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Context in human performance models as applied to dynamic resectorization

Savita Arora Verma
San Jose State University

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**CONTEXT IN HUMAN PERFORMANCE MODELS AS APPLIED TO
DYNAMIC RESECTORIZATION**

A Thesis

Presented to

The Faculty of the Graduate Program in Human Factors and Ergonomics

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Savita Arora Verma

August, 2001

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IN HUMAN FACTORS AND ERGONOMICS

A handwritten signature in black ink, appearing to read "Kevin Corker", written over a horizontal line.

(Dr. Kevin Corker – Thesis Chairperson signs here)

A handwritten signature in black ink, appearing to read "Kevin Jordan", written over a horizontal line.

(Dr. Kevin Jordan – Thesis Committee Member signs here)

A handwritten signature in black ink, appearing to read "Louis Freund", written over a horizontal line.

(Dr. Louis Freund – Thesis Committee Member signs here)

APPROVED FOR THE UNIVERSITY

A large, stylized handwritten signature in black ink, appearing to read "Joseph Penel", written over a horizontal line.

ABSTRACT

CONTEXT IN HUMAN PERFORMANCE MODELS AS APPLIED TO DYNAMIC RESECTORIZATION

Savita Arora Verma

The role of the operator in air traffic management is evolving due to introduction of new technology and new tasks through decision support systems. A modeling tool that is sensitive to context is required to predict behavior in the new changing scenario. The present research added functionality to a human-performance-model by defining contextual parameters and their impact on cognitive strategies or control modes using the Contextual Control Model (COCOM). The independent variables- number of simultaneous goals and look-ahead time defined context. The behavior characteristics of the three control modes- strategic, tactical and unplanned were defined using the dependent variables – order of goals, frequency of planning-done, time-pressure, state of goals and workload. In general the model could predict behavior of the operator in the different control modes, while accomplishing dynamic resectorization goals. Other operational concepts in National Airspace for Air Traffic Control can also be explored using the simulation model.

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Introduction

There have been significant changes made in the field of air traffic management and the factors driving these changes have been increase in traffic density, delays, and associated heavy costs. The new initiatives undertaken in the aviation domain have brought in new technology, decision-support tools and have also led to changes in the procedures for work. One of these aiding procedures requires resectorization in advance of high workloads and use of different cognitive processing strategies on part of air traffic controllers. Thus a fundamental change in the work performed by pilots and air traffic controllers is imperative. There is a need for a modeling tool that predicts performance of the operators in the new changing context. None of the current human performance models can predict the impact of context on cognition, so the present research focuses on building an added functionality into the modeling tool – Man Machine Integrated Design Analysis System (MIDAS).

To make MIDAS sensitive to work environment that can be a used for predicting behavior, context and cognitive strategies called control modes in this thesis, have been encoded into the modeling tool. Context is defined as number of simultaneous goals and look-ahead time or planning time and they affect the cognitive strategy or control mode (strategic, tactical and unplanned) the simulated operator selects.

The application domain for testing MIDAS with its new added functionality will be dynamic resectorization. Federal Aviation Administration (FAA) has identified three external factors - weather, traffic density and special use airspace (SUA) that have a strong impact on the air traffic controller's work environment. These three contextual

factors are known to increase the ATCo's workload, which eventually affects their performance and creates limitations on the amount of air traffic that can be controlled with minimum number of operational errors. Dynamic resectorization (DR) means that the sector monitored by the air traffic controller will reconfigure and this configuration may be a solution to problems caused by weather, traffic or status of special use airspace. Hadley et. al. (2000) studied sector boundary adjustments across facilities and posed some operational questions regarding DR such as when to reconfigure? How often to reconfigure? The authors also recommend the use of simulations or human performance models to address issues like communications, procedures etc. for DR or time required for an operator to adjust to the reconfiguration of sector boundaries.

A model is a schematic representation of a system, or phenomenon that consists of some known properties and can be used to further explore its interaction with the environment or another system. Human performance models like MIDAS have been successfully used to predict human behavior in large complex systems. MIDAS comes from a background in human information processing and optimal control model and neither of those have behavioral sensitivity to context. MIDAS is an agent-based system, which has physical representation of the world in terms of the equipment, and anthropometrics of the operator. It has the perceptual and internal cognitive environment represented in the form of the updateable world representations (UWR) and various modules on perception, attention and so on. But it lacks a module that incorporates context or external environment, which can accordingly influence the internal cognition and subsequent goal achievement.

The inclusion of context into the human performance model (MIDAS) for the present study has been based on Hollnagel's model of context called COCOM (Contextual Control Model). The contextual model of cognition consists of a model of competence together with a model of control. The model of competence refers to available plans, activity sets or templates that are derived from one's skill base. The model of control is concerned with planning action in the immediate future. Hollnagel defines four levels of control – Scrambled, Opportunistic, Tactical and Strategic. The levels of control are different in terms of the degree of planning done in each of these control modes. Scrambled mode is marked with zero planning or random selection of activities, Opportunistic mode is concerned with the salient features of the interface, but planning is restricted to the present context. There is more planning in the Tactical mode, but it is of limited scope, whereas in the strategic mode the operator is actually acting out of well-formed goals and intentions. According to Hollnagel (1993), the variables that affect the context and control mode are number of simultaneous goals, event horizon, availability of plans, mode of execution and so on. Only two of these variables – simultaneous goals and event horizon were incorporated into the human performance model.

Purpose

The purpose of the research is two-fold. First, it aims to incorporate context and its influence on control exercised by the simulated operator in the human performance model. Second, it aims to perform a task analysis for DR and then encode rules and procedures for the same. The two within subject (independent) variables – number of

simultaneous goals and event-horizon or look-ahead time, will represent context. Characteristics of behavior in the control modes were represented by the dependent variables – order of goals, frequency or times the planning module is evoked, ratio of time used to time available (time pressure), state of goals/activities, and workload. It is important to note here that independent variables and rules associated with them do not simply generate the expected behavior in MIDAS. These rules interact with other micro models of MIDAS like attention, perception, and other activities encoded for the operational processes of the airspace to generate behavior. Thus the resultant behavior in MIDAS is not deterministic but an amalgamation and interaction of various interacting systems.

The purpose of the research will be to implement and verify Hollnagel's contextual control model and assess whether the contextual variables - number of simultaneous goals and event-horizon have an effect on the control mode selected by the operator. The study will also evaluate the behavior of the operator in the different control modes as specified by the dependent variables. The control modes will have different values for the dependent variables – order of goals, times planning module is evoked, ratio of time used to time available (time pressure), state of goals/activities, and workload. The application domain for testing the above-mentioned hypotheses will be DR-scenarios that include procedures for handoffs, accept-handoffs, point-outs, communications and other sector management activities that take place within a sector.

Hypotheses

Two sets of hypotheses were generated for this study. The first set (Hypotheses 1.1 - 1.2) focused on the relationship between the two independent variables – number of simultaneous goals and event horizon time on the model's control processes. The second set (Hypotheses 2.1-2.5) focused on the behavior of the human performance model in relation to its action as an air traffic controller. The hypotheses and sub-hypotheses generated for the study are as follows:

Hypothesis 1.1

It is predicted that as the number of simultaneous goals increases, the control modes will change from strategic to tactical to unplanned.

Hypothesis 1.2

It is hypothesized that as the event horizon time decreases, the control modes will change from strategic to tactical to unplanned.

Hypothesis 2.1

It is anticipated that as the control modes change from strategic to tactical to unplanned, the order of goals will get more varied.

Hypothesis 2.2

It is anticipated that as the control modes change from strategic to tactical to unplanned, the frequency or times the planning module is evoked in the simulation will increase.

Hypothesis 2.3

It is predicted that as the control modes change from strategic to tactical to unplanned mode, the ratio of times-used to time-available (time pressure) will decrease.

Hypothesis 2.4

It is anticipated that as the control modes change from strategic to tactical to unplanned, the state of goals will be mostly “aborted or resumed”.

Hypothesis 2.5

It is hypothesized that as the control modes change from strategic to tactical to unplanned, the workload calculated will increase.

Hypotheses 2.5.1 through 2.5.2 were generated to address the complex relationship between the different components of workload.

Sub-Hypothesis 2.5.1

It is hypothesized that as the control modes change from strategic to tactical to unplanned, the visual workload will increase.

Sub-Hypothesis 2.5.2

It is hypothesized that as the control modes change from strategic to tactical to unplanned, the auditory workload will increase.

Sub-Hypothesis 2.5.3

It is hypothesized that as the control modes change from strategic to tactical to unplanned, the cognitive workload will increase.

Sub-Hypothesis 2.5.4

It is hypothesized that as the control modes change from strategic to tactical to unplanned, the psychomotor workload will increase.

Definition of Terms

Human Performance Model. A model is a representation of the real world or some aspect of the same. Simulations serve many purposes like aiding in the engineering design process or identification of operator error. Psychological models are constructed primarily to explore or help validate psychological processes, whereas the engineering models of human behavior aim to achieve practical engineering processes e.g. manufacturing or nuclear processes. The engineering models incorporate psychological findings to achieve their objective.

MIDAS. Man Machine Integrated Design Analysis and System is a human performance model. It has an object oriented agent-based architecture. It has a symbolic operator model (SOM), which contains a module for perception, attention, cognition and a scheduler. It has the world represented in the form of an Updateable World Representation (UWR). What it lacks is a connection between the representation of context and its influence on cognition i.e. changes in control modes. The present research aims at building the bridge between context and cognition in MIDAS.

Context. Many researchers have defined context or an environment model in different way. Hollnagel has defined context in general as the factors of work environment that influence human performance. In particular he describes the contextual factors as number of simultaneous goals, event horizon, availability of plans (based on skill levels), use of feedback. The present study will only evaluate the two within-subject variables – number of simultaneous goals and event-horizon or look-ahead time. The number of aircraft in the scenario represents the number of simultaneous goals, whereas

the look-ahead time has been encoded as the total time available to accomplish plans for any aircraft while it is in the sector.

Control Modes. Control refers to the extent of planning that is done by an operator. Hollnagel defines four control modes- scrambled, opportunistic, tactical and strategic modes. The extent of planning increases from current context to long term as the control modes change from scrambled to opportunistic to tactical to strategic modes. For the purpose of this study, opportunistic and tactical modes have been combined into a tactical mode, since their implementation into MIDAS would be based on similar rules. Thus behavior in the three control modes – unplanned, tactical and strategic have been explored with the help of the five dependent variables – order of goals, times planning module is called, time used to time available, state of goals or activities (completed, aborted and remembered) and workload calculation.

Sector. In an operational sense, it means the unit of airspace delegated to a controller or a controller team.

Dynamic Resectorization. Dynamic resectorization refers to a change in the boundaries of a sector that is being monitored by the ATCo. Dynamic resectorization is the solution proposed for handling the peak workloads associated with traffic, weather and special use airspace. In this study task decomposition of a dynamic resectorization process has been done, which includes handoffs to the next sector, accept-handoffs, communication, point-outs and other sector management activities within a sector.

Free Flight. Free Flight is an advanced flight concept, which refers to relaxation of constraints like schedule control, route control etc. This can change the flow of traffic

in the sectors and dynamic resectorization may be required to handle that.

Literature Review

Air Traffic Management Applications

The Federal Aviation Administration (FAA) has been considering increased application of automation to air traffic control as a means of achieving minimum accidents and maximum efficiency of air travel. However, these goals can be potentially in conflict, the FAA has expressed its resolve that under such circumstances, safety will remain the number one priority. The FAA has recommended an acceptability criterion for safety and efficiency that includes the assessment of interaction between safety and efficiency factors. It also includes taking into account the cognitive tasks of controllers in balancing the pressures of both safety and efficiency in tactical and strategic decisions and behavior; and lastly to take into account the variables associated with different air control options, regions, and facilities (RTCA, 1995, 1996).

FAA's resolve for safety becomes more prominent in the light of the concept called "Free Flight" (RTCA, 1996). The Requirements and Technical Concepts for Aviation (RTCA) has defined Free Flight as a new air traffic management concept that proposes a relaxation of rigid airway structure and in-trail spacing of aircraft. This relaxation of constraints was motivated by studies that suggest that reduction in schedule and route constraints (calculated for US National Airspace – NAS) could save the airline-operators as much as 3.5 billion US dollars annually (Coularis & Dorsky, 1995). This relaxation on air traffic constraints will aid in the achievement of FAA's strategic goals of improving accessibility, flexibility, and predictability of the aviation system (RTCA,

1995). The relaxation will include schedule control, route control, and potentially separation authority in some phases of flight, for example self-separation in enroute and oceanic operations. The current restrictions imposed on the aviation system have been made in order to assure a controlled regimented environment because it is through control that safety is achieved. Free Flight concept not only means introduction of new technology and more automation but also the assessment of the impact these changes will make on the procedures of work. The relaxation of constraints in operations will involve changing the procedures for both ATCo (Air Traffic Controller) and Flight crew. The dynamic interaction between the airborne systems and ground control forms critical coupling that will guide the design and evaluation of such systems.

The rules associated with the transition from an air traffic controlled system to a free flight operating system are being currently established. Currently, the task structure of ATCo requires them to monitor and control a particular sector, which is unique in terms of its shape, size, terrain, and procedures. Flemming, Lane, and Corker (1999) examined the effect of control authority on operational measure like handoffs, accept handoffs, and subjective measures of workload. They found that there were significant differences in the operational and subjective measures, communication time, and that operational errors increased as the percent of self-separation by aircraft increased, in turn decreasing the control exercised by ATCo. Thus the Free Flight concept is likely to bring with it a plethora of new technology and new procedures. It will firstly make the process of decision-making distributed. Secondly, it will make concept of operations dynamic, which would mean that human operators (pilots, air traffic controllers, and airline

operators) must monitor and predict the changes in the distribution of authority and control.

It is also likely that Free Flight will introduce changes in sector configurations based on anticipated workloads (changed by traffic flows) of the ATCos in a particular sector. This will have a considerable impact on the “context” under which the ATC operate. The most important parameters of context as defined by FAA are weather, traffic density, and special use airspace (SUA).

Dynamic Resectorization

Airspace configurations consist of sector combinations, boundary locations, and the designation of Special Use Airspace (SUA) areas. Currently, the altitude and route restrictions placed on the aircraft are formalized by the static sectorization of airspace. The term “sector” is used to mean, in an operational sense, the unit of airspace delegated to a controller or a controller team. Currently, resectorization takes place in a limited sense, to manage peak traffic flows and peak controller overload; the sectors (mostly belonging to the same facility) are split into smaller volumes of airspace. Severe weather, turbulence, communication equipment failures, and similar emergencies divert traffic off their normal or preferred route. Sometimes, there are more aircraft requesting routing through a particular area than it would be acceptable for an operation to handle. Allowing airspace users more flexibility in determining flight routes, and the implementation of Free Flight proposals will further exacerbate these pressures over preferred routes or sectors (RTCA 1995a, 1995b; Planzer & Jenny, 1995). Based on the forecasts of air traffic demand in the next few years, it is predicted that traffic density in

most of the sectors of the National Airspace System (NAS) will substantially increase (Honeywell, 1997; Wickens, Mavor, Parasuraman, & McGee, 1998). Eurocontrol (1998) made similar predictions regarding European Airspace; they expect the traffic to double between 1997 and the year 2015. Such increases in traffic demand will require initiatives in the aviation domain to increase capacity.

It is suggested that in order to avoid sector overload, the Traffic Management Unit (TMU) may implement initiatives like En Route Spacing Program (ESP), mile in trail restrictions, or a ground delay, to alleviate the problem. But these initiatives will bring delays to the aircraft and leave the service provider with business losses. Instead of implementing a ground delay or rerouting the aircraft and possibly causing overloads in nearby sectors, adaptive airspace management techniques like dynamic airspace boundary adjustments or dynamic resectorization have been proposed (Eurocontrol, 1998). A preferred and efficient solution to the problem could be dynamic airspace boundary adjustment or dynamic resectorization, which could theoretically optimize ATC resources and lead to a more balanced system workload.

The increased flight flexibility associated with Free Flight could lead to changes in traffic flows that may cause changes in the current airspace sector configurations. To accommodate Free Flight, the sectorization of airspace will also need to be more flexible, especially if controllers are responsible for safe separation. Carlson and Rhodes (1998) described some adaptive airspace management practices currently in use in the operational environment. Some involve the lateral reconfiguration of sectors within the same facility. In other instances, facilities delegate some of their airspace to neighboring

facilities. In most of the cases, predefined airspace configurations were used and feedback to the survey conducted by the researchers indicated that no serious operational problems were associated with these practices.

