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Human-Centered Technologies and Procedures for Future Air Traffic Management:

A Preliminary Overview of 1996 Studies and Results

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INTRODUCTION

In this project, we have been exploring the use of a general methodology to predict the impact of future Air Traffic Management (ATM) concepts and technologies. In applying this methodology, our emphasis has been on the importance of modeling coordination and cooperation among the multiple agents within this system, and on understanding how the interactions among these agents will be influenced as new roles, responsibilities, procedures and technologies are introduced. To accomplish this, we have been collecting data on performance under the current air traffic management system, trying to identify critical problem areas and looking for exemplars suggestive of general approaches for solving such problems. Based on the results of these field studies, we have developed a set of scenarios centered around potential future system designs, and have conducted studies using these scenarios involving a total 40 controllers, dispatchers, pilots and traffic managers.

The purpose of this report is to provide NASA with an early summary of the major recommendations that have resulted from our research under the AATT Program thus far. Recommendations 1-3 deal with general approaches that our findings suggest should be incorporated in future AATT Program activities, while Recommendations 4-11 identify some specific topics and technologies that merit research and development activities. Detailed technical reports containing supporting data, as well as the results of our still ongoing analyses, will be provided at a later date.

The remainder of this report is organized as follows. Section 1 briefly describes the general design philosophy supported by our empirical studies. Section 2 presents the research methods we have used for identifying requirements for future system designs and for evaluating alternative design solutions. Section 3 discusses preliminary results from an initial set of investigations that we have conducted using these research methods. Section 4 then provides an overall summary. An outline of the rest of this preliminary project summary is provided on the following page.

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1. PROPOSED DESIGN PHILOSOPHY

Our central conclusion is that attempts to improve the safety and efficiency of the air transportation system must take a human-centered approach to support the cooperative problem-solving of both airborne and ground-based operators. The impact of new ATM concepts and technologies must be considered in the context of the roles, responsibilities and interactions of the people using them, in terms of procedures and the regulatory environment, in terms of organizational behavior, and in terms of the different types of situations or scenarios that arise. In particular, design efforts need to explicitly take into consideration the distributed nature of this system, which includes human and computerized agents with multiple complementary and competing goals and overlapping responsibilities, who at times have different sources of information and differing situation assessments. Furthermore, we must study how this system, with all of its complex interactions, can evolve from its current state. We need to start with an understanding of interactions within the current system, and then take a hard-headed approach, asking where the real problems lie, and determining where opportunities for improvement with significant payoffs really exist.

Thus, our focus has been on how the participants within the ATM system can coordinate their activities to achieve overall safety and economic goals. We believe this is the appropriate project focus because a fully autonomous air traffic management system, whether air- or ground-based, is not likely to be technically possible or desirable in the foreseeable future given the dynamic and uncertain nature of the national airspace system.

We believe that the allocation of resources for future system development should be based on a broad systems perspective, with emphasis on how system elements interact and how they are to be integrated. One method that can help to accomplish this goal is to construct and use concrete scenarios that focus attention on the necessary interactions among participating agents in proposed ATM systems. Such scenarios can also focus attention on requirements for new technologies in a future system.

Finally, we believe that it is important to use empirical methods to provide the basis for developing informed judgments about alternative system enhancements early in the design process. This requires examining the implications of alternative design proposals in rich, realistic contexts, using experienced practitioners to generate predictions about performance in such future designs. To be cost-effective, the design process also needs to include methods that allow exploration at different levels of fidelity.

2. METHODS FOR THE DEVELOPMENT OF FUTURE SYSTEM REQUIREMENTS

2.1 Introduction

One important question is methodological: How can we identify system requirements for new ATM concepts and technologies, recognizing the potential for these changes to create new roles and procedures for individual participants, new forms of coordination across personnel and organizations, and new types of information to communicate, assess and integrate. This is difficult in part because the system of interest does not yet exist. A further challenge arises because many details of this future system design may be underspecified. To design and test these new roles before committing large pools of resources, we need a model method to quickly prototype and study how the people and technologies will coordinate in realistic operational scenarios for different ATM concepts.

