and behaviors are determined by the inherent structure of the activity, whereas in the latter "the control of the activity is determined by the sequence of cognitive goals; the sequence of cognitive goals is, in turn, determined by the context: the environment and the previous development" [7].

Traditionally, analyzing human behavior was based on an mechanical system analysis where behaviors of interest were broken down into atomic behaviors, such as judgment, and studied individually [8]. The hope was that understanding each of these atomic behaviors would enable predictions about the behaviors of interest. For example, the past 50 years of decision making research has revealed much about the nature of decision making (DM) and both the task and contextual aspects of DM [2], [9]–[15].

However, if we take decision making as an example of one, well studied, atomic behavior we find that there is growing evidence that individuals employ different decision strategies in response to context. Although the 'when' and 'why' these different decision strategies are used is still the subject of much interest, it has recently been suggested that contextual factors (such as perceived time limits and information availability) may have a large influence over decision strategy selection [10], [16], [17].

One contextual factor which has been identified is time pressure. Examining the effect of time pressure on decision making, it is generally believed that the greater the time available to make a decision the better the decision will be. Maule and Edland stated, however, that there is relatively little evidence supporting these beliefs [9]. Their sentiments have been further echoed by Johnson, Payne and Bettman who concluded that "heuristics, under time constraints, may be even more accurate than a 'normative strategy'. [15](p103)" Maule and Edland concluded that the effects of time pressure on performance depended crucially on the strategy adopted and its appropriateness to the situation [9]. This evidence suggests that the performance of the decision made may be more dependent on the decision strategy adopted than time pressure.

Consequently, there is a demonstrated need to support not only multiple decision strategies, but, if this trend generalizes to other behaviors (i.e. judgment, information gathering, coordination, communication, etc.), then there is a corresponding need to support multiple strategies for a variety of different behaviors in addition to decision making. An even further level of generalization would lead us to believe that not only do the behavior strategies change in response to context, but that the patterns of activities which govern the choice of individual behaviors might also change in response to context.

Supporting a different patterns of activities in response to the context presents a number of questions. First, what are the important contextual features which affect specific behaviors? Second, how do the contextual features affect specific behaviors? Finally, how should a support system be designed to support such a wide variety of behaviors?

To address these questions, let us revisit the idea of cognition as control, an idea examined in depth by Erik Hollnagel [7], [18]–[20]. The concept of cognition as control represents a fundamental break with the traditional notion that cognition can be viewed as a information processing system. The information processing model assumes that human behavior can modeled as a series of actions carried out in a predefined order. Unfortunately, this method has proven inadequate to account for the complexity found in sociotechnical systems [8], [21].

The next generation of models of cognition have consequently eliminated the idea that atomic behaviors are linked together in a specific manner. Instead, the Contextual Control Model (COCOM) state that pattern of atomic behaviors are determined not by any inherent relation between themselves, but rather by the context. "In contrast to the information processing view, [COCOM] focus on the functions deemed necessary to explain orderly performance and is intended to be applicable to a range of systems, including individuals, joint cognitive systems, and complex social-technical systems" [19] (p9). Accordingly the pattern of atomic behaviors can, and are anticipated to, change depending on context.

A specific instantiation of a COCOM has been described by Hollnagel as containing three elements. The first is a model of competence; the second is a model of control; and the third is constructs [7]. Of most interest here is the model of control.

III. COCOM as a Framework for Support System Design

The different patterns of activity seen in the contextual inquiry of AOMs appear to correspond to perception of time and other contextual features such as knowledge of situation. This paper postulates that the same variability in time pressure and other contextual features which cause the AOMs to utilize different patterns of activity also has an effect on the successful implementation of support systems into dynamic environments, such as Airline Operations. The Model of Control devised by Hollnagel provides a useful framework to view the changes in patterns of activity in response to contextual features such as time limit or information availability [7], as it describes a model of control. In the light of expanded system boundaries, it can be viewed as a model of internal control.

The model of control envisioned 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" [7].

To better describe this continuum of control, Hollnagel has developed a classification of four contextual control modes [7]:

- "Scrambled control denotes the case where the choice of next action is completely unpredictable or random." (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... The strategic control mode should provide a more efficient and robust performance, and thus be the ideal to strive for." (p170)

These are characterized by the seven characteristics shown in Table I.

An important aspect of Hollnagel's model of control is the idea that individuals will transition between COCOM control modes to maintain control over a dynamic situation [22], [23]. 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" [7](p194). Several factors are thought to influence transitions between CCMs, including expertise, knowledge, and system interface (ease of information access).