An initial demonstration (Honeywell, 1997; Goldberg & Eberlin, 1997) of the benefits of dynamic resectorization was provided by a fast-time simulation-adjusting sector boundaries in response to representative traffic flows of an actual environment, the Salt Lake City en route center (ZLC). Results indicated that adaptive sectors offered more user-preferred routing, thus reducing delays and enhancing aircraft fuel efficiency.

Pawlak, Bowles, Goel, and Brinton (1997) evaluated the impact of lateral resectorization on controller performance. They conducted a human-in-the-loop simulation in which pairs of controllers were responsible for two adjacent high-altitude sectors above Cleveland. Each of the ten controllers was assigned four scenarios. A cross of two independent variables - sector dynamics and sector set, defined these four scenarios. The sector dynamics varied in two ways - continuously changing and interval condition. In the continuously changing condition, the sector boundaries were adjusted as often as necessary. In the interval condition, boundaries were optimized only at 15-minute intervals. There were also two types of sector set (limited and unlimited). During the limited set condition, only seven possible new sector configurations could be used, whereas for the unlimited sector set condition, any boundary configuration was possible.

Results from this study indicate the following recommendations for future research. It is suggested that first, procedures for changing sector boundaries must be

formalized to ensure that transitions proceed smoothly. Secondly, automated enhancements can be used to minimize the amount of controller-to-controller coordination needed to accommodate a sector change. Thirdly, the frequency with which sector boundaries can change should be constrained by the complexity of traffic situation and the complexity associated with making each boundary change. Fourth, unless significant Air Traffic Management (ATM) system changes are made, the magnitude of boundary changes will probably be restricted by current radio frequency limitations and controller specialization in certain areas of airspace. Fifth, new sector configurations may need to be limited to a pre-defined set so that controllers can receive appropriate training for each configuration. Lastly, added flexibility to accommodate weather systems or unusual traffic pattern may also be beneficial.

In airspace with high traffic density, there is a higher probability for conflicts and increased controller workload. Airspace sectors that can be restructured to make use of the complete resources of the ATCo have the potential to increase overall system safety, provide a more balanced workload for the controller, and reduce costly delays. But this restructuring of the sector has implications for change in the roles and responsibilities of ATCo and it is highly probable that their contextual-control behavior will change. The current human performance models discussed in the next section cannot handle changes related to contextual control behavior.

Human Performance Models

A model is a representation of the real world or some aspect of the same. Simulations serve many purposes like aiding in the engineering design process or

identification of operator error. Psychological models are constructed primarily to explore or help validate psychological processes such as attention, cognition, perception etc., whereas the engineering models of human behavior aim to achieve practical engineering processes like manufacturing, processing control etc. The engineering models incorporate psychological findings to achieve their objective.

Full mission or hi-fidelity simulations are commonly used in safe environments (Campbell et. al., 1997). These techniques provide a realistic evaluation of the human-machine interaction but can become very costly. Also, they cannot be used for the assessment of dangerous situations due to ethical considerations. Unlike the traditional design process, which considers ergonomics or usability late, modeling can be used at an earlier stage in the development of a process, product, or technology. Laughery and Corker (1997) indicated that human performance modeling could also avoid dangers associated with new technology by incorporating past empirical data into the simulation software. Thus the human performance model does not require the human operator to physically interact with the system, which diminishes the risks and costs associated with system experiments.

Background of Human Performance Models.

The seminal work done in Human Performance Modeling was with manual control models and quasi-linear models, in the times when process control industry was the norm. Most Human Performance Modeling effort was concentrated in the domain of human tracking behavior in a closed-loop person-machine system (Craig, 1947). These models were termed Quasi-linear because the models were derived from the engineer's

assumption that the operator's control behavior in perceiving an error and translating this error to a response can be modeled as a linear transfer function. This error is only an approximation of linear behavior and therefore has been designated as quasi-linear (Wickens, 1992). In performing such experiments, data in tracking control studies led Craik to conclude that the human operator behaves basically as an intermittent correction servo. This means that the human operator monitors the relationship between input and output of a system and if desired output is not being achieved, then the operator corrects the level of input i.e. controls the system in such a way that the desired output is achieved.

This formulation was further refined by McRuer and Krendall (1957) and summarized by McReur and Jex (1967). The resultant description of the human operator is a good servo with bandwidth constraints and crossover frequency response characteristics. The human operators in tracking system tasks operate as a good servo because of their ability to act as an error-nullifying device or as a servomechanism, which is a transfer function that amplifies the control input to achieve a desired output. They have a consistent forcing function and a consistent response in control. A consistent forcing function ensures that in the process of controlling the system, desirable responses are forced out of the system. The human can function effectively if the control order (position, velocity, rate) and the rate of change in the forcing function are consistent with the physical characteristics of neuromotor control (reaction time and neuromotor lags). If the control order and forcing function are not within the perceptual, cognitive and neuromotor constraints of the operator, then aiding systems can be developed to augment

control stability and/ or offset control lags or “predict” system behavior and display that prediction to human operator. The model of human operator as servo guided the design of aiding systems for operator in that task (Birmingham & Taylor, 1954).

In continuation of the engineering based models, Kleinman, Baron, and Levison (1971) developed a manual control model in the early seventies. This model got developed for a multitask environment (multi-input and multi-output) where there is some kind of noise in observation or in perception due to conflicting tasks or criteria for every task. The human operator has to assess the state of the system in a noisy environment. Then the human operator generates control outputs to minimize some criteria, with the exception that rate of change gets penalized. This change introduces sluggishness in the system, called the motor noise with a covariance proportional to the variance of the control output.

These engineering models were developed to quantify different aspects of human performance so that the usability of a technology could be predicted to some extent by performing an analysis of a task network. Engineering models have primarily focused on the individual components making up human behavior. Cognitive modeling concepts made an attempt to integrate different engineering models to predict complex human behavior. The engineering based models of human performance permit a priori predictions of human behavior of a very restricted set of responses for specific tasks. Human Performance modeling was traditionally used to predict sensory processes (Gawron, Laughery, Jorgenson & Polito, 1983), or for human motor response like Fitt’s law (Fitts & Posner, 1967) and many aspects of cognition (Newell, 1990).

Another cognitive model called supervisory control model was defined for processes that are semi-automated or respond very slowly. With such automation, it is not necessary for humans to devote full attention to the process, such that control actions are not continuously produced. This allows the human operator to control multiple processes. In situations where each individual process is automatically controlled, the human operator can be viewed as a supervisor whose role includes monitoring the processes to ensure that the automatic controls are working. The supervisory function also includes adjusting the reference points to which the automatic controllers are regulating the processes, and intervening in the case of failures and emergencies (Ferrell & Sheridan, 1967). In this mode the operator stands back from the direct manual control of the systems and has managerial functions like setting goals, training, observing performance, intervening etc. The requirement for local autonomy of a function could be distance/ time relationships, bandwidth limits, or efficiencies gained by removing the human from critical path of control (Laughery & Corker, 1997).

Following the paradigm of control representation consistent with the human operator(s) mode of control in a system, has been the representation of the “internal models and cognitive function” of the human operator in complex control systems. These systems are a hybrid of continuous control, discrete control, and critical decision-making. These systems are also characterized by critical coupling among control elements that have shared responsibility among humans and machines in a shifting and context sensitive function (Billings & Woods, 1995). It is these hybrid control systems that have been undertaken to represent the “internal models and cognitive functions” of

the human operator in complex control systems. The nature of a human operator's interaction with a system often changes the behaviors required for completing a task. Often, this change in interaction is a result of changing technologies and automation (Laughery & Corker, 1997).

Baron and Corker (1989) discuss other models that were developed to represent the multi-variable, multi-task environment like DEMON (Muralidharan & Baron, 1980 as cited in Baron & Corker, 1989) and the Dynamic Decision making model (DDM). Both these models extend the theoretic control approach to modeling. Another model PROCRU (Procedure Oriented Crew Model) was developed (Baron, Zacharias, Muralidharan & Lancraft, 1980 as cited in Baron & Corker, 1989), which was most comprehensive in the range of coverage of human activities in monitoring and control of a large system. The model consists of a set of "procedures" to be performed in some optimizing fashion. At any given time the task chosen is one that will maximize the gain of the operator with the given state of the world. The model does not incorporate any changes in the way tasks may get performed as a function of time available and time required to execute a task while the operator attempts to maximize his or her gains in the given "situation".

The classical information processing views have emphasized on the sequential progression through the internal mechanisms of cognition and that they are dependent on a stimulus or event to start the processing. Another metaphor called the cognitive processing emphasizes the overall performance rather than the mechanisms of performance. The cognitive viewpoint does so because behavior is not simply a function

of input and system (mental) states and also because the complexity of the inner mechanisms is too high to be captured adequately by a single theory.

Hendy, Liao, and Milgram (1997) developed a Human Information Processing model, which was a function of time-used and time-required for prediction of workload. They computationally defined an information-processing model to assess workload by combining time and intensity effects. The researchers described the model as “*Time pressure* drives an effortful process which causes the information processing system to adapt by decreasing the *task difficulty* which is associated with the *Task Load* (in terms of bits of information)”. Task difficulty was equated with bits of information to be processed), and capacity (equated with the processing rate). The researchers argue that humans adapt to excessive processing load by changing processing strategies so as to reduce the amount of information to be processed or to increase the time available before an action has to be emitted. They used the ratio of total amount of information to be processed in time available in their Human Information Processing model. The researchers later validated their Human Information Processing model by performing an experiment with cognitive tasks in a simulated ATC environment. They observed that the ratio of information to be processed and time available had a significant effect on errors (near misses, collision with other aircrafts and so on). Thus the Human Information Processing model developed here is a quantitative description of the human processor used for prediction of operator’s workload and does not focus on the way tasks get done or the control mode an operator adopts as a function of time or information to be processed.

The world of human performance models can be separated into two classes:

Reductionist models and First Principle models (Laughery & Corker, 1997).

Reductionist models use human-task sequence as the primary organizing structure. They utilize a task-networking modeling approach, where a comprehensive task decomposition or task analysis is undertaken and used to establish the sequence of tasks performed to achieve some system goal. They are referred to as Reductionist because they reduce higher-level goals into lower level tasks. The second class of human performance models is based on First-principle approach. This approach of modeling human behavior is structured around an organizing framework that represents the underlying goals and principles of human performance. For example, these models might directly represent processes such as goal-seeking behavior, task scheduling, sensation and perception, cognition and motor-output. MIDAS (Man-machine Integration Design and Analysis System) is the human performance model that will be used for the present study and the model is designed using First-principal approach. MIDAS has been chosen as the human performance model because it offers a framework in which interplay of its micro models such as perception, attention, activity sets, working memory etc. produce simulations of behaviors that can be compared to empirical data. The present research requires a tool that can predict the behavior of air traffic controllers in different aviation scenarios like dynamic resectorization, and MIDAS with its predictive abilities will be quite useful.

MIDAS.

Man-machine Integration Design and Analysis System (MIDAS) is a set of interactive and integrated software modules, editors, and analytic simulation tools

(Corker & Smith, 1993). The system is designed using an object oriented software paradigm with architecture based in agent-actors theory. The model has a Functional and a Structural architecture. The Functional architecture of the full MIDAS system depicts that MIDAS can operate in three modes - Specification Mode, Interactive Mode, and Simulation Mode. Inputs about the flight crew station, mission tasks and operator characteristics are provided to the system using the Specification mode. MIDAS allows the user of the system to perform analysis in two ways - Interactive mode, which uses scenario independent layout and animation of displays and controls for assessment of visibility and legibility, examination of anthropometrics, and analyses of cockpit topology and configuration. The other analysis path for MIDAS is that of dynamic simulation. Dynamic Simulation mode provides facilities whereby specifications and mission can be run together. The simulation mode integrates the system and runs it together generating an output of activity traces, task loads timelines, and information flow analyses and mission performance measures.

In terms of its Structural Architecture, MIDAS is built as an object oriented software, the various objects or components of the system interact with each other using an agent-based architecture. Each agent has a message interface that determines how messages have to be delivered between various agents or objects. Each agent has a biographer that keeps track of what messages are received, sent, what actions were taken and so on. The biographer generates most of the outputs that are critical to the examinability of MIDAS.

MIDAS also has a Physical Component and Human Operator Agents. The

Figure 1. Pictorial Representation of Man Machine Integration Design and Analysis

Physical Component agents include representation of equipment and other aspects of the physical world like terrain etc. The Human operator agents are represented as Symbolic Operators that execute and supervise both automated processes and vehicular control, thereby generating appropriate responses. This Symbolic operator also has a physical representation of the operator in terms of anthropometrics and has cognition represented in the modules of perception, attention, memory etc. The symbolic operator also has an Updateable Representation of the World (UWR), which is actually accomplished with a structure called semantic net. Semantic net is a structure containing objects called nodes that represent concepts. Other components of the human operator include activity representation, which is composed of activity preconditions, satisfaction conditions, workloads (visual, auditory, cognitive, and psychomotor resource requirements), priority and duration of each activity. Rule-based activities, decision activities and a scheduler are also a part of the human operator agents. It is important to note that although MIDAS has the representation of “context” in the form of UWR, it is deprived of rules that depict the influence of context on information processing. Thus MIDAS does not contain a component that specifies which control mode will the human operate in, as a result of contextual influence.

In the specifications for a system model Laughery and Corker (1997) pointed out that a system model must contain a human performance representation, equipment representation, interface requirements, control requirements, logical and physical constraints and a simulation driver. They also specified a set of questions that each of these components should answer. For instance, the human performance component

should answer questions like – what time or duration of performance are important? What time or initiation of human performance can be defined and what resolution of behavior is required? What time profiles of human management including task management, goal management and load management structures are expected? These questions essentially mean that the effect of speed-accuracy factors on cognition and in the way humans control the system should be taken into account. MIDAS has representations of all the components specified by Laughery and Corker but its Human performance representation does not effectively answer all the questions posed by the researchers. Specifically, the interaction of context and control does not get addressed.

Context

Context has been defined and researched in various different ways. FAA defines weather, special use airspace and traffic density as the most important contextual variables in air traffic management. Vicente (1997) emphasized the need for research in human factors to strive for more ecologically valid results by including the real world variables into the experiments. Just the way researchers emphasize having a representative population sample, there is need to place an equal emphasis on the representativeness of the task variables. Kirlik (1991) explains as to why context has not been included in the current human performance models. He points to the fact that experimenters often feel the need to simplify their environments. Also, they do not make any distinctions between the description of external environment and the internal representation of the same environment. It is a known fact that the way experts and novice represent the environment is different. Kirlik also notes that rarely are researchers

forced to think across a variety of environmental conditions, so they consider context as implicit.

Context, Control and Human Performance.

Dunn, Brown, and McGuigan (1994) formulated a framework to include the effect of context on human performance and called it the ecology of human performance (EHP). Their framework was built for occupational therapy theory, practice, and research. According to the theory, the interrelationship between the person, his context (physical, social, cultural), and task structure has an influence on human performance. As context shifts behavior required to accomplish the goal also shifts. EHP has a non-linear, dynamic perspective. Dynamic principles describe systems as multiply determined, complex, and self-organizing (Thelen, 1992 as cited in Dunn, Brown & McGuigan, 1994) and air traffic management is one such dynamic system. They eschew schemas and static programs, and emphasize variability. Persons tend toward certain modes, behaviors or patterns however small changes in the person or context alter these tendencies. Although EHP was used for occupational therapy, the description of the system and the behavior of the human in that dynamic system are also characteristics of the Air Traffic Management system. Other studies on human performance have looked into displays, and interfaces and their representation of context.

Woods (1991) discussed the use of representation aiding as a useful strategy for aiding human performance in complex tasks. The rationale behind the use of representative aiding follows from Simon's (1969) findings as cited in Woods (1991) that "solving a problem simply means representing it so as to make the solution transparent".

Among factors that are important in representation aiding, Woods (1991) specifies that the representation of both the task and goal context is important as an aid for decision-making.

Continuing the discussion on representativeness, Norman (1993) states that the study of cognition was mostly concerned with the symbolic representation of the world, which is also referred to as “the-representation-knowledge” problem. The problem of understanding human cognition still looms large due to the dense information in the world, complexity of the world and the impossibility of observing all the relevant aspects of human cognition. The complexity of world comes from the fact that the world is unpredictable and our sensory channels have limited capacity. Norman further explains that there are two approaches to study cognition; one is concerned with symbolic processing and it focuses on the processing structures of the brain, thus all actions are happening inside the head. The second approach called the “situated action” approach to cognition is concerned with structures of the world and how it constrains and guides human behavior. Thus situated action emphasizes the role of situation (context) on cognition and action. It takes into account historical influences, social interaction, culture, the environment, and minimizes the importance of internal cognition.