Different developers, stakeholders and decision makers are each likely to develop their own insights and views on how the whole system will work in the future. Consequently, another challenge is how to rigorously explore all of the implications of these different viewpoints. For without doing so, it would be easy to oversimplify the impact of a new system on the roles, decisions, coordination needs, and information requirements of the people involved in ATM system.

These characteristics--a still underspecified system design, accompanied by the potential to oversimplify the impact of design decisions on people's roles and activities--create a difficult methodological challenge. How can we assess the impact of new ATM concepts and technologies on the individual and collective performances of controllers, dispatchers, flight crews and traffic managers? Figure 1 illustrates a range of techniques available to us to investigate possible characteristics and design choices for the future ATM system. This space of methods was deliberately laid out to reveal a basic tradeoff: methods that are high on both dimensions in the figure can only be deployed relatively late in the development process and tend to be resource intensive. How do we generate the needed information to support decisions about the development of new ATM concepts and technologies in a cost-effective and timely manner?

Overall, in planning for the future of the AATT program, NASA needs to consider the appropriate mix and timing for using these different methods. In our work we have been using methods that try to balance cost, timeliness, degree of control, face validity and environmental richness to provide useful input to system developers early in the design process. The methods that we have been exploring to support requirement identification are:

- empirical--collecting data about how people may carry out new roles and utilize possible new systems, thus helping to identify potential problems and define requirements for system development.

- scenario driven--rigorously exploring the implications of new ATM concepts and technologies by having different kinds of expert practitioners explore them in the context of concrete situations.
- iterative and converging--using multiple approaches that build on each other and converge on results that can support design decisions.

The end result for us has been an emphasis on different forms of CONCEPTUAL WALKTHROUGHS. In these conceptual walkthroughs, we posit a future ATM system, or parts of it, through development of a concrete scenario that instantiates a situation within that future system. We then collect data by asking a set of aviation practitioners with different areas of expertise to evaluate or play out potential roles and interactions under that scenario, identifying how it could work and where it might be vulnerable.

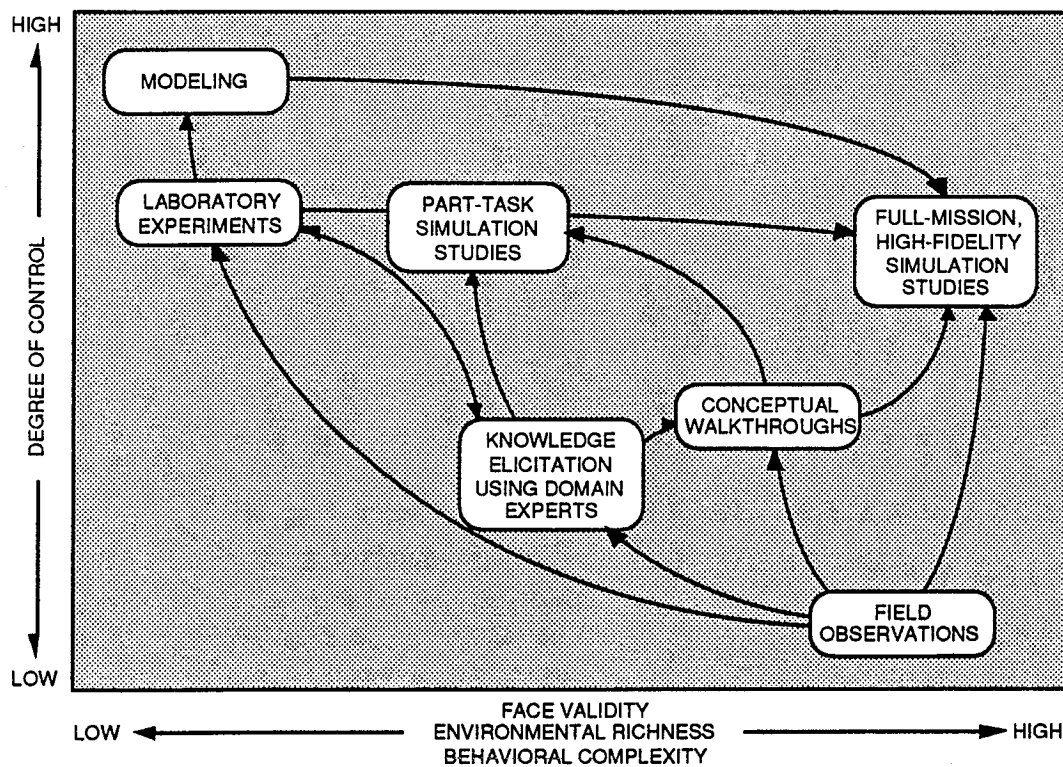


Figure 1: Potential research approaches. Methods high on both dimensions are resource intensive and generally become available relatively late in the development process.