According to the COCOM, a major contextual feature governing an individual's choice of CCM is the subjectively available time. If the subjectively available time is short, actions will tend to be in the 'opportunistic' CCM. However, if subjectively available time is greater an individual will begin to seek additional information, evaluate alternatives, or execute procedures and actions which corresponds to the tactical CCM; if subjectively available time is perceived to be large, an individual will be able to fully explore the situation and evaluate all possible actions, which corresponds to the strategic CCM. This impact of time pressure has been experimentally linked directly to COCOM control modes in dynamic tasks, by both Jobidon et al (2004) and Feigh et al. (in press) who concluded that increased time pressure, i.e., less time to complete the task, corresponds to 'lower' COCOM control modes [23], [24].

Building on the great diversity of models of component actions, including judgment and decision making, COCOM allows for many different patterns of behavior and many different ways of approaching a high level task. This breadth is necessary because observation of airline managers has revealed a wide variety of approaches to the overall task of schedule adherence, including not just how to make a decision, but also which decisions to make, which patterns of communication, coordination, and information seeking to employ, and when and how to apply these actions. Using the framework provided by the COCOM suggests that support systems could be tailored for specific CCM [25]–[27].

IV. Implications/Designing for Multiple Control Modes

Schedule adherence is a high level cognitive activity which includes behaviors such as perception, situation assessment, communication, coordination, analysis, alternative generation and comparison of alternatives. all organized by the worker's internal control [28]. Using the the CCMs we can begin to determine how each of these activities might change under different contexts. For example it can be imagined that an AOM operating in an opportunistic mode, where

TABLE I
COCOM CONTEXTUAL CONTROL MODES

	Strategic	Tactical	Opportunistic	Scrambled
Number of Goals	Several	Several (limited)	One or two (competing)	One
Subjectively Available Time	Adequate	Adequate	Just adequate	Inadequate
Selection of Next Action	Prediction based	Procedural	Association based	Random
Evaluation of Events	Elaborate	Normal details	Concrete	Rudimentary
Event horizon	Extended	Normal	Narrow	None
Plans Available	Pre-defined or generated	Available and used	Negligible or limited	None
Execution mode	Mix of subsumed and feed-back	Feedback (with comparison to expected outcome)	Feedback (with observation of effects on system)	Subsumed

the choice of next action is often heavily influenced by the salient features of the environment, may need the interface to highlight the most relevant information in the environment and then facilitate task execution (in our test case, perhaps identifying the most imminent flight that is 'in trouble' and providing 'one-click' mechanisms to delay or cancel it). On the other hand, an AOM operating in a tactical mode may want their interface to support a common procedure for planning and double checking their task solution. Finally, an AOM operating in a strategic mode may want their interface to support solution 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 the support with task execution and solution checking.

It may be that specific atomic functions dominate the activity observed in the different CCMs. For example, the strategic mode may be dominated by decision making, especially the kind of rational, compensatory decision making described by multi-attribute utility theory. Similarly, we could view the Tactical CCM as being dominated by procedure following behaviors where the decision making just falls out of the procedure and is not really the focus of the work. Further, we could view the Opportunistic CCM as being dominated by judgment and other situation assessment activities. In this case 'decision making' would be much more of a function of the salient features of the environment than of deliberate information gathering and selection between options.

A. *Designing for the Strategic CCM*

The Strategic CCM is the highest level of control, and is often the default mode that SS have traditionally been designed for. It has a resolution time horizon (RTH)[1] which is long and thus a well calibrated worker will perceive subjectively available time which is more than adequate. In this CCM the AOM feels they have time to fully assess the situation, without the need for much information filtering. In a strategic CCM, AOMs can develop multiple feasible solutions on their own, or in conjunction with some support system. They can use information storage devices other than their short term memory. They can store information in a computer or on a piece of paper, e.g. such as lists of resources, options, ideas etc. In a strategic CCM AOMs will also be most likely to deliberately configure their work environments, e.g. taping up options to their monitors, or organizing their computer screens for a specific task.

AOMs will also be able to compare the solutions and iterate multiple 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 separate "optimal" solutions to minimize passenger delay, maximize aircraft usage, or even minimize the number of reserve crews required. In addition, AOMs will be 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 bad weather event. This abstraction of 'thinning' will consequently color all of their future actions.

In the Strategic CCM, the decision 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, which consider the values of each alternative on all the relevant attributes and considers the relative importance (weight) of each attribute, to the equal weight strategy, where the attributes for each alternative are equally weighted so that the relative importance or probability of each attribute is ignored [29].

The SS should therefore support rational decision making strategies by providing a comparison tool which is capable of comparing a large number of alternatives on a number of

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

weighted attributes. While the raw values for each attribute will also be available, the AOM may want to assign weightings to each attribute.