Many earlier studies, in understanding context and its relation to cognition or control mode, were concerned with conceptualizing error on study of the failure of human performance. Woods (1988) explains the basis for error by analyzing the constituents of the problem-solving world. He noted that when experiments are reduced to a laboratory in search for precise results, the researcher runs the risk of eliminating the

critical features of the world that drive behavior. This creates the problem of deciding what constitutes an effective stimulus. To solve this problem Gibson (1979) and Dennett (1982) (as cited in Woods, 1988) have pointed that a semantic and pragmatic analysis of the environment-cognitive agent relationships with respect to the goals/ resources of the agent and the demands / constraints of the environment need to be undertaken.

Woods (1988) continued to define the problem solving world as composed of an interaction of three mutually constrained factors (apices) – the world to be acted on, the agents who act on the world and the external representation through which the agent experiences that world. The world and its characteristics place cognitive demands on the agent.

A study undertaken by Parasuraman (1997) clearly depicts that the experience of the operator with automation defines the mode or style in which automation is controlled. According to Parasuraman, the usage of automation is dependent on the operators' trust and confidence in automation. Their trust depends on the reliability of automation. If automation fails too often, they under-use or disuse automation and if their experience with automation is good then they over utilize it or misuse automation. It can be interpreted that context in this case is defined by the reliability of automation and it has a considerable influence on human performance. Both under utilization and over utilization of automation can be a cause of human error.

Rasmussen and Vicente (1989) have proposed an error taxonomy based on cognitive control mechanisms. Rasmussen (1983) discusses the three levels of cognitive control and the adaptation processes associated with learning at each level. The first

level of control – Knowledge based control is a mode in which the operator faces novel and complex situations and has to experiment with the situation. For purposes of problem solving, experiments are necessary to update the mental model, and to test hypotheses. The second level of control called Rule-based control requires the development of effective know-how, rules-of thumb, and informal cues that only discriminate between the perceived alternatives for action in the given familiar context according to the law of least effort. The third level of control is the skill-based control, where sensorimotor patterns (overlearned routine tasks) develop during training, but sensorimotor schemata are continuously updated as a response to the time-features of the task environment under the influence of speed-accuracy tradeoff. Rasmussen pointed that in real-life work conditions, the operator will consider requirements from several different tasks on a time-sharing basis. Consequently, the performance will be sensitive to interference between control mechanisms belonging to otherwise unrelated-activities. This interference will generate errors and the unattended activity will be more vulnerable to error. Similarly, current schemata will be more sensitive to frequently used rules and errors will take place whenever there will be a dearth of resources. There have been other cognitive models that have some component of context embedded in them.

Contextual Control Model (COCOM)

A contextual control model implies that actions are determined by the context rather by an inherent relation between them. It is therefore not possible a priori to describe procedural prototypes or natural relations between actions. This viewpoint assumes that the choice of the next action at any given time is determined by the context.

The model therefore concentrates on how control of the choice of next action takes place rather than deliberating on whether certain sequences are more proper or more likely.

The contextual model of cognition (Hollnagel, 1993) consists of a model of competence together with a model of control. The model of competence is necessary because every person has certain competencies corresponding to the basic cognitive functions in decision making, which are applied according to the current needs and demands. In the model of competence the possible actions provide a set to choose from in a given context. Possible actions may be found on different levels of aggregation, i.e. mixture of simple and composite actions. Common to them is only that they are ready to use in a given context. In this thesis, model of competence has not been addressed, because it will introduce a between-subject variable and the present research effort is scoped to assess the influence of within-subject variables like number of simultaneous goals and look-ahead time available to a human operator, on the control modes as defined by the model of control.

The control function may be defined in many ways. The most important issue is the granularity of the description and the mode of functioning. The Law of Requisite Variety can be used for modeling cognition, where one can obtain guidance for how the control function is accomplished and for how much the control functions should be able to do. In the contextual control model the pre-conditions, which are part of how actions are described, constitute the basis for tactical or strategic planning of actions.

The model of competence consists of an activity set and a template set. The Activity set must include the various competencies (the "ready" actions). These need not

be elementary actions, they will rather be the actions that the person is capable of carrying out and which are meaningful in the existing context. The template set is another part of the model of competence, which constitute a set of templates or patterns for carrying out actions - cognitive as well as physical. A template denotes a specific relation between two or more actions, which in a given situation can determine the order in which they are carried out. The templates may be plans (pre-defined or produced by the task), procedures, rules, guidelines (heuristics), strong associations, or in fact anything else that may serve as a guide for performance. In the contextual control model the control mode will determine which particular template is used. Seen by themselves, templates may appear to be very similar to procedures. Thus in a sense the procedures can be represented as templates.

Control is essential to organize the actions in the short term, i.e. within a person's event horizon. The essence of control is planning what to do next and this is influenced by the context as experienced by the person. The outcome of planning prescribes a certain arrangement of the competencies, hence a certain sequence of the actions. It is important to note that the sequence is constructed during goal execution rather than pre-defined.

The degree of control a person will have over a situation can vary. The model of control discusses four different control modes. The Scrambled Control mode denotes the case where the choice of next action is completely unpredictable or random. The corresponding situation is one in which the person is in a state of mind where there is no reflection or cognition involved, but blind trial and error. This type of performance is

marked with lack of control. This is typically the case when people act in panic. The scrambled control is the zero point of control and acts as a good anchor point.

The Opportunistic Control mode corresponds to the case when the next action is chosen from the current context alone, and mainly based on the salient features of the interface rather on more durable intentions or goals. It is opportunistic not because the person is exploring an alternative but because there is no time or possibility.

Opportunistic control corresponds to a heuristic that is applied when there is a knowledge mismatch either due to inexperience or lack of knowledge or due to unusual state of the environment.

The Tactical Control is characteristic of situations where the person's performance is based on some kind of planning, hence more or less follows a rule or known procedure. 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. The planning is of limited scope or limited range, and the needs taken into account may sometimes be impromptu.

The Strategic Control means that the person is considering the global context, using a wider event horizon. He is looking ahead at higher-level goals - either those, which have been suspended, and have to be resumed or those, which according to experience or expectations may appear in the near future. The person will be less influenced by the dominant features of the interface, but still be hampered by inadequate system support, e.g. for information retrieval. In strategic control, there will be an immense influence of knowledge and skills of the person, and the level of competence.

The functional dependencies between the task steps are important, simply because they are taken into account during planning.

A common aspect of human performance in a variety of situations is the ability to “muddle through” (Hollnagel, 1992). The term “muddle through” was introduced by Lindblom (1959) (as cited in Hollnagel, 1992) to describe an alternative to the conventional theories of decision-making. Hollnagel expresses that muddling through may be a common approach used during Information Input Overload. The reactions to information overload have been used to hypothesize the characteristics of behavior such as order of goal handling in different control modes.

According to Hollnagel (1993), the variables that affect the context and control mode are number of simultaneous goals, event horizon, availability of plans, mode of execution and so on. The number of goals and their relation to event horizon, which are also the independent variables for the present study, can be compared to the action stacks described in Carnino, Nicolet, and Wanner’s (1990) human operator model.

Carnino, Nicolet, and Wanner (1990) described the human operators’ model, with the control, operating, piloting, and command loops representations of their behavior to be characterized by voluntary uptake of information. After the situation (context) has been analyzed, the operator model computes the differences in the collected and desired values and based on those builds a plan of action. Thus succession of envisioned actions is memorized and constitutes what is called an action stack. The choice of action depends on the specific mission and value of the parameters followed up, and on risk management model. If the operator thinks that the situation is stationary and no

interference will occur over the next few hours, she will make up a stack of only few actions. If on other hand she considers the situation to be critical, she will program numerous actions in the stack and will "unstack" it as fast as possible.

A stationary world can be likened to one with less interruption from environment (more time available) and low stacking of actions to a less number of simultaneous goals. Similarly, a confusing situation is one where there is less available time for more actions or goals to be performed. Based on this logic one can hypothesize that the ratio of time available to every action or goal is the highest under strategic control mode and the lowest in the unplanned mode.

Flemming, Lane, and Corker (1999) studied the effect of shift in separation authority on controller performance in complex control center. Their results obtained for both the operational measures like handoffs, and subjective measures of workload can be explained with Hollnagel's theory of contextual control. In the study the controllers managed simulated air traffic in the Ocala sector of Jacksonville center. Controllers managed traffic under conditions of full positive ground control and two levels of separation authority being ceded to aircraft (20% and 80% self-separation traffic) while the ATCo had all responsibility for the traffic. It was found that there was an increase in communication load and subjective workload for ATCo operating under 20% self-separation traffic due to their need to exchange intent information. But there was a decrease in communication load accompanied with heightened subjective workload under the 80% self-separation condition because here the ATCo had to constantly monitor the moves of the aircraft in the absence of intent information. Thus the ATCo had an

increase in the number of multiple goals and due to the absence of intent information, their event horizon or "look-ahead time" was reduced, pushing them into a reactive or opportunistic control mode as postulated by Hollnagel. They operated in a strategic mode under full positive control. Based on this observation, Hollnagel's contextual control theory can be used to provide an operational definition for context and control modes. The research findings of Flemming et. al. (2000) have also been used to hypothesize the characteristics of behavior in terms of workload for the control modes.

The intent of the present research is to study the relationship of context (as defined by event horizon and number of simultaneous goals) on the control mode (the information processing and perceptual-motor level). Although Hollnagel defined context using many variables like number of simultaneous goals, event horizon, availability of plans, execution mode, nature of feedback, this study will be manipulating the first two, which are also within-subject variables. Only, three control modes scrambled (unplanned), tactical and strategic modes will be used for the study, since the distinction between tactical and opportunistic is very fine and use similar rules would be used for their implementation in MIDAS.

Using Warner's (1990) logic for action stack management, which is dependent on the dynamic nature of the environment (having more interruptions), a ratio of event horizon (time) per goal can be used to operationally define context. It can be stated using prior evidence that having the two variables - time and goals is likely to result in some speed-accuracy tradeoff, a classic example is provided by Fitt's law (1954). The dependent variables in the study used to characterize behavior in control modes are order

of activities, number of times planning module is called, ratio of time-used to time-available, state of goals and workload calculation.

Based on Hollnagel's postulations on "muddling through" during high input information load, it was hypothesized that order of activities will be the least varied in the strategic mode and variation will increase as the control mode changed from tactical to unplanned. Similarly based on Hollnagel's postulate on choice of next action in COCOM and Carnino et. al. (1990) theory on action stacking management, it was hypothesized that activities will scheduled or planned least number of times in the strategic mode and that this number will increase as one moved to tactical and unplanned mode. Hendy's (1997) human information processing was used to hypothesize that the ratio of time-used to time-available will be the lowest in strategic mode and increase towards the tactical and the unplanned control mode. It was hypothesized that state of goals will be mostly in incomplete state in the unplanned mode due to shedding of tasks or goals due to Selection or Sequence errors as described in Norman's taxonomy of errors, whereas less errors or more goals will be complete in the tactical and strategic modes. Based on Flemming, Corker, and Lane's (2000) study on workload estimation, one can hypothesize that less workload will be calculated for the strategic mode and that it will increase for tactical and unplanned mode.

According to Hollnagel's theory, as the number of goals decrease the control mode will move from unplanned mode to tactical to strategic mode. Similarly as the event horizon increases control mode moves from unplanned to tactical to strategic mode. If the operator behaves in an unplanned mode for least ratio of time per goal, in a tactical

mode for next larger ratio and in a strategic mode for the highest ratio of event horizon time per goal, the behavior can be explained using Hollnagel's theory of contextual control.

Identification of Contextual Parameters

To identify the levels of the two contextual parameters – number of simultaneous goals and event horizon, the ratio of time required for every successful completion goal was used. Three studies were found useful for identification of the above-mentioned ratio and these have been discussed hereunder.

Study 1: Cardosi (1993)

The sources for independent variable's level identification included a communication study by Cardosi (1993), who studied the time to complete a successful communication between an Air Traffic Controller and a Pilot. The communication was a meaningful message containing a maneuver required for traffic avoidance transmitted to the pilot by an Air Traffic Controller (ATCo) in the en route environment. The time taken to transmit the message was broken down into three components- duration of the ATCo's message, time between the end of the controller's message and beginning of pilot's response and duration of pilot's acknowledgement.

The time taken to complete communication was analyzed for periods of high and moderate verbal workloads. The workload was determined by counting the number of controller communications per hour. Also within each workload level, half the tapes assessed were from high altitude and rest was from low altitude. Forty-nine of the transmissions were high workload and thirty-one were from moderate workload, but there

was no significant difference in the total time for the transmission in the two-workload conditions. The results of the study showed that total time required to transmit a message successfully took 4 – 40 sec as can be seen in Table 1.

It is clear that the variability in the scores is very high. Thus taking the conservative value 20 seconds which is on the higher end of the range, one can deduce that to successfully complete the goal of communication most of the times a minimum of 20 seconds is required. This was used to infer values of look-ahead time in the different control modes in the Method chapter. However, the limitation of using this study is that it does not completely represent all the tasks handled by the ATCos in the post-Dynamic Resectorization. Also, Cardosi (1993) qualifies her study by calling the samples of time periods being in the high and moderate workload range. Since there is no significant difference between the moderate and high workload periods, the time period samples are taken to come from one workload zone.

Study 2: Remington et. al. (1999)

Another study on conflict detection time under Free Flight condition by Remington, Johnston et. al. (1999) was used to compute levels of variables for the current evaluation. The authors of this study examined the time to detect conflict under various conditions of conflict geometry – convergence angle and length of time before a conflict occurred (complexity), traffic density (number of aircraft) under free flight conditions (presence or absence of altitude restrictions and fixed routes). This study examined the effect of free flight and is useful for the current study on dynamic resectorization (DR), since DR would also take place under free flight conditions.

Table 1

The mean and SD of communication time (seconds) for different types of messages in the study by Cardosi (1993).

Type of message	Mean	SD	95 th percentile
Traffic avoidance	9.9	4	23
Turns not for traffic	10.4	5.9	21
Traffic advisories	10.96	7.26	18
Average across type of message	10.42	5.72	20.6

The mean response times for conflict detection ranged from 15 to 31 sec as a function of increasing number of aircraft, from 18 to 28 sec for conflict angle and from 20 to 25 sec for conflict time. For the easiest combination (least number of aircraft, short conflict time, small conflict angle) the mean response time was 10.7 sec versus 48 sec for the hardest combination of conditions (maximum number of aircraft, long conflict time, large conflict angle). Conflict detection times are taken as equivalent to event horizon or look-ahead for the conflict resolution goal. Thus it was inferred that if the look-ahead time available per goal becomes less than 10.7 sec, the operator would behave in an unplanned mode. It is evident from the above mean values that their range exists between 15 and 31 sec (which is considered as the time period for the tactical control mode) and look-ahead time above 31 sec per goal was considered for Strategic control mode. Again the limitation of using this study is that it does not represent all the tasks handled by ATCo under Dynamic Resectorization.

Study 3: Subject Matter Experts

Other sources for inferring the levels of variables included discussion with Subject Matter Experts (SMEs). Although the SMEs found it hard to quantify time required per unit goal, they were instead asked to quantify their comfort zones in time required per unit goal. The two SMEs who participated in the discussion, mentioned that the comfort zones are a function of - the tasks to accomplish (number and priority), the number of aircraft being handled at any given time, complexity and the experience level of the controller.

They mentioned that tasks, number of aircraft, and complexity will increase the

time (more event horizon time) that a controller would need to feel comfortable and level of experience would decrease the time required by the ATCo to feel comfortable about his / her work. The tasks and the number of aircrafts contribute to the independent variables – number of simultaneous goal. We defined comfort levels as equivalent to the control modes that are investigated in the present evaluation.

The least comfort zone was considered equivalent to the unplanned control mode and was given a look-ahead time per goal value of less than 10s, moderate comfort zone (tactical mode) ranged between 10 to 30s, and the high comfort zone (strategic mode) was over 30s as the time available per goal. These numerical values provided by the SMEs are based on their respective experience levels and are not representative of all the ATCos or SMEs.