2.2 Research Methods for Studying the Existing Aviation System

In order to understand and support the kinds of changes in human performance that may occur as we consider new ATM concepts and technologies, we have studied the effects of changes that are currently underway. Our work under the AATT project has drawn upon substantial efforts focused on documenting and

modeling performance in the existing aviation system, with an emphasis on new FAA initiatives like the expanded National Route Program and the MAR program. This work has taken a broad systems perspective, examining how system elements interact in the context of integrated real world factors.

These studies of the existing ATM system have proved essential in stimulating and guiding our studies of possible future systems. They are a rich stimulus for the development of scenarios to guide our exploration of the consequences of different technologies and designs on human performance. They help to provide a conceptual framework to guide the use of techniques like conceptual walkthroughs.

Equally important, we believe that these studies, by taking a broad systems perspective, have served to provide important insights into how various system elements are integrated and how they interact. Of particular importance is their emphasis on the impact of new technologies in the context of the roles, responsibilities and interactions of the people using them, in terms of procedures and the regulatory environment, in terms of organizational behavior, and in terms of the different types of situations or scenarios that arise.

Recommendation 1: The AATT Program should continue to fund significant efforts to study and model the impact of changes currently being made or planned within the existing aviation system. These studies should take an integrated systems view in collecting and analyzing data, specifically addressing the interaction and coordination among the multiple agents within this system. These studies will help to further identify problem areas and provide objective data to guide decisions about future system development.

2.3 Research Tools for Studying Future Systems

Since the system of interest does not yet exist, we have chosen to use conceptual walkthroughs of possible future ATM worlds to study the impact on human roles, decisions, coordination requirements and information needs. In preparing for these conceptual walkthroughs, we develop a scenario that instantiates various generic issues or challenges for air traffic management and posit a hypothetical ATM world, or parts of it, in terms of proposed technologies or procedures. Different experts representing different roles and perspectives within the ATM system then think through or play out their potential roles, interactions and information needs within this scenario. We do not provide detailed simulations of particular interfaces or systems; rather we ask the participants to describe in detail how such systems would have to function to provide support so that they could accomplish their tasks successfully.

Critical to this method is the use of concrete scenarios to anchor the participants in the details of the coordination, communication, decision making and information exchange requirements necessary to handle the situation successfully. In addition, we have found that having multiple participants representing different perspectives about the ATM system maximizes the information generated by such scenario-driven conceptual walkthroughs. Anchoring people in concrete situations quickly reveals ambiguities about what their roles are and about how they would carry out those roles. Having people with different perspectives explore how to deal with these roles and interactions provides insights about how different people and organizations can coordinate to achieve all of the parties' goals for a safe, efficient and economical ATM system.

We have constructed a number of scenarios and used them in several conceptual walkthroughs to demonstrate the value of this approach. The scenarios developed to date address several kinds of issues for the development of future ATM systems such as transitions in method or locus of control (e.g., the transition from free flight rules to controlled airspace) and factors limiting system capacity (e.g., crossing traffic) among others. However, this set represents only an initial exploration of the kinds of factors that should be considered.

Recommendation 2: Develop a set of scenarios that represents as fully as possible the range of tasks and situations that must be considered in designing components of a future aviation system.

2.3.1 Sample Scenarios

Given the importance of coordination among multiple agents in future ATM systems, scenario design was based on factors that pose challenges to such coordination within the system. For example, we considered factors that create the need for timely communication and coordination between multiple agents, factors that create the need for updated situation assessments and decisions, and factors that lead to conflicting goals.