In addition to decision strategies, the mode and level of coordination, number of iterations, time spent on individual activities and extent of information seeking will also vary. In the strategic mode the amount of information sought is expected to be extensive, and consequently coordination is expected to also be extensive as the AOM seeks to take information from a large number of sources and individuals into account. Additionally, the time for iteration and desire to find the absolutely best alternative will be high leading to a large number of iterations with the support system. Likewise, it is expected that the time spent on individual activities will be high as time restraints will not limit the AOMs analysis.

B. Designing for the Tactical CCM

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 subjectively available time limit which AOM feels gives sufficient time to assess the situation and use a procedure, i.e. a familiar sequence of actions to solve the disruption, possibly generating multiple feasible solutions.

In the tactical mode the amount of information sought is expected to be beyond what is immediately observable, but may not be beyond what routine procedure requires. Coordination is expected to be formulaic as the AOM seeks to take information from a limited set of preferred sources and individuals. It is expected that the time spent on individual activities 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 spend much time on any one activity because the procedure may does not include evaluating outcome from the previous activity to determine which activity to undertake next.

The procedure followed in the tactical mode may mediated by the use of a support system. The AOM, while having enough time and information in this CCM to allow the a support system to compute "optimal" decision alternatives, may not fully evaluate them for multiple reasons. First, the procedure they are using would need to accommodate iteration. Second, the large number of decision attributes that are evaluated by the support system to generate a decision alternative is likely to be larger than the small number of attributes that the AOM will be able to use in the Tactical CCM. Finally, the AOM may not have time to iterate with he support system to create an appropriate solution for the small number of attributes that the AOM is interested in satisfying. This does not mean, however, that decision alternatives generated by the support system are valueless, just that their utility may be limited in this CCM.

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 the outcome for each choice is not certain at that point in the procedure. Finally, the support system should be capable of double checking the AOM's solution as derived from a procedure, and provide feed back to the AOM on a set of evaluation criteria.

C. Designing for the Opportunistic CCM

The Opportunistic CCM 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 does not have time to fully assess the situation. In the Opportunistic CCM individuals often have difficulty finding and assessing relevant aspects of the environment. The AOM in an opportunistic mode is not able to abstract the task in to higher level patterns such as 'thinning' or 'increasing fuel load for anticipated reroutes'.

The strategy which best describe the the Opportunistic CCM pattern of activities are a non-compensatory decision strategy called satisficing, where the first minimally acceptable decision alternative is accepted and implemented [29], or recognition primed decision making (RPD), where the domain expert recognizes the situation from a previous experience and uses mental simulation to determine a solution.

The Opportunistic CCM is characterized by a person's actions and decisions revolving around salience, where the most salient cue often garners the most attention. Correspondingly, information seeking is expected to be limited to necessary information and salient information. The amount of coordination in the Opportunistic mode is expected to be limited to only what is necessary. 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 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 in such short supply in the Opportunistic CCM, the aspects of the task which are appropriate for automation are those which are well defined, such as a action execution. Over time, however the AOM may develop expertise in understanding which types of schedule disruptions for which the SS is capable of generating acceptable solutions. Should this expertise develop, the AOM may begin to selectively use the SS solution generation capabilities in the Opportunistic mode.

Otherwise, in this CCM, the SS should evaluate the decision alternative generated by the AOM with the aim of 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 current alternative (which may be the case). It follows then that the SS should aid the execution of decisions, and double check the AOM's decision for unintended consequences.

V. Summary

The availability of computer based support systems for information exchange and e-commerce has huge implications for Airline Operations. As current modernization efforts attempt to further increase productivity and efficiency, increasingly support systems are being devised and implemented in these and similar environments.

These support systems have often been specifically designed to support a single human activity, decision making, and have consequently ignored the other behaviors which are required for successful schedule adherence. This paper also argues that, instead of focusing on supporting the decision making activity in isolation, a broader set of activities should be supported including decision making, judgment, coordination, information gathering, solution generation and decision execution concurrently. The support system should support individuals with selecting and prioritizing their activities so as to accomplish the tasks required for Airline Operations. Challenges include supporting a variety of activities concurrently, supporting activities over a range of time horizons for task completion [3], and supporting multiple activities with varying amounts of information.

In order to meet these challenges a new approach to the design of support systems has been suggested. The approach expands the boundaries of the regulated dynamic system to include the human, thereby acknowledging that the same contextual features that affect the external dynamic system simultaneously affect the human operator. The paper has further suggested that by using Hollnagel's Contextual Control Modes as a framework support systems could be tailored to the support a variety of different patterns of behavior.

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