All the above-mentioned sources were used to identify the value for the ratio of event horizon time and simultaneous goals and correspond it to the expected control mode behavior. The ratio of time per unit goal was then used to identify the three levels of the two independent variables. These ratio of time per unit goal was also used to trigger the rules of the control mode switcher, corresponding to the control modes (unplanned, tactical and strategic), which have been elaborated in the method section.

Study Goals

There were two main goals for the current research. The first goal was to develop contextual control modes into the human performance model. This will make the model more sensitive to shifts in context, which was represented by event horizon time and number of simultaneous goals. These contextual shifts accordingly change the control

modes or behavior of the symbolic operator in human performance simulation model. The second goal for the current study was to develop scenarios for dynamic airspace resectorization procedures that involve communications, handoffs, and related sector management activities in a sector. Dynamic resectorization is a concept that is being currently investigated by the FAA to problems associated with high workload. The procedures for dynamic resectorization will be used for testing contextual-control mode switching introduced in the first goal.

Method

To make the human performance model sensitive to contextual control modes, two dimensions of context - number of simultaneous goals and event horizon; and the rules that trigger shifts in control modes were encoded into the model- MIDAS. As discussed in the Literature Review chapter, Hollnagel's (1993) theory on contextual control modes (COCOM) was used to operationally define the context and control modes. The domain of study here was procedures involved in dynamic resectorization, which were mainly handoffs and communications related to them.

Participants

There are no human participants in this study. The human performance simulation model – MIDAS has a symbolic operator model (SOM), which is representative of human behavior. MIDAS includes representations of human cognitive, perceptual and motor operations. In other words, the modules on perception, attention, activity selection, and task loading allow simulated human behavior to emerge as the scenario under study unfolds itself. Thus every run of the simulation transforms the

information differently for every scenario because performance times and activity scheduling follow a probability distribution, and produces a new set of emergent behavior that can be aptly regarded as a participant. The simulation was executed 15 times, but one simulation run was discarded to insufficient data written by the software, thus 14 sets of simulation behavior were used for analyses.

Instrumentation

The human factors computer-aided engineering system called MIDAS (Man Machine Integrated Design and Analysis), which was a result of the joint Army-NASA Aircrew/Aircraft (A3I) program initiated in 1985, was the main instrument used in the current study. MIDAS system is built around object oriented software structure and it works on IRIX platform on SGI machines. This model supported the contextual control mode switching rules; and was also used to code the scenarios and procedures involved in dynamic resectorization.

Procedure

The contextual- control modes were encoded into MIDAS; these were operationally defined using Hollnagel's Contextual Control Model (COCOM). The independent variables defining context are number of simultaneous goals and look-ahead time or event horizon. To define the levels of the independent variables, different studies were explored and finally the ratio of look-ahead time required for per unit goal was identified. The dependent variables – order of goals, frequency or times the planning module is called, ratio of time used to time available, state of goals, and workload were used to define behavior in the three control modes (strategic, tactical, and unplanned).

These are clearly elucidated (see Table 3) and have been elaborated upon in the section on dependent variables.

The next step in the process of setting up the study required defining rules for switching control modes in the simulation. The ratio of look-ahead time per unit goal was used to identify rules for control mode switches. Most previous researchers have focused on the ratio of intensity of information to time available (Hendy et. al., 1997). Instead the ratio of time required to successfully complete a goal was used in the present study. This ratio in a way represents time pressure, but takes the goal or amount of information to be processed into account. These rules were written in pseudo-code language to facilitate its coding into the simulation software.

The task and goal decomposition of dynamic resectorization was performed using the rules and handbook of En-route Air traffic controllers and the same was validated with the Subject Matter Experts (SMEs). Every identified task was then assigned time duration and VACP (Visual, Auditory, Cognitive Psychomotor) workloads. Subsequently, rules and procedures for the tasks identified for dynamic resectorization scenario were also formulated. Dynamic resectorization entailed communications, handoffs, point-outs and other sector management activities that occur after the sector boundaries have been resectorized. The task decomposition, their associated rules along with time durations and VACP workloads have been outlined in Appendix A and Appendix B. A generic sector scenario was developed using another dynamic density study (Kopardekar & Morrow-Magyritas, 2000). The generic scenario consisted of designing a 128 x 128 miles sector, which was a simplified version of Denver Sector-25.

The sector had four routes – two in the north-south direction and two in the east-west direction. The aircraft entered at the rate of 1 aircraft per minute and the maximum number of aircrafts was 20 (see Figure 2).

After the introduction of the contextual variables, control modes, task decomposition of dynamic resectorization and scenarios, the simulation model was executed in the Monte-Carlo fashion 15 times, where performance times and scheduling behavior follow a probability distribution; and outputs (dependent variables) were recorded.

Design

Independent Variables

The two within-subject independent variables (number of simultaneous goals and event horizon) of the study were the contextual variables as defined by Hollnagel's (1993) COCOM theory. The operator in the simulation model is being referred to as the participant in the present evaluation. The variables had three levels - number of simultaneous goals could be 2, 3 or 4 and the Event Horizon could be 60-120s, 120-180s or greater than 180s. To encode Event horizon or look-ahead time, the total look-ahead time was computed. The value obtained was 16 minutes, calculated as the total amount of time available in a sector, by multiplying the 128-mile sector with the speed of the aircraft as 8 miles per minute. Thus after conversion to seconds the total look-ahead time would be 960 seconds. The look-ahead time available for every aircraft is a function of the number of aircraft and a formula that normalizes the number of aircraft to airspace volume is used, which is as follows:

Figure 2

Generic Scenario encoded into MIDAS

Look ahead time = $960 - (960 * (\log (\text{number of aircraft in sector to the base } X)))$ where
X = maximum number of aircraft possible in the sector (in our case it is 20).

Various sources were used to identify the ratio of event horizon time required for the successful completion of every goal, which was then used to identify the three levels of the two independent variables - number of simultaneous goals and event horizon and when the control modes would get switched between strategic, tactical, and unplanned control modes. The different studies used to identify the levels of the independent variables have been discussed in Literature Review and their results are discussed hereunder:

Study 1: Cardosi (1993)

The sources for independent variable's level identification included a communication study by Cardosi (1993), who studied the time to complete a successful communication between an air traffic controller and a pilot. It was found that 20s is the time required to successfully complete the goal of communication most of the times.

Study 2: Remington et. al. (1999)

Another study on conflict detection time under Free Flight condition by Remington, Johnston et. al. (1999) was used to compute levels of variables for the current evaluation. Conflict detection time was taken as equivalent to look-ahead time for the conflict resolution goal. Thus it was inferred that in the unplanned mode the look-ahead time available per goal would be less than 10.7 sec. The tactical mode would be associated with a range of 15 and 31 sec and look-ahead time above 31 sec was associated with strategic control mode.

Study 3: Subject Matter Experts

Subject Matter Experts (SMEs) quantified their comfort levels, which are defined as equivalent to control modes. The least comfort zone was taken as equivalent to the unplanned control mode, and was given a look-ahead time per goal value of less than 10 sec, moderate comfort zone (Tactical mode) was established between 10-30 s and the high comfort zone (Strategic mode) was taken over 30 s as the time available per goal.

Study 4: Time calculations

A mean value for the time duration of goals decomposed for dynamic resectorization scenario was computed to get a sense of time required to successfully complete all the tasks of a goal without interruptions. The calculated mean was 22 s and was validated by Cardosi's (1993) study on communication time analysis, where the mean time to successfully complete the communication goal was also 20 s.

Levels of Independent Variables

For purpose of encoding the two independent variables into the simulation, number of simultaneous goals was encoded as number of aircraft and the look-ahead time was encoded as per the formula.

Thus the two independent variables get combined into the ratio of time required for every goal and the control modes are driven by a single variable, i.e. the above-mentioned ratio. The rules for the control-switcher involve checking the ratio of time per goal (as shown in Table 2) to decide on the control mode the simulator's operator should be in. The rules for these control modes have been outlined in Appendix C. For the purpose of rules defined for control switching in the simulation, the mean time duration

to complete the goal (22 s) and the look-ahead time durations (15s, 15-30s or greater than 30s) provided by conflict detection study and SMEs were combined, resulting in the rules shown in Table 2. The expected control modes for every level of the independent variable has been shown in the experimental design table (see Table 3).

Dependent Variables

This study aimed to examine the effect of contextual variables on control mode behavior in the dynamic resectorization domain. The hypothesized behavior in each of the control modes was explained using the five dependent variables. The dependent variables were – the order in which goals are performed, the frequency or number of times the planning module is evoked, the ratio of time-used to time-available, the state of the goals/ activities (completed, aborted, or remembered) and the workload calculation. Initially nature of errors was one of the dependent variables, but instead state of activities/ goals (completed, aborted, dropped, or remembered) was used because the state of the activities/goals is an index of level of interruption and has been considered as a precursor to errors. Norman (1981) and Reason and Mycielska (1982) provided a taxonomy of error based on their underlying causes; they hypothesized that slips and mistakes might lead to errors. Slips are based on well-formed but poorly executed plan, that take place due to omissions of activities or intrusion of unwanted acts. Thus the state of activities (completed, aborted, remembered) is likely to lead to different kinds of errors. The values of these dependent variables are determined as values relative to the control mode rather than as absolute values. A model of dependent variables and their relative values for the different control modes are shown in Table 4.

Hypotheses

Two main sets of hypotheses were generated for the evaluation of context on control modes. The first set of hypothesis focus on control mode switching and are a validation of the rules incorporated into the simulation model.

Hypotheses 1

The first set of hypotheses examined the effect of the number of simultaneous goals and event-horizon on the control modes. These hypotheses were evaluated by using the frequency of the control modes in the each of the nine conditions (3 (number of simultaneous goals) x 3 (event horizon))

Hypothesis1.1

It was hypothesized that as the number of simultaneous goals will increase the operator will move from strategic to tactical to unplanned control modes.

Hypothesis1.2

It was also hypothesized that the operator's control mode will move in the same direction (Strategic to Tactical to Unplanned) as the look-ahead time or event horizon decreases (see Table 2 and 3).

Hypotheses 2

The second set of hypotheses, which tested the effect of control mode on a set of dependent variables, had five sub-hypotheses. In other words they addressed the behavior of a human under similar situations. The dependent variables of interest were order of goals, number of times planning module was evoked by the simulation, ratio of time used to time available, state of the goals and workload calculations obtained from

Table 2

Rules for control mode switching based on time duration required per unit goal.

Time duration /goal (time to complete + planning time)	Control Mode
Less than 37 s	Unplanned mode
Between 37 and 52 s	Tactical mode
Greater than 52 s	Strategic mode

Table 3

Experimental Design Table with the three levels of the two within-subject variables – event horizon (sec) and number of simultaneous goals

Event Horizon (sec)	60-120 s	120-180 s	>180 s
Number of simultaneous goals			
2	30-60 (mostly unplanned)	60-90 (tactical and strategic)	>90 (mostly strategic)
3	20-40 (mostly unplanned)	40-60 (mostly tactical)	>60 s (strategic)
4	15-30 (mostly unplanned)	30-45 (mostly unplanned)	>45 (tactical and strategic)

Note: Values in the cells are range values for the ratio of time (sec) and number of goals. The brackets show the expected control mode.

Table 4

Model Dependent Measures

Dependent Variable	Control Modes		
	Unplanned	Tactical	Strategic
Order of goals	More variability	Less variability	Least variability
Frequency planning done	Most	More	Least
Time Pressure	High	Moderate	Low
State of goals	Mostly completed	Frequently completed	Rarely completed
Workload calculation	High	Moderate	Low

Note:

Order of goals performed by the operator in the simulation.

Number of times planning module refers to the times an activity gets scheduled in the scheduler module of the simulation.

Time pressure - Ratio of time used to time available gives a sense of sufficiency of time available experienced by the operator.

State of goals considered as a precursor for errors based on Reason and Mycielska (1982) taxonomy of errors, they can have three possible values- completed, aborted, or remembered/resumed.

Workload calculations in the simulation are based on the VACP workloads taken separately for each activity and combined together to obtain a measure of overall workload.

the outputs of MIDAS. These dependent variables are likely to take unique combination of values for the different control modes.

Hypothesis 2.1

It was hypothesized that the order of goals performed by the operator will change as a function of the control mode the operator is in. This change in control mode will be marked by a significant change in the order of goals performed by the operator. The strategic control mode will be marked by a less varied order of goals, whereas the order of goals will be more varied in the tactical mode and the most varied in the unplanned control mode.

Hypothesis 2.2

It was anticipated that change in the control mode from strategic to tactical to unplanned control mode would be marked with a change in the number of times planning module is evoked by the simulator. The number of times planning module was evoked depends on the way the scheduler schedules and prioritizes the goals and the related activities. A strategic control mode was likely to call the planning module minimum number of times, whereas the planning module will be called moderately in the tactical mode and most frequently in the unplanned mode. There would be a significant difference in the number of times the planning module is called in the different control modes.

Hypothesis 2.3

It was also predicted that the ratio of time-used to time-available is likely to be significantly different for each of the control modes. The ratio of time-used to time-

available is regarded as Time Pressure (Hendy, 1997). The time pressure experienced would be the lowest in the strategic control mode, moderate in the tactical control mode and high in the unplanned control mode. There would be a significant difference in the ratio of time-used to time-available in the different control modes.

Hypothesis 2.4

It was anticipated that the state of goals or activities in the three control modes would be significantly different. Initially it was hypothesized that there will be different kinds of errors in the three control modes, but instead state of goals was used because the state of the goal can be considered as a precursor of errors. The classification of errors based on underlying causes describes slips, which refer to poor execution of plans as precursors of errors (Norman, 1981 and Reason and Mycielska, 1982). The state of the goals can take three values – completed, aborted, or remembered. A completed activity is one that gets successfully completed; an aborted activity gets dropped or abandoned before completion; and a remembered activity is one, which gets resumed after being remembered. It is hypothesized that the frequency of completed goals will decrease as the simulated operator moves from the strategic control mode, to tactical to unplanned control mode.

Hypothesis 2.5

The calculated-workload is anticipated to significantly increase as the operator moves from the strategic to the tactical to the unplanned mode. The workload measures are calculated as averages of VACP across the activities performed by the operator. Thus the calculated workload for a strategic mode is likely to be the lowest, moderate for the

tactical mode and highest for the unplanned control mode. A complex interaction between the control modes and components of workload is also anticipated. Another set of sub-hypotheses was generated to address the complex interaction between control modes and workload-components i.e. visual, auditory, cognitive, and psychomotor workloads.

Sub-Hypothesis 2.5.1

It was hypothesized that the visual load will be lowest in the strategic mode and moderate in the tactical mode, and the highest in unplanned mode.

Sub-Hypothesis 2.5.2

It was hypothesized that auditory load will be lowest in the strategic and will increase as one moves from the strategic mode to the tactical to the unplanned mode.

Sub-Hypothesis 2.5.3

It was anticipated that the cognitive load would be the lowest in the strategic mode and increase in the tactical mode and further increase in the unplanned mode.

Sub-Hypothesis 2.5.4

It was hypothesized that the psychomotor load would be the lowest in the strategic mode and increase as the operator moves to the tactical mode to the unplanned mode.

Analyses

Both descriptive and inferential analyses were performed for each of the dependent variables. To analyze the first set of hypotheses, where the effects of number of simultaneous goals and event horizon on control mode were tested, a chi-square was

computed for two 3 x 3 tables. Instead of calculating expected frequency, the total number of cases were divided by the number of cells (nine in this case) to obtain an equal frequency, because if all the control modes were equal with regard to goals and time, they would have equal occurrence in every cell of the 3 (control modes) x 3 (number of goals) and 3 (control modes) x 3 (event horizon time) table.

For the second set of hypotheses, standard descriptives and one-way ANOVA were performed for the each of the dependent variables where the control mode was the independent variable. Tukey's post-hoc tests of contrast were performed to assess the difference between the three control modes on the various dependent variables.

Results

The output of Air-MIDAS was used to assess the effect of contextual variables on control modes. The output of 14 runs of the simulation was used and each run was considered as an individual. The results of the current evaluation are presented in two sections – the first section describes the validation of rules and the second section describes the characteristics of behavior in each control mode.

Validation of Rules

This set of analyses focuses on the validation of rules built into MIDAS using the number of simultaneous goals and look-ahead time or event horizon. These hypotheses are used to verify the implementation of COCOM into MIDAS by testing two hypotheses i.e. Hypotheses 1.1 and 1.2. Hypothesis 1.1 stated that as the number of simultaneous goals increase the operator would move from strategic to tactical to unplanned control

modes. Hypothesis 1.2 stated that as time decreases, the control mode changes from strategic to tactical to unplanned.

To analyze the first set of hypothesis, chi-square was computed for the two 3 x 3 tables. Table 5 and 6 shows the observed frequency of control modes in the two 3 x 3 contingency tables. Outliers were not included in the two frequency tables. A chi-square was computed for a 3 x 3 contingency table comparing the frequency of control modes (strategic, tactical and unplanned) for number of goals and a significant effect was obtained ($\chi^2(4) = 9.67, p < .05$). Another chi-square was calculated to analyze the effect of look-ahead on frequency of control mode occurrence, a significant effect was computed ($\chi^2(4) = 36, p < .001$). A significant interaction was also found ($\chi^2(16) = 82.5, p < .001$) for the combination of the number of simultaneous goals and event horizon time on the control mode an operator is in. Thus contextual variables in Air Traffic Management like weather, traffic and status of special use airspace will change the number of simultaneous goals and event horizon for the ATCos and eventually change the control modes they operate from. The characteristics of behavior in the control modes can then be used to determine operational issues linked with dynamic resectorization.

Characteristics of Control Mode behavior

The second section has analyses of the effect of control modes on the characteristics of operator behavior. This section presents the analyses of Hypotheses 2.1 through 2.5; it describes the descriptive analyses and one-way ANOVA on the dependent variables with control modes as the independent variable.

Table 5

Observed frequency of control modes by number of simultaneous goals

Number of goals	Control Modes		
	Strategic	Tactical	Unplanned
2	8	8	3
3	5	11	7
4	3	5	4
Total	16	24	14

Table 6

Observed frequency of control modes by event horizon time

Event Horizon (sec)	Control Modes		
	Strategic	Tactical	Unplanned
60-120	8	16	12
120-180	4	6	2
> 180	4	2	0
Total	16	24	14

Hypothesis 2.1 predicted that there would be less variability in the order of goals in the strategic mode over the tactical and unplanned mode. The order of the goals is defined by the number of times the goals get switched or resumed in the scheduler. Figure 3 shows the frequency of resumption of goals in every control mode. Resumption of goals/activities is an index of the orderliness of goals, the resumption of every goal is marked with switching from another goal. Chi-square computation for frequencies of goal resumption in the control modes depicted a significant effect. ($\chi^2(2) = 1134.31$, $p < .001$). Thus control modes have a significant effect on the number of times goals in the dynamic resectorization domain get resumed. A common reaction to information overload is frequently resuming goals because there is paucity of time available to complete a goal uninterrupted.

Two simulation runs were randomly picked for more qualitative analyses on orderliness of goals. Figure 4 and Figure 5 show goal switching for the two randomly picked runs. One can see from the two graphs (Figure 4, 5) that the variability is the lowest in strategic mode and tactical mode and the highest in the unplanned mode (seen by the number of spikes). It is important to mention here that as the simulation time progresses, more aircraft are introduced into the simulated scenario, leading to more number of simultaneous goals, and more random ordering of goals. In some cases the variability in the tactical and strategic mode is almost equivalent, they seem to be in most part of the simulation switching between two goals at any given time.

Hypothesis 2.2 was tested for the number of times the planning module is called in the three control modes. It was predicted that the planning module would be evoked

Figure 3

Frequency of resumption of goals across control modes

Figure 4

Qualitative analyses for order of goals for Simulation Run#5

Note. See Appendix E for the goal# and corresponding goal name.

Figure 5

Qualitative Analyses for order of goals for Simulation Run#9

Note. See Appendix E for the goal# and corresponding goal name.

maximum number of times in the unplanned mode, and that the frequency would increase as the control mode changed from strategic to tactical to unplanned. Calculating the number of times an activity gets scheduled or prioritized in the scheduler module collected data for this hypothesis. There is a significant effect of the number of times planning is done in the three control modes ($\chi^2(2) = 170561.8, p < .001$). It is evident from Figure 6, where the frequency of planning module invocation across control modes is plotted that there is a difference between the tactical and unplanned mode, and also between the strategic and unplanned mode, but there is no difference between the strategic and tactical modes. Thus control modes have a significant effect on the amount of planning done for the goals and tasks accomplished for dynamic resectorization. The frequency of planning done for an activity or goal shows that queuing is being used to match demand and capacity differences that occur due to the changes in the work environment under dynamic resectorization.

Hypothesis 2.3 predicted that the ratio of time-used to time-available would be the lowest in the strategic control mode, moderate in the tactical control mode and highest in the unplanned control mode. Hendy et. al. (1997) described the ratio of time used to time available as an index of Time pressure used for the development of a workload model for Human Information Processing (HIP). Table 7 depicts the descriptive statistics for the three control modes. There was no significant effect of the control modes on this dependent variable – ratio of time used to time available ($F(2,78) = 2.554, p < .084$), where time-used refers to the time duration the control mode was in and time-available refers to the look-ahead time in that control mode. It is clear from Table 7 that both

Figure 6

Frequency of planning module invoked across control modes

unplanned and strategic modes experience the same level of time pressure while performing tasks for dynamic resectorization. High time pressure is known to change the cognitive strategies the operator uses to deal with the demanding work environment.

The influence of control modes on the state of the goals was also evaluated as per Hypothesis 2.4, which stated that the frequency of completed goals would decrease as the simulated operator moves from the strategic control mode, to tactical to unplanned control mode. The state of goal or activities (completed, aborted, or remembered) was likened to number and nature of errors based on the classification of errors provided by Reason and Mycielska (1982). The authors provide a classification of errors based on underlying causes, such as slips, which refer to poor execution of plans as the precursors of errors (Norman, 1981; Reason & Mycielska, 1982). Thus the states of the goal are considered as pre-cursors to errors. For instance, abortion of goals may lead to sequence errors (change in sequence) (Norman, 1983). A remembered state of goal signifies a state where the goal was resumed after being remembered; this may lead to selection errors. Selection errors occur where a wrong goal gets selected due to different reasons like habit, also known as “strong but wrong rules”. A Chi-square test of independence was calculated for a 3 x 3 contingency table (State of goals x Control mode). The observed frequencies are shown in Table 8. A significant interaction was found for control mode and state of goals ($\chi^2(4) = 3833.17, p < .001$). The state of the goals is affected by the control mode the simulated operator is operating from, in the dynamic resectorization domain. Figure 7 shows the bar graph for the observed frequencies of the three states of goals (completed, aborted and remembered) for the three control modes.

Table 7

Descriptive statistics for the ratio of time-used to time-available by control mode

Control Mode	N	Mean	SD
Strategic	27	0.58	0.12
Tactical	39	0.26	0.19
Unplanned	51	0.52	0.22
Total	81	0.60	0.67

Table 8

Observed frequencies for the State of the Goal by Control Mode

Control Mode	State of the Goal		
	Completed	Aborted	Remembered
Strategic	2222	42	38
Tactical	470	6	14
Unplanned	1593	2312	2255
Total	4285	2360	2307

Figure 7

Frequency Distribution of State of Goals by Control Mode

The final hypotheses – Hypotheses 2.5.1-2.5.4 analyzed the effect of control modes on workload calculation. Hypothesis 2.5 stated that overall workload would increase as the control mode changes from strategic to tactical to unplanned mode. Table 9 depicts the mean and SD values of all the components of workload. It can be seen in the error bar plots for the overall workload (Figure 8), there is a significant difference between the three control modes ($F(2,9084) = 167.986, p < .0001$).

The overall workload was further analyzed by breaking down the components of overall workload i.e. visual, auditory, cognitive and psychomotor. One-way ANOVA was calculated for each of the workload component (visual, auditory, cognitive and psychomotor).

The results of one-way ANOVA for the different workload components were significant in some cases and not significant in other. It was hypothesized in Hypothesis 2.5.1 that the visual load would be the lowest in the strategic mode and moderate in the tactical mode, and the highest in unplanned mode. The visual workload was significantly different ($F(2,9084) = 226.83, p < .0001$), but contrary to the predictions in Hypothesis 2.5.1 it was the highest in the strategic control mode, moderately high in tactical and the least in unplanned control mode (see Figure 9). Tukey's post hoc analysis for contrasting means of the visual workload for the three control modes shows that the strategic and unplanned control mode, and tactical and unplanned modes are significantly different from each other whereas strategic and tactical modes are not significantly different from each other.

Hypothesis 2.5.2 predicted that auditory load will be lowest in the strategic mode

and will increase as one moves from the strategic mode to the tactical to the unplanned mode. Analysis of variance done for auditory workload showed no significant results ($F(2,9084) = 1.91, p < 0.15$). Tukey's HSD post hoc analysis (see Appendix D) was done to compare differences between the three control modes on the auditory workload, and it was found that there were no differences among the three control modes (Figure 10).

Cognitive Workload was predicted to be the highest in the strategic mode, moderate in the tactical and the lowest in the unplanned control mode, in Hypothesis 2.5.3. Analysis of variance showed that there was a significant difference between the three control modes ($F(2,9084) = 233.71, p < 0.0001$), but in the opposite direction (Figure 10). The mean-values show that the cognitive workload was higher in the strategic and tactical control modes with respect to the unplanned control mode. Tukey's HSD post hoc analysis (see Appendix D) provided results similar to the prior ones, i.e. there was no significant difference between the strategic and tactical mode, but there was a significant difference both between the strategic and unplanned as well as tactical and unplanned control mode.

Psychomotor Workloads were analyzed for the three control modes to test Hypothesis 2.5.4, which stated that the psychomotor load would be the lowest in the strategic mode and increase as the operator moves to the tactical mode to the unplanned mode. There was a significant effect of control modes on psychomotor workload ($F(2,9084) = 33.64, p < 0.0001$). The highest psychomotor workload was found in the unplanned mode, next highest in the tactical and least in the strategic mode (Figure 11). This was in the direction as predicted in the Hypothesis 2.5.4. Tukey's HSD post hoc

analysis comparing the means of all the three control modes also proved that unlike earlier results for the different workloads, all the three control modes were significantly different from each other.

Thus overall workload, visual and cognitive workload were significantly different for the control modes but in the direction opposite to the one hypothesized for the dynamic resectorization goals performed by the simulated operator. There were no significant differences between the control modes on auditory workload. Only psychomotor workload was significant and in the direction predicted for the simulated operator performing tasks and goals in the domain of dynamic resectorization. Differences in the workload calculated for the various control modes imply that there are differences in the cognitive strategies selected for a given context. If the resources (visual, cognitive, auditory, or psychomotor) available for a particular kind of activity do not match the work demands a high workload would be experienced.

Discussion

This modeling effort concentrated on building a link between context and cognition, such that the model could become sensitive to changes in context and could be used to predict behavior in complex dynamic systems. A model is a schematic representation of a system, or phenomenon that consists of some known properties that can be used to further explore its interaction with the environment or another system. When a model is used to represent a system that contains human-technology interaction to achieve a goal, then the way control is maintained or established becomes an important issue in model development (Hollnagel, 2000). Hollnagel further explains that the

Table 9

Descriptive Statistics for Workload by Control Mode

Workload	Control Mode	Mean	SD
Visual	Strategic	1.29	1.59
	Tactical	1.23	1.58
	Unplanned	0.62	1.25
Auditory	Strategic	0.98	1.84
	Tactical	1.15	1.95
	Unplanned	0.99	1.82
Cognitive	Strategic	2.71	1.95
	Tactical	2.71	1.86
	Unplanned	1.78	1.87
Psychomotor	Strategic	0.46	0.58
	Tactical	0.53	0.62
	Unplanned	0.38	0.55
Overall	Strategic	5.45	3.61
	Tactical	5.67	3.58
	Unplanned	3.87	4.01

Figure 8

Error Bar plots for Overall Workload by Control Mode

Note. Bars depict 95% confidence intervals

Figure 9

Error Bar plots for Visual Workload by Control Mode

Note. Bars depict 95% confidence intervals

Figure 10

Error Bar plots for Auditory Workload by Control Mode

Note. Bars depict 95% confidence intervals

Figure 11

Error Bar plots for Cognitive Workload by Control Mode

Note. Bars depict 95% confidence intervals

Figure 12

Error Bar plots for Psychomotor Workload by Control Mode

Note. Bars depict 95% confidence intervals

essence of control is in its ability to predict, and this ability would require a set of constructs about the world, which are used for selection of actions based on the same constructs. The traditional approach to human performance analysis makes a strong distinction between the two entities, the “outer” world or context and the “inner” world or a cognitive mechanism. Most classical models describe humans as sequential information processing systems, with context and affect decoupled from each other except via input and output relationship. In reality humans switch between strategies they use, and the decisions they make, which cannot be explained without bringing the contextual factors into play (Hollnagel, 1983).

Thus any attempt to model human performance must begin with the inclusion of context, which could be resources, physical working environment, tasks, goals, organization, and social environment. The current research modeled context as number of simultaneous goals and event horizon and explored its effect on cognition, which was represented by control modes or strategies adopted by the ATCo. Previous human information processing that concentrated on workload and system performance either focused on the time domain (percentage of time occupied) or on the intensity domain (i.e. amount of attentional resources required, Wickens, 1989). The current research is among the first few studies that have modeled both the context and its impact on cognition of a system as postulated by Hollnagel’s COCOM theory (1993). Hendy, Liao, and Milgram (1997) developed another similar model that was discussed in chapter on Literature Review but focused it on workload only. Although the researchers do not focus on the way tasks are done or controlled, they did argue that humans adapt to

excessive processing load by changing processing strategies so as to reduce the amount of information to be processed or to increase the time available before an action has to be completed. These cognitive strategies correlate with the control modes in the present study.

To add new functionality into the human performance model-MIDAS, only two contextual parameters – number of simultaneous goals and event horizon were used from Hollnagel's contextual control model because they are within-subject variables. Also, the effect of these contextual parameters was explored on three control modes – unplanned, tactical and strategic versus the four control modes- scrambled, opportunistic, tactical and strategic originally postulated by Hollnagel. Since the implementation of the tactical and opportunistic control mode is based on the similar rules, they were merged into one mode for purposes of coding into MIDAS.

The analysis of the model output is done in two sections. The first section– Hypotheses and Data restates the hypotheses and the behavioral data collected for the same in the simulation. The second section- Empirical evidence, attempts to provide supporting evidence for the results obtained from the simulated human performance model.

Hypotheses and Data

Hypothesis 1.1

It was predicted that as the number of simultaneous goals increase, the control modes would change from strategic to tactical to unplanned. This hypothesis was upheld with a significant interaction obtained for the chi-square that was computed for the three

levels of number of simultaneous goals across the three control modes. Figure 13 shows the percentage of observed control modes as a function of simultaneous number of goals. It can be seen from Figure 13 that a higher proportion of the Strategic and Tactical modes are observed when the number of goals are less such as “2” goals. As the number of goals increase, we see higher percentage of unplanned control mode with respect to the other control modes. The chi-square test of independence for 3 x 3 (number of goals x control modes) also yielded significant results showing that number of goals have a significant effect on the occurrence of control modes for goals and tasks performed under dynamic resectorization.

Hypothesis 1.2

It was hypothesized that as the event horizon time decreases, the control modes will change from strategic to tactical to unplanned. This hypothesis was upheld with the results of the chi-square, where a significant interaction was obtained for event horizon categories compared across the three control modes. It can be seen from Figure 14 that in the last category “>180 s”, the event-horizon is the largest i.e. greater than 180 s and the simulated operator mostly behaves in the strategic mode, which explains that more available time also has an effect and induces the strategic mode as was hypothesized. Similarly, the proportion of strategic control mode is the least in the lowest event horizon category “60-120” whereas tactical and unplanned modes have a higher proportion of occurrence.

Figure 13

Percentage of Observed Control modes as a function of number of goals.

The interaction between event horizon and number of simultaneous goals also yielded a significant result across the control modes the simulated operator was in while accomplishing the goals related to dynamic resectorization.

Hypothesis 2.1

It was anticipated that as the control modes change from strategic to tactical to unplanned mode, the order of goals would get more varied. This hypothesis was analyzed with the help of both a chi square calculation for resumption of goals and qualitative analysis. The frequency of resumption of goals (see Figure 3) is an index of the orderliness of goals, since every goal-resumption is marked with switching from another (current) goal. The chi-square on frequency of resumption of goal across control modes yielded significant results. The qualitative analysis was provided by the line-graph showing the number of times the goals were switched in the three control modes (see Figure 4 and 5). Both chi-square and qualitative data provide support for the current hypothesis. We see that as the simulation time goes by, the number of goals to be serviced simultaneously also increases and that the unplanned mode is marked with too many goals being switched shown by the spikes in Figure 4 and 5, whereas the strategic and tactical modes show less switching of goals.

Hypothesis 2.2

It was predicted as per Hypothesis 2.2 that the frequency or number of times the planning module is evoked would be the lowest in the strategic mode and increase in the tactical mode and further increase in the unplanned mode. For the purpose of the present model development, number of times planning is done is implemented by tallies or the

Figure 14

Percentage of Observed Control modes as a function of event horizon or look-ahead time.

number of times the goal gets scheduled in the scheduler of the symbolic operator model (SOM). This hypothesis was upheld with the significant effect of control modes on the frequency or number of times the planning module is invoked in the simulation. But it was also seen that there was no difference between the strategic and tactical control modes on this dependent variable, whereas they were remarkably different from the unplanned mode (see Figure 6).

Hypothesis 2.3

This hypothesis anticipated that ratio of time-used to time-available would be lowest in the strategic mode, and increase as one proceeded to the tactical and unplanned mode. This ratio of time used to time available has also been referred to as Time-Pressure (Hendy, 1997). This hypothesis was not upheld with very significant results ($p < .084$). But descriptive analyses show that the unplanned and strategic control modes experienced similar time pressure than the tactical control modes. Thus time pressure did not change significantly as a function of control mode.

Hypothesis 2.4

This hypothesis was conceptually associated with precursors of error, it was predicted that the state of goals (completed, aborted and remembered or resumed) would be significantly different, there would be more number of completed goals in the strategic control mode and that they would reduce as the control mode changed from strategic to tactical to unplanned modes. This hypothesis was supported with a significant value obtained for the chi-square computed for the three states of goals (completed, aborted and remembered) and three control modes (Strategic, Tactical and Unplanned).

Hypothesis 2.5

It was hypothesized that as the control modes change from strategic to tactical to unplanned mode, the workload calculated would increase. The overall workload was significantly different in the strategic and unplanned modes, also in the tactical and unplanned mode, but it was not different between strategic and tactical mode. Also, the direction of the workload was contrary to the one hypothesized. It was high in the strategic and tactical modes and decreased in the unplanned mode. Thus, this hypothesis was rejected.

Sub-Hypothesis 2.5.1-2.5.4

It was hypothesized that the visual, auditory, cognitive and psychomotor workloads will increase from the strategic to tactical to unplanned mode in Sub-Hypothesis 2.5.1, 2.5.2, 2.5.3, and 2.5.4 respectively. The results on the visual and cognitive workload pertaining to Sub-Hypothesis 2.5.1 and 2.5.3 had results similar to Hypothesis 2.5 – overall workload, they were the highest in the strategic and tactical mode, and decreased in the unplanned mode. These results were significant but were in the direction opposite to the one predicted in Sub-Hypothesis 2.5.1 and 2.5.3. Contrary to the Sub-Hypothesis 2.5.2, there were no significant differences in the auditory workload across the three control modes - strategic, tactical and unplanned. The Sub-Hypothesis 2.5.4 on psychomotor workload was significant and also in the direction as predicted i.e. the psychomotor workload calculated was the lowest in strategic mode and increased toward the tactical and the unplanned mode. Thus except for the hypotheses on psychomotor workload, none of the other hypotheses pertaining to the workload

components were upheld.

Empirical Evidence

The analysis of the results from the model developed for the current evaluation clearly depicts that context embedded into cognition does change behavior. Number of simultaneous goals and event horizon are good parameters to define context since they did cause changes in cognitive strategies used by the simulated operator to accomplish goals of dynamic resectorization. Though they were strictly manipulated to induce changes in control modes, they did produce changes that are consistent with those defined by Hollnagel's theory and the subject matter experts. Hollnagel parameterized context as number of goals, event horizon, subjective available time, choice of next action, and evaluation of outcome. Competencies, Construct and Control form the three vertices of the Contextual Control (COCOM) triangle. For the present modeling effort, number of simultaneous goals and event horizon time were used to further develop the model.

Results on Hypothesis 1.1, which was associated with the number of simultaneous goals can be explained using Hollnagel's theoretical framework. The number of goals can be considered as directly or indirectly connected with cognition, in the sense that they change mental overload, especially when demands exceed capacity. This gets referred to in various ways such as task demands, workload, task load, and information (over)load. Thus the number of goals handled at a given time is an internal parameter of the person and gets directly correlated with the external parameter - number of tasks that a person must attend to, as derived for example, from a goals-means task analysis.

The significant effect of event-horizon time on control modes as per Hypothesis

1.2, shows that decrease in event horizon does lead to change of control modes from strategic to tactical to unplanned. This can be explained with the Time reliability correlation. The time reliability correlation (TRC) states that the probability of not responding to an event or the probability of responding incorrectly decreases as a function of time (Hall, Fragola, & Wreathall, 1982 cited in Hollnagel, 2000). Thus as available time increases, the chances of an operator acting randomly as is predicted for the unplanned mode may decrease.

Although there were two independent variables, the transition between the control modes was based on the rules defined by the two parameters – event horizon and goals and more specifically they are based on the ratio of time per unit goal. There is evidence to suggest that a similar ratio of total amount of information to be processed to the time available has been used in the development of a workload model for Human information processing by Hendy et. al. (1997). Since the transitions between control-modes are currently based on discrete values of the ratio of time per goal, the switching mechanism is rather abrupt. In the subsequent sections we will see that values of dependent variables associated with one kind of control mode continue in the next control mode as well because some of these changes are continuous and not completely based on control mode switching, which is more discrete in nature.

The order of goals as was predicted by Hypothesis 2.1 was less varied for the strategic and tactical mode and was a lot more varied for the unplanned mode, due to goals being switched too many times. Miller (1960) classical study on demand –capacity mismatches for information processing can be used to discuss the results of Hypothesis

2.1. Miller explained that there were typical reactions to information-input overload such as omission or no processing of information, speed-accuracy-trade off, escaping or abandoning the task altogether, filtering information, queuing or delayed response, cutting categories, and decentralization. Hollnagel explains that these typical reactions to information overload may be expressed as person's strategy for maintaining their situation awareness or maintaining their construct of the situation. For instance, the reaction of escape, corresponds to unplanned mode where the person wants to get out of the situation irrespective of the cost and therefore abandons the task altogether. The descriptive analysis of the order of goals proves the fact that increased number of goals, increases the information overload, leading to switching between goals because they are queued or information is filtered. Hollnagel discussed another parameter of context - Choice of next action, which was also used to provide explanation of order of goals or tasks, as specified in Hypothesis 2.1. Whether a goal should be considered a goal or a task depends on granularity of the task decomposition. According to Hollnagel, the choice of next action will be random in the unplanned mode, because the choice is determined by the single, dominant goal of the situation. Any action that seems likely to succeed, because it seems easy or for any other reason, will be tried. This postulate provides further support for Hypothesis 2.1, where goals were switched too many times in the unplanned mode, less number of times in strategic and tactical mode.

The idea of choice of next action was used to provide support for the significant results of Hypothesis 2.2 that predicted that the number of times the planning module is evoked would be the lowest in the unplanned mode, increase in the tactical mode and

further increase in the unplanned mode. Since the choice of action begins with the screening for apparent characteristics that correspond to the goal, such as preconditions or consequences, then any goals that have dependencies or higher priorities are checked. In case of the unplanned mode, where the number of times a task or a goal was planned was very high, any action that seemed likely to succeed was chosen, and tried. This process was performed a large number of times, because deliberate search for an action or deliberate planning was absent in the system. The number of times the same task gets scheduled or planned in part has to do with shifts in strategies or control modes to reduce the information overload (Hendy et. al. 1997). Change in strategies or control modes are made to adopt computationally less intensive processing approach. In the unplanned mode, the simulated operator switches between tasks and goals many times leading to an increase in the number of times the same task or goal gets planned in the scheduler. This seems to reduce the time necessary for processing while increasing the apparent processing rate. Actually the overall rate of processing remains the same it just gets shared in the additive sense between tasks, which compete for attention.

Hypothesis 2.3 anticipated that the ratio of time-used to time-available would be lowest in the strategic mode, and increase as one proceeded to the tactical and unplanned mode. The result of the hypothesis 2.3, associated with time used to time available did not have significant results. The results are explained with a model of human information processing developed by Hendy et. al. (1997). The researchers explained that all human problem solving is subject to some form of time constraint, which could be either explicit or implicit and is used for the definition of Time pressure.

As the value of Time Pressure increases, the operator will adapt by investing effort consciously or unconsciously, to match the demand with capacity. Using the descriptive analyses to evaluate time-pressure, strategic and unplanned modes were marked with high ratio of time-used to time-available, since there is high information processing involved in these modes than in the tactical mode. However, the nature of processing in the strategic and unplanned modes is different. In the strategic mode, long-term plans have to be devised. In the unplanned mode, goals were being switched too many times, and many goals were aborted mid-way, leading to high information processing, whereas in the tactical mode, the operator's behavior is based on rules or learned behaviors, similar to Rasmussen's rule-based behavior. Hendy (1993) and other researchers (Gopher & Braune, 1984 cited in Hendy, 1997) also added that time pressure will lead to an experience of high workload if it is coupled with high level of effort to adapt to the demands of the task. It is also interesting to note that both strategic and unplanned mode mostly make transitions to the tactical mode (See Figure 15 and 16), which has a low information processing approach, as is evident from the low ratio of time-used to time-available.

Significant results were obtained for Hypothesis 2.4, which predicted that the state of goals (completed, aborted and remembered or resumed) would be significantly different, there would be more completed goals in the strategic control mode, and the number of completed goals would be reduced as the control mode changed from strategic to tactical to unplanned. Hendy's (1997) results on errors for simulated ATCo tasks provide support for the significant results of hypothesis 2.4. The dependent variable,

Figure 15

Transition between control modes

Note: Figure 15 shows the transition between the control modes.

Figure 16

State Transition Diagram for the control modes.

States of goals or activities, in the present research were also dependent on the ratio of time required for successful completion of goals, which changes the strategy of information processing also referred to as Control modes. As the operator chooses a low information processing strategy to lower their time pressure, they may abort and resume many goals, as is evident from the results provided for the unplanned mode. Many goals were put into queues and were called remembered when they get resumed in the unplanned mode. This is similar to Miller's (1960) filtering or queuing of goals that are frequently taken up when information overload is experienced. These states of the goals (completed, aborted, remembered) correspond to the slips that Reason and Mycielska (1982) identified as the cause for errors. They explained that slips occur because a well-formed plan is poorly executed, due to omissions of tasks, or intrusion of unwanted tasks.

There were significant results but in the direction opposite to the one hypothesized for Hypothesis 2.5, which hypothesized that the unplanned mode would experience the highest level of overall workload, and it would decrease in the tactical and further decrease in the strategic control mode as per Hypothesis 2.5. Workload was calculated in the present research work by classifying the attention demands on the tasks by using VACP taxonomy provided by Aldrich, Craddock, and McCracken (1984). The overall workload was significantly different in the strategic and unplanned modes, also in the tactical and unplanned mode, but it was not different between strategic and tactical mode. The results are also supported by Hendy's et. al. (1997) model on Human Information Processing (HIP), where high workloads are experienced when there is a high information processing demand. Although both strategic and unplanned control

modes reported equally high time pressures, but high overall workload was calculated for the strategic mode versus unplanned mode. This happened because in the unplanned mode the high time pressure is combated with a strategy that involved movement to low information processing approach so that less overall workload was experienced. In the strategic control mode, a low information processing strategy is not adopted, because the operator is involved in formulating and executing plans for mission completion, thus the simulated operator experiences high overall workload. The results on the visual, and cognitive workload pertaining to Sub-Hypothesis 2.5.1, and 2.5.3 respectively can be explained similarly, they were the highest in the strategic and tactical mode, and decreased in the unplanned. Contrary to the Sub-Hypothesis 2.5.2, there were no significant differences in the auditory workload across the three control modes. This could be partly due to the fact that amount of auditory communication required in the simulation was limited. But Sub-Hypothesis 2.5.4 was upheld with significant results, the simulated operator experienced highest workload in the unplanned mode and it decreased as the control mode changed to tactical to strategic mode. The explanation provided for these significant results is that the motor responses have a higher duration and a lag, therefore in the unplanned mode the simulated operator is unable to immediately abort psychomotor task, thereby experiencing a higher psychomotor workload.

Another study on free flight and nature of control (Flemming, Lane & Corker, 1999) provided support for the workload hypothesis. Flemming, Lane and Corker found that as the percentage of self-separating aircrafts was increased to 80% especially in the

complex scenario (largest number of aircraft, greatest number of aircraft types), the controllers experienced the highest subjective workload in conflict detection and resolution. The authors hypothesized that high workload is experienced because the scenario that originally supported strategic control mode has changed to one that support tactical or unplanned control mode, but the controllers continue to behave as if they are in strategic mode, thus reporting high workloads.

Summary

The human performance model is capable of providing predictive analysis for complex dynamic systems like National Airspace (NAS). The application domain that was explored in the present research to study behavior in control modes (strategic, tactical and unplanned) was dynamic resectorization, which modeled communications, point-outs, and handoffs between ATCos. Hadley et. al. (2000) compared workloads and other performance indices between a baseline and dynamically resectorized airspace under heavy traffic and weather conditions. They found that both heavy traffic and weather conditions benefited under the dynamic resectorization condition. But they posed other questions about dynamic resectorization such as when dynamic resectorization should take place? Is there a need for a predictive index like dynamic density, which takes into account sector complexity at some pre-determined look-ahead time, to decide the timing for dynamic resectorization? Other questions asked were how often should one resectorize? How to resectorize? Should pre-defined regions of airspace be used or should there be infinite number of configuration capabilities?

The human performance model used for the current evaluation with the contextual

control built into it has predictive ability to help answer some of the questions posed by Hadley and other researchers. The effect of context on cognition, by means of changing the control mode an operator behaves in, provides the researchers with anticipated behavior under different contexts. Thus the effect of different contextual factors like weather, traffic, and change of status of special use airspace on dynamic resectorization can be explored using the human performance model in its current form.

Conclusion

Previous modeling efforts on human information processing have focused modeling on sensory processes (Gawron, et. al. 1983), motor responses (Fitts & Posner, 1957), cognition (Newell, 1990), and workload (Hendy et. al., 1997). The assessment of the impact of context on cognition was missing in most of the human performance models. The human performance model, MIDAS was developed using rules concerning time required for successful completion of goals to make the control modes switch. Thus, event horizon time and number of simultaneous goals were the independent variables that changed the control modes. The characteristics of behavior in the three control modes (Strategic, Tactical and Unplanned) were anticipated using the dependent variables – order of goals, number of times the planning module is called, ratio of time used to time available (Time pressure), state of goals (completed, aborted, remembered) and workload calculations.

Hollnagel's Contextual Control theory describes choice of next action, feedback, skill level, number of simultaneous goals, and event horizon as the contextual factors. To add new functionality into the human performance model, MIDAS, only two within-

subject contextual parameters, number of simultaneous goals and event horizon were used from Hollnagel's contextual control model. Also, the effect of these two contextual parameters was investigated on three control modes – unplanned, tactical, and strategic versus the four control modes- scrambled, opportunistic, tactical, and strategic originally postulated by Hollnagel. Contextual factors do have a relationship with control modes, as was provided by Hollnagel's theoretical framework.

Although the control modes switching takes place based on the ratio of the two variables – event horizon time and number of simultaneous goals. The behavior predicted for every control mode does overlap between the three control modes and is not as discrete as the ratio used for control mode switching. The human performance model predicts that the increase in number of simultaneous goals will make the simulated operator's control modes change from strategic mode to tactical to unplanned mode. Similarly, an increase in the event horizon or look-ahead time will change operator's control modes from unplanned mode to tactical to strategic mode.

In terms of behavior under each control mode, various performance and workload measures were collected. As predicted by Hollnagel's theory, unplanned mode is marked with random ordering of goals, or high frequency of goal-switching, which in turn leads to the same goal being planned or scheduled high number of times. The random selection of goals and task leads to goals being frequently aborted or resumed. Although the time pressure index provided by the ratio of time-used to time-available for the unplanned mode was the same as that of the Strategic mode, the workload calculated for unplanned mode was significantly less for the overall workload and its visual, and cognitive

components. Reduced overall workload in unplanned mode is explained from the fact that the simulated operator adopts a low information processing strategy to combat time pressure. This reduces workload but degrades performance.

The tactical and strategic control modes do not have remarkable differences between each other, as was evident from the post hoc analyses (see Appendix D). But the two modes are quite different from the unplanned mode. The order of goals is marked with less switching of goals, the same goal is not scheduled a large number of times, maximum number of goals reach completion state. There is high time pressure felt in these two modes, and is marked with high calculated workloads. The high workload is experienced because the simulated operator has to exert effort to maintain a coherent view of the world and plan actions for the completion of goals within the given time frame. Unlike, the unplanned mode, the operator cannot abandon activities in the strategic mode. With similar results obtained for the tactical and strategic mode, it seems useful to combine the two into one control mode. Thus instead of the four control modes specified by Hollnagel (Strategic, Tactical, Opportunistic and Unplanned, we suggest the use of two control modes – Strategic/Tactical and Unplanned.

It is recommended that instead of having discrete values of the derived ratio between event horizon time and number of goals for switching control modes, fuzzy sets or logic may provide non-discrete values for switching. Fuzzy logic is a superset of conventional (Boolean) logic that has been extended to handle the concept of partial truth i.e. truth-values between "completely true" and "completely false" as a means to model the uncertainty. They can be used to model transitions between the control modes.

Hollnagel's other contextual parameters like feedback; skill level etc. may be used for further development of the human performance model. The present research was used to investigate and predict behaviors in the post-dynamic resectorization application domain. Further predictive analysis of the simulated contextual factors – traffic, weather, and special use airspace in the human performance model is suggested for testing advanced flight concepts like dynamic resectorization.

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**Appendix A. Overall Picture of Task Decomposition for post-Dynamic
Resectorization.**

Appendix B. Task Decomposition for Post-Dynamic Resectorization

VACM MODEL FOR ATC POST-DYNAMIC RESECTORIZATION

REACTION TO CHANGE IN SECTOR BOUNDARIES

VERB	OBJECT	SENSORY	COGNITIVE	PSYCHOMOTOR	DURATION (sec)	SD (duration)
Monitor	radar display	maintain minimum vigilance V= 1, A= 0, K=0	recognize relevant visual elements C=1	P=0	15	3
Note	signal	Visually detect a flashing announcement V= 1, A= 0, K=0	recognize signal C = 3.7	P=0	5	1
*Prepare	sector configuartion	attend to the sector changes on radar V= 3.7, A= 0, K=0	estimate likely changes in sector boundaries C = 7.0	P=0	10	2
Communicate d-side		initiate audio message receive speech feedback V=0, A=4.3, K=0	determine message content (sector changes) C = 3.3 (5.3)	speech P=0	2.5	0.5
Note	sector boundary changes	attend to the sector changes on radar V= 3.7, A= 0, K=0	interpret sector changes C = 6.8	P = 0	5	0.2
Communicate d-side		initiate audio message receive speech feedback V=0, A=4.3, K=0	determine message content C = 3.3 (5.3)	speech P= 1	2.5	0.5
Monitor	radar display	visually register new sector boundaries V= 3.7, A= 0, K=0	evaluate all changes within sector boundaries C = 6.8	P=0	15	3
Prepare	point-outs hand-outs	visually locate aircraft to be pointed or handedoff V= 5.0, A= 0, K=0	evaluate scenario within sector to decide hand-off C = 6.8	P=0	10	2

* indicates an inner or mental activity

VACM MODEL FOR ATC POST-DYNAMIC RESECTORIZATION

ISSUE A POINT OUT (ATC - 1 : R-SIDE)

VERB	OBJECT	SENSORY	COGNITIVE	PSYCHOMOTOR	DURATION	SD (duration)
Monitor	radar display	maintain minimum vigilance V= 1, A= 0, K=0	recognize relevant visual elements C=1	P=0	15	3
Note	sector boundary changes	Visually attend to sector changes on radar V= 3.7, A= 0, K=0	evaluate sector changes C = 4.7	P=0	5	2
Decide	need for Point Out	visually attend to projected path of aircraft V = , A = , K =	determine if aircraft is crossing another sector C = 4.7	P = 0	1	0.2
Communicate	point-out message	attend to sent-message determine keys to be pressed V=1.5, A=0, K=2 (4)	determine message content C = 1.0	press appropriate keys P = 2.2	2.5	0.5
*Expect	response	maintain minimum vigilance V= 0 (1), A= 0, K=0	recognize relevant visual elements C= 0.5 (1)	P=0	30	5
*Recall	message	maintain minimum vigilance V= 1, A= 0, K=0	remember message C=1	P=0	2	0.2
Monitor	radar display	visually register new sector boundaries V= 3.7, A= 0, K=0	evaluate all changes within sector boundaries C = 6.8	P=0	30	6
Receive	acceptance of point out	detects acceptance of message V= 1, A= 0, K=0	interpret the message C = 3.3 (5.3)	P=0	2.5	0.5
*Expect	response to point-out request	maintain minimum vigilance V= 0 (1), A= 0, K=0	recognize relevant visual elements C= 0.5 (1)	P=0	30	5
*Recall	message	maintain minimum vigilance V= 1, A= 0, K=0	remember message C=1	P=0	2	

* indicates an inner or mental activity

VACM MODEL FOR ATC POST-DYNAMIC RESECTORIZATION

ISSUE A POINT OUT (ATC - 3 : R-SIDE)

This is a sink variable

VERB	OBJECT	SENSORY	COGNITIVE	PSYCHOMOTOR	DURATION	SD (duration)
Monitor	radar display	maintain minimum vigilance V= 1, A= 0, K=0	recognize relevant visual elements C=1	P=0	15	3
Note	point-out messages	Visually detect message on radar V= 1.0, A= 0, K=0	interpret changes C = 5.3	P=0	1	0.2
Communicate	response to point-out	attend to sent-message determine keys to be pressed V=1.5, A=0, K= 4	determine message content C = 1.0	press appropriate keys P = 2.2	3	0.5
*Expect	response to point-out request	maintain minimum vigilance V= 0 (1), A= 0, K=0	recognize relevant visual elements C= 0.5 (1)	P=0	30	6

VACM MODEL FOR ATC POST-DYNAMIC RESECTORIZATION

RESPONSE TO A POINT OUT (ATC - 1 : R-SIDE)

VERB	OBJECT	SENSORY	COGNITIVE	PSYCHOMOTOR	DURATION	SD (duration)
Monitor	radar display	maintain minimum vigilance V= 1, A= 0, K=0	recognize relevant visual elements C=1	P=0	15	3
Communicate	point-out message	attend to sent-message determine keys to be pressed V=1.5, A=0, K= 4	determine keys to be pressed C = 1	press appropriate keys P = 1.2 (2.2)	2.5	0.5
*Expect	response	maintain minimum vigilance V= 0 (1), A= 0, K=0	recognize relevant visual elements C= 0.5 (1)	P=0	30	6
Receive	acceptance of point out message	detects acceptance of message V= 1, A= 0, K=0	interpret the message C = 3.3 (5.3)	P=0	2.5	0.5
Discuss	point out	initiate audio message receive speech feedback V= 0, A= 4.3, K=0	determine message content C=1	speech P = 1.0	10	2
Monitor	radar display	visually register new sector boundaries V= 5.0, A= 0, K=0	evaluate all changes within sector boundaries C = 6.8	P=0	30	6
Receive	decision on point out request	detects message on decision of point out request V= 1, A= 0, K=0	Interpret the message C = 5.3	P = 0	1.5	0.3
Decide	alternatives with pointed aircraft	track the pointed-out aircraft V= 5.4, A= 0, K=0	evaluate situation (decision alternatives) C = 6.8	P = 0	2.08	0.5

VACM MODEL FOR ATC POST-DYNAMIC RESECTORIZATION

RESPONSE TO A POINT OUT (ATC - 3 : R-SIDE)

VERB	OBJECT	SENSORY	COGNITIVE	PSYCHOMOTOR	DURATION	SD (duration)
Monitor	radar display	maintain minimum vigilance V= 1, A= 0, K=0	recognize relevant visual elements C=1	P=0	15	3
Note	point-out message	Attend to message on radar V= 1.0, A= 0, K=0	interpret changes C = 3.3 (5.3)	P=0	2	0.2
Communicate	acceptance message	attend to sent-message determine keys to be pressed V=0.5 (1.5), A=0, K= 2 (4)	determine keys to pressed C = 0.5 (1.0)	press appropriate k keys P = 1.2 (2.2)	2.5	0.5
Search	pointed out aircraft	visually search the pointed aircraft on radar screen V= 5, A=0, K=0	compare pointed aircraft with specifications C = 4.6	P = 0	20	2
Note	full data block message	visually detect the full data block of pointed out aircraft V= 1, A= 0, K=0	evaluate situation C = 6.8	P=0	2.5	0.8
Discuss	point out	receive speech feedback initiate audio message V= 0, A= 4.3, K=0	determine content message C = 5.3	speech P = 1.0	10	2
Select	response to point out request	visually check all the essential parameters of pointed-out aircraft V= 4, A= 0, K=0	evaluate situation (own workload) C = 6.8	P=0	2.5	0.4
Communicate	response to point out request	attend to sent-message determine keys to be pressed V=0.5 (1.5), A=0, K= 2 (4)	determine keys to pressed C = 0.5(1.0)	press appropriate keys P = 1.2 (2.2)	2.5	0.5

VACM MODEL FOR ATC POST-DYNAMIC RESECTORIZATION

IF POINT OUT REJECTED ATC1 : r-side

VERB	OBJECT	SENSORY	COGNITIVE	PSYCHOMOTOR	DURATION	SD (duration)
Receive	denial of message	visually detects message V= 1, A= 0, K=0	interpret the message C = 5.3	P=0	1.5	0.3
Select	holding pattern	scan the sector V= 7.0, A=0, K=0	evaluate airspace C = 6.8	P = 0	3	0.6
Transmit	holding pattern radio message	receive speech feedback feel switch movement V= 1, A= 4.3, K=1	determine the message content C = 1	speech P = 1	2.5	0.5
Receive & check	copied message	receive auditory message V= 1, A= 4.9, K=0	determine correctness of original message C = 4.6	P = 0	30	6
Transmit	radio message	receive speech feedback feel switch movement V= 1, A= 4.3, K= 1	determine the message content C = 1	speech P = 1	2.5	0.5
Expect*	change in aircraft position	maintain minimum vigilance V= 0 (1), A= 0, K=0	recognize relevant visual elements C= 0.5 (1)	P=0	30	6
Monitor	radar display	maintain minimum vigilance V= 1, A= 0, K=0	recognize relevant visual elements C=1	P=0	15	3
Note	aircraft on radar screen	visually discriminate changes V= 1.7 (3.7), A= 0, K=0	evaluate situation (aircraft) C = 2.6 (4.6)		2.5	0.5

VACM MODEL FOR ATC POST-DYNAMIC RESECTORIZATION

IF POINT OUT REJECTED (ATC 3 r-side)

This is a sink variable

VERB	OBJECT	SENSORY	COGNITIVE	PSYCHOMOTOR	DURATION	SD (duration)
Transmit	automated denial message	detect message sent on radar display V= 1, A= 0 , K=0	determine keys to be pressed C = 1	press keys P = 2.2	5.5	1.1

IF POINT OUT REJECTED (PILOT r-side)

Recieves	radio message	detects audio message V = 0, A = 4.9 , K = 0	interprets message C = 5.3	P = 0	5.5	1.1
Copies	radio message	receive speech feedback feel switch movement V = 1, A = 4.3, K = 1	determine the message content C = 1	speech P = 1	30	6
Expect*	radio message	maintain minimum auditory vigilance V= 0 (1), A= 0, K=0	recognize relevant audio elements C= 0.5 (1)	P=0	30	6
Recieves	confirmation message	detects audio message V= 0, A= 4.9 , K=0	interprets message C = 3.3 (5.3)	P = 0	5.5	1.1
Press	keys	detects changes in speed, heading and altitude determine keys to be pressed V = 4.6, A =0, K = 4	evaluate action w.r.t. ATC message C = 4.6	Press various keys P = 2.2	5	1

VACM MODEL FOR ATC POST-DYNAMIC RESECTORIZATION

HAND OFF PROCESS (ATC - 1 : R-SIDE)

VERB	OBJECT	SENSORY	COGNITIVE	PSYCHOMOTOR	DURATION	SD (duration)
Receives	acceptance of point-out request	visually attends to message on radar V= 1, A= 0 , K=0	interpret the message C = 3.3 (5.3)	P = 0	2.5	0.5
Communicate	hand-off message	visually attends to message on radar screen determine keys to be pressed V=2.8 (0), A=0, K= 2.0 (4.0)	determine message content C = 1.0	press appropriate k keys P = 1.2 (2.2)	2.5	0.5
expects *	blinking on radar	maintain minimum vigilance V= 0 (1), A= 0, K=0	recognize relevant visual elements C= 0.5 (1)	P=0	30	6
Note	special data indicator	visually detects signal on radar V= 1.0, A= 0, K=0	recognize blinking of special data indicator C = 1.7 (3.7)	P=0	1	0.2
Expects*	decision on hand-off request	maintain minimum vigilance V= 0 (1), A= 0, K=0	recognize relevant visual elements C= 0.5 (1)	P=0	30	6
Monitor	radar display	maintain minimum vigilance V= 1, A= 0, K=0	recognize relevant visual elements C=1	P=0	15	3
recalls*	message sent	maintain minimum vigilance V= 1, A= 0, K=0	remember message C=1	P=0	2	0.6
Receives	hand-off decision	visually attends to message on radar V= 1, A= 0, K=0	interpret the message C = 3.3 (5.3)	P = 0	2.5	0.5
Decide	retraction	determine keys to be pressed V= 0, A= 0, K= 2.0 (4.0)	determine selection of response to hand-off decision C = 1.2	P = 0	2	0.6
Receive	request for transfer of control	auditory input V= 0 , A= 4.9, K=0	interpret message C = 3.3 (5.3)	P = 0	2.5	0.5

VACM MODEL FOR ATC POST-DYNAMIC RESECTORIZATION

HAND OFF PROCESS (ATC - 2 : R-SIDE)

VERB	OBJECT	SENSORY	COGNITIVE	PSYCHOMOTOR	DURATION	SD (duration)
Monitor	radar display	maintain minimum vigilance V= 1, A= 0, K=0	recognize relevant visual elements C=1	P=0	15	3
Receives	hand-off request	receives audio message V = 0, A = 4.9, K = 0	interpret the message C = 3.3 (5.3)	P=0	2.5	0.5
Note	special data indicator	visually detects signal on radar V= 1.0, A= 0, K=0	recognize the blinking of special data indicator C = 1.7 (3.7)	P=0	1	0.2
Decide	hand-off decision	visually scan sector for all the aircrafts V = 5.0 (7.0), A = 0, K = 0	evaluate situation C = 6.8	P=0	3	0.4
Communicate	hand-off decision	attend to sent message determine keys to be pressed V=2.8 (0), A=0, K= 2.0 (4.0)	determine message content C = 1.0	press appropriate k keys P = 1.2 (2.2)	2.5	0.5
Receive	hand-off retraction	receives auditory message V= 0 , A= 4.9, K=0	interpret message C = 3.3 (5.3)	P = 0	2.5	0.5

VACM MODEL FOR ATC POST-DYNAMIC RESECTORIZATION

DETECT NEED FOR MANUAL HAND-OFF ATC1- R-SIDE

VERB	OBJECT	SENSORY	COGNITIVE	PSYCHOMOTOR	DURATION	SD (duration)
Monitor	radar display	maintain minimum vigilance V= 1, A= 0, K=0	recognize relevant visual elements C=1	P=0	15	3
Searches	full data block	visually scan the screen for full data block V = 5.0 (7.0), A = 0, K = 0	evaluate full data block C = 6.8	P = 0 P=0	10	2
Communicate	hand-off request	attend to sent message determine keys to be pressed V=2.8 (0), A=0, K= 2.0 (4.0)	determine message content or keys to be pressed C = 1.0	press appropriate keys P = 1.2 (2.2)	2.5	0.5
Note	special data indicator	visually detects signal on radar V= 1.0, A= 0, K=0	detect blinking of special data indicator C = 1.7 (3.7)	P=0	2.5	0.2
searches	receipt of hand-off message	checks display for acceptance of message V = 4, A = 0, K = 0	interprets the message C = 3.3 (5.3)	P=0	10	2
Decide	manual hand-off request	V = 0, A = 0, K = 0	choose from two alternatives C = 4.6	P = 0	2	0.2
Receive	manual hand-off decision	detects message on decision of hand off request V= 1, A= 0, K=0	Interpret the message C = 3.3 (5.3)	P = 0	2.5	0.5
Decide	retraction	check display V=1 , A= 0, K=0	choose from alternatives C = 4.6	P = 0	2	0.4
Receive	request for transfer of control	auditory input V= 0, A= 1, K=0	Interpret the message C = 3.3 (5.3)	P = 0	2.5	0.5

VACM MODEL FOR ATC POST-DYNAMIC RESECTORIZATION

DETECT NEED FOR MANUAL HAND-OFF ATC 2- R-SIDE

VERB	OBJECT	SENSORY	COGNITIVE	PSYCHOMOTOR	DURATION	SD (duration)
Monitor	radar display	maintain minimum vigilance V= 1, A= 0, K=0	recognize relevant visual elements C=1	P=0	15	3
Note	special data indicator	visually detects signal on radar V= 1.0, A= 0, K=0	detect blinking of special data indicator C = 1.7 (3.7)	P=0	2.5	0.6
Receive	verbal hand-off request	auditory input V= 0, A= 1, K=0	Interpret the message C = 3.3 (5.3)	P = 0	2.5	0.3
Decide	manual hand-off	V = 0, A = 0, K = 0	choose from two alternatives C = 4.6	P = 0	2	0.4
Decide	hand-off decision	V = 0, A = 0, K = 0	choose from two alternatives C = 4.6	P = 0	2	1.6
Communicate	manual hand-off decision	initiate audio message and receive speech feedback V=0 , A=4.3, K=1	determine message content C = 3.3 (5.3)	speech P = 1.0	10	2

VACM MODEL FOR ATC POST-DYNAMIC RESECTORIZATION

DETERMINE AIRCRAFT ENTERING SECTOR ATC 1 R-SIDE

VERB	OBJECT	SENSORY	COGNITIVE	PSYCHOMOTOR	DURATION	SD (duration)
Monitor	radar display	maintain minimum vigilance V= 1, A= 0, K=0	recognize relevant visual elements C=1	P = 0	15	3
Searches	geographic map	visually scan the screen for map V= 5 (7), A= 0, K=0	interpret symbols seen during scanning C = 3.3 (5.3)	P = 0	10	2
Note	sector characteristics	read geographic map V= 3.9 (5.9), A= 0, K=0	evaluate sector characteristics C = 6.8	P=0	2.5	0.2
Compare	pilot's position	read PIREP, HOST message from pilot V= 3.9 (5.9), A= 0, K=0	evaluate position C = 4.6	P = 0	10	2
Communicate	d-side	initiate audio message and receive feedback message V= 0, A=4.3, K=0	determine message content or C = 3.3 (5.3)	speech P = 1	2.5	0.5
Receive	FPS information	receive audio message V = 0, A = 4.3, K = 0	interpret message C = 3.3 (5.3)	P = 0	2.5	0.5
Recognize	position of aircraft	locate position of aircraft on screen V = 3 (5), A = 0, K = 0	evaluate data w.r.t aircraft position C = 6.8	P = 0	2.5	0.3

VACM MODEL FOR ATC POST-DYNAMIC RESECTORIZATION

MANAGE INFORMATION ATC 1 R-SIDE

VERB	OBJECT	SENSORY	COGNITIVE	PSYCHOMOTOR	DURATION	SD (duration)
Monitor	radar display	maintain minimum vigilance V= 1, A= 0, K=0	recognize relevant visual elements C=1	P=0	15	3
Evaluate	information status	read the information on aircraft V= 3.9 (5.9), A=0, K=0	evaluate information for complete- ness and relevance C = 4.6	P = 0	10	2
Set	datablock on top of aircraft	locate datablock and align it on top of aircraft V= 3.9 (5.9), A=0, K=2.8 (4.8)	recognize that aircraft's control has transferred C = 3.3 (5.3)	press keys P = 1.2 (2.2)	1	0.02
Monitor	radar display	track the datablock/aircraft V=3.4 (5.4), A= 0, K=0	recognize that aircraft is leaving sector C = 4.6	P = 0	15	3
Set	datablock to nil	determine keys to be pressed to remove data block visually locate the position of aircraft V = 3 (5), A = 0, K = 0	recognize need for non-tracking aircraft C = 3.3 (5.3)	press keys P = 1.2 (2.2)	1	0.02
Check- mark	all items on Checklist	visually determine status of every aircraft in one's sector V= 1, A=0, K=1	evaluate every item on checklist C = 3.3 (5.3)	write check mark P =1	5	0.3

VACM MODEL FOR ATC POST-DYNAMIC RESECTORIZATION

TRANSFER OF CONTROL ATC 1 R-SIDE

VERB	OBJECT	SENSORY	COGNITIVE	PSYCHOMOTOR	DURATION	SD (duration)
Receive	transfer of data request	read message on radar V = 3.9 (5.9), A=0, K=0	interpret message C = 3.3 (5.3)	P=0	2.5	0.5
Transfer	flight-data	visually attend to sent message using ATRS-III detect keys to be pressed V = 1.0, A = 0, K = 1	determine message content C = 3.3 (5.3)	press keys P = 1.2 (2.2)	5	1
Monitor	radar display	maintain minimum vigilance V= 1, A= 0, K=0	recognize relevant visual elements C=1	P=0	15	3
Note	acceptance of message	detect acceptance of message on the other end V= 1.0, A= 0, K=0	interpret message C = 3.3 (5.3)	P = 0	2.5	0.2
Discuss	transfer of control	initiate audio message and receive feedback message V= 0, A=4.3, K=0	determine message content C = 5.3	speech P = 1	10	2
Communicate	relinquished control	initiate audio message and receive feedback message V=2.8 (0), A=0, K= 2.0 (4.0)	determine message content C = 3.3 (5.3)	speech P = 1	2.5	0.5
Transmit	radio message	send audio / radio message to pilot V = 0, A = 4.3, K = 0	determine message content (changed radio frequency) C = 3.3 (5.3)	speech P = 1	2.5	0.5

VACM MODEL FOR ATC POST-DYNAMIC RESECTORIZATION

TRANSFER OF CONTROL ATC 2 R-SIDE

VERB	OBJECT	SENSORY	COGNITIVE	PSYCHOMOTOR	DURATION	SD (duration)
Communicate	transfer of data request	visually attend to sent message on screen detect keys to be pressed V= 1, A= 0, K= 4	determine message content C = 3.3 (5.3)	press keys	2.5	0.5
Receive	transfer flight-data	read flight data received from ATRS-III V = 3.9 (5.9), A=0, K=0	interpret message C = 3.3 (5.3)	press keys	2.5	0.5
Communicate	acceptance of message	detect keys to be pressed V= 0, A= 0, K=4	determine message content C = 1	press keys	2.5	0.5
Discuss	transfer of control	initiate audio message and receive feedback message V= 0, A=4.3, K=0	determine message content C = 3.3 (5.3)	speech	10	2
Receive	transfer of control	detect relinquished control aurally V= 0, A= 4.3, K=0	interpret message C = 3.3 (5.3)		5	0.5
Communicate	aircraft	speech feedback and switch movement V = 0, A = 4.3, K = 1	determine message content C = 3.3 (5.3)	speech	2.5	0.5

Appendix C. Rules for Contextual Control Mode Switching

Rules for Control Mode Selection

A= if resources available

Block arrow = new connections to be constructed

The above flow chart partly describes AIR-MIDAS. It describes how the Executive sends ticks to the world and to the Scheduler. The scheduler in its current form based on priority of the goals performs the corresponding activities of the Current goals. If it has resources available, it performs activities of the Suspended goals and if it still has resources then it also performs activities of the pending goals.

The current reserach on the introduction of context and control modes into MIDAS will require the introduction of the control switcher and a change in how it will schedule the activities. The logic for switching the control modes is defined using the rules for the Strategic, Tactical and unplanned control modes. The rules and their subsequent consequences are described:

The logic of switching the control modes is dependent on three sets of rules – Rule A, Rule B and Rule C. Rules A, which are based on the ratio of time per goal and Rules B, which are based on relative state transitions. Once the control mode is identified then Rules C for a specific control mode are evoked, according to which the scheduler produces its output of activity performance.

Rules A

Ratio of event horizon and goals is calculated:

$$\text{Ratio} = (\text{Event Horizon}) / (\text{Current} + \text{Suspended} + \text{Pending goals})$$

If Ratio $\leq$ 37 sec

Then switch to unplanned control mode

Else if Ratio $>$ 37 sec and $<$ 52 sec

Then switch to tactical control mode

Else if Ratio $>$ 52 sec

Then switch to strategic mode

Rules B

Rules B and Rules A will be checked together using the Boolean AND.

Relative state transition will also be kept in mind when switching the control mode. A table describing the set of rules that will be evoked when there is a switch of control mode is shown:

Compare calculated control mode (future) to current control mode.

Calculated $\rightarrow$ Current $\downarrow$	Strategic	Tactical	Unplanned
Strategic	Rules C	Rules C	Rules C
Tactical	Rules C	Rules C	Rules C
Unplanned	Rules C	Rules C	Rules C

Thus when there is transition to the same control mode, no rules are evoked, when there is a transition from one mode to another mode, Rules C get fired. The pseudo code for the above rules A and B is as follows:

```
If (calculated ratio < 37 sec) and (Current ratio < 37 sec)
Then Continue Rule C for Unplanned mode
Else If (calculated ratio < 37 sec) and (Current ratio > 37 sec and < 52)
Then goto Rule C for Unplanned mode
Else If (calculated ratio < 37 sec) and (Current ratio > 52 sec)
Then goto Rule C for Unplanned mode

If (Calculated ratio > 37 sec and < 52) and (Current ratio > 37 sec and > 52)
Then goto Rules C for Tactical mode
If (Calculated ratio > 37 sec and < 52) and (Current ratio < 37 sec)
Then goto Rules C for Tactical mode
If (Calculated ratio > 37 sec and < 52) and (Current ratio > 52 sec)
Then goto Rules C for Tactical

If (calculated ratio > 52 sec) and (Current ratio > 52 sec)
Then goto Rules C for Strategic mode
Else If (calculated ratio > 52 sec) and (Current ratio > 15 sec and < 52)
Then goto Rules C for Strategic mode
Else If (calculated ratio > 52 sec) and (Current ratio < 37 sec)
Then goto Rules C for Strategic mode
```

Rules C

Once Rule A and Rule B have identified the control mode, then the set of rules that will be evoked are as follows:

Strategic Mode:

If Strategic Mode, do current planning (no new rules required here) thus use the priorities for scheduling activities.

Tactical Mode:

1. Keep a tally (how frequently it is scheduled/ planned) of every activity in the last 30 seconds. (Tallies are not based on how frequently the activities are performed but how frequently they are scheduled/ interrupted)
2. Rank Order the activities (irrespective of the nature of goal being: current, suspended or pending) according to their tally.
3. Schedule and perform the activity in the descending order irrespective of the fact which goal it belongs to current or suspended or pending (highest tally first). Priorities are not used here.

Unplanned Mode

{

Check precondition before performing the activity and not before scheduling it.
Then select a random activity from current, suspended and pending goals (without regard to priority).
Perform the activity

}

Appendix D. Tukey's Post-Hoc Analysis for dependent variables

Table D1

Tukey HSD : Multiple Comparisons between control modes for Ratio of time-used to Time-available

(I) Control Modes	(J) Control Modes	Mean Difference (I-J)	Std. Error	Significance
Strategic	Tactical	.31540	.147	.089
	Unplanned	6.3711E-02	.190	.940
Tactical	Strategic	-.31540	.147	.089
	Unplanned	-.25169	.179	.342
Unplanned	Strategic	-6.3711E-02	.190	.940
	Tactical	.25169	.179	.342

Note: The mean difference is significant at the .05 level

Table D2

Tukey HSD : Multiple Comparisons between control modes for Overall Workload

(I) Control modes	(J) Control modes	Mean Difference (I-J)	Std. Error	Significance
Strategic	Tactical	-.2188	.192	.491
	Unplanned	1.5780	.095	.000
Tactical	Strategic	.2188	.192	.491
	Unplanned	1.7968	.181	.000
Unplanned	Strategic	-1.5780	.095	.000
	Tactical	-1.7968	.181	.000

Note: The mean difference is significant at the .05 level

Table D3

Tukey HSD : Multiple Comparisons between control modes for Visual Workload

(I) Control modes	(J) Control modes	Mean Difference (I-J)	Std. Error	Significance
Strategic	Tactical	6.099E-02	.067	.638
	Unplanned	.6699	.033	.000
Tactical	Strategic	-6.0992E-02	.067	.638
	Unplanned	.6089	.064	.000
Unplanned	Strategic	-.6699	.033	.000
	Tactical	-.6089	.064	.000

Note: The mean difference is significant at the .05 level

Table D4

Tukey HSD : Multiple Comparisons between control modes for Auditory Workload

(I) Control modes	(J) Control modes	Mean Difference (I-J)	Std. Error	Significance
Strategic	Tactical	-.1756	.091	.129
	Unplanned	-1.9501E-02	.045	.900
Tactical	Strategic	.1756	.091	.129
	Unplanned	.1561	.085	.161
Unplanned	Strategic	1.950E-02	.045	.900
	Tactical	-.1561	.085	.161

Note: The mean difference is significant at the .05 level

Table D5

Tukey HSD : Multiple Comparisons between control modes for Cognitive Workload

(I) Control modes	(J) Control modes	Mean Difference (I-J)	Std. Error	Significance
Strategic	Tactical	3.600E-03	.093	.999
	Unplanned	.9276	.046	.000
Tactical	Strategic	-3.5995E-03	.093	.999
	Unplanned	.9240	.088	.000
Unplanned	Strategic	-.9276	.046	.000
	Tactical	-.9240	.088	.000

Note: The mean difference is significant at the .05 level

Table D6

Tukey HSD : Multiple Comparisons between control modes for Psychomotor Workload

(I) Control modes	(J) Control modes	Mean Difference (I-J)	Std. Error	Significanc e
Strategic	Tactical	-6.3882E-02	.028	.056
	Unplanned	8.922E-02	.014	.000
Tactical	Strategic	6.388E-02	.028	.056
	Unplanned	.1531	.026	.000
Unplanned	Strategic	-8.9219E-02	.014	.000
	Tactical	-.1531	.026	.000

Note: The mean difference is significant at the .05 level

Appendix E. List of goal Numbers and corresponding goals

Table E1.
Goals for Run #5

Goal#	Goal Name
1	Handoff2-Aero18
2	Handoff2-Aero15
3	Handoff2-Aero7
4	Monitor-Situation
5	Handoff2-Aero8
6	Handoff2-Aero13
7	Divert aircraft Aero2
8	Handoff2-Aero19
9	Handoff2-Aero16
10	Handoff2-Aero9
11	Restore aircraft course Aero2
12	Handoff1-Aero6
13	Handoff2-Aero10
14	Handoff1-Aero5
15	Handoff2-Aero11
16	Handoff1-Aero2
17	Handoff1-Aero3
18	Handoff2-Aero20
19	Handoff2-Aero14
20	Handoff2-Aero12
21	Manual Handoff2-Aero14
22	Manual Handoff2-Aero12
23	Handoff2-Aero17
24	Manual Handoff2-Aero17
25	Handoff1-Aero18
26	Handoff1-Aero7
27	Handoff1-Aero4
28	Handoff1-Aero8
29	Handoff1-Aero1
30	Handoff1-Aero9
31	Handoff1-Aero13
32	Handoff1-Aero15
33	Handoff1-Aero19
34	Handoff1-Aero10
35	Handoff1-Aero16
36	Handoff1-Aero11
37	Handoff1-Aero14
38	Handoff1-Aero12

Table E2.
Goals for Run#9

Goal#	Goal Name
1	Handoff2-Aero7
2	Handoff2-Aero17
3	Handoff2-Aero8
4	Handoff2-Aero15
5	Handoff2-Aero18
6	Handoff2-Aero13
7	Handoff2-Aero9
8	Handoff2-Aero19
9	Handoff2-Aero10
10	Handoff2-Aero11
11	Handoff2-Aero12
12	Handoff2-Aero14
13	Handoff2-Aero20
14	Handoff2-Aero16
15	Manual Handoff2-Aero20
16	Manual Handoff2-Aero16
17	Handoff1-Aero5
18	Handoff1-Aero9
19	Handoff1-Aero10
20	Handoff1-Aero4