Some of these scenarios are derived from field observations, structured interviews and focus groups conducted as part of previous FAA and NASA funded research on the impact of the National Route Program (NRP) as initially defined in Advisory Circular 90-91, and more recently modified under orders defining the expanded NRP (Smith, McCoy, Orasanu, et al., 1995). These particular scenarios focus on the impact of giving the airlines more flexibility in flight planning so that their business concerns can be better addressed.

Other scenarios focus on components of a hypothetical free flight system, incorporating issues raised by the previous work of Sarter and Woods (1995) and Billings (1996) dealing with the impact of cockpit automation and air-to-ground communication technologies on performance. They involve operations in which a

mix of free flight and controlled aircraft coexist, as is likely to be the case during the transition from the present to a future system.

Samples of these scenarios are contained in Appendix A.

2.4 Using These Tools To Evaluate System Designs

The initial scenario set can be used to support many different activities. We have used them as the basis for several different kinds of investigations to explore the potential impact of new ATM technologies on individual performance and on the coordination among multiple parties in the ATM system. The scenario set can eventually support more in-depth methods such as full or part scope simulation techniques as the AATT program matures.

2.4.1 Scenario-driven knowledge elicitation using subject-matter experts

One method that we have applied is to use our scenarios to structure interviews with subject-matter experts, either singly or in a group. These subjects have been asked to comment on the likelihood of certain events occurring given alternative future system designs, to predict the effects of such events on their operations, and to discuss ways in which they would avert the occurrence of such events or compensate for them if they did occur. In applying this method, an effort is made to utilize subjects from different specialties, in order to elicit their different perspectives. Several scenarios have been explored (and refined) using this approach.

2.4.2 Conceptual walkthroughs using future "incident reports"

Scenarios have also been used as the basis for "incident reports" in which a future incident is predicted, and is presented in the form of a formal report investigating that incident. These incident reports, with supporting documentation, are presented to participants (we have used groups of air traffic controllers, dispatchers and pilots) to consider as if they had actually occurred in some future system. The technique is used to structure a conceptual walkthrough by the participants, eliciting the ways in which the incidents might have been avoided, and how the system might be insulated against such occurrences or their effects. We have used this method to study how cooperative problem-solving in a hypothetical system can be facilitated, and how roles, responsibilities, procedures, policies and technologies must be designed to enhance performance and to make the system as error-tolerant as possible.

2.4.3 "Role-playing" conceptual walkthroughs

Another scenario was constructed to permit the observation of cooperative problem-solving more directly. Using this method, subjects are given the background and context of a scenario and the rules under which the system is operating. They are presented with the onset of an event and are then asked to "play out" the scenario as it occurs. The role playing is supported by a gaming board

that represents the aircraft in particular ATC sectors. The participants can manipulate the gaming board to play out how the situation could evolve given different contingencies, actions, and interventions. Multiple participants debate among themselves different strategies for handling the situation. The methods by which they jointly resolve the problem are the data of interest. We believe this approach has considerable potential as a second method to conduct a conceptual walkthrough, eliciting additional insights concerning how various human and machine elements would interact in some future system.

Our research to date indicates that the use of these methods, based on concrete scenarios depicting incidents in hypothetical worlds, is a very effective approach for identifying critical issues that need to be addressed in considering specific design proposals.

Recommendation 3: As new designs (technologies, procedures, etc.) are proposed as part of the AATT Program, these three empirical methods should be applied early in the development process to assess the viability of each such proposal, and to identify the critical issues that must be addressed prior to its implementation.

3. PRELIMINARY FINDINGS

We have applied all three of the methods described above, working with a total of 40 professional controllers, dispatchers, pilots and traffic managers. Details will be provided later in a set of technical reports. However, based on our studies involving these practitioners, certain preliminary recommendations have been developed about where to focus future research and development activities. These recommendations are outlined below. Note that our investigations to date have dealt primarily with the situations that will most challenge performance under future system designs from a safety and efficiency perspective.

3.1 Conflicting Goals and Capacity Constraints: Crossing Traffic

New ATM concepts shift authority and responsibility across different organizations. In particular, many of the ATM concepts currently being discussed decentralize and distribute authority for many decisions such as the planning and rerouting of flights. This decentralization creates the potential for cases where the goals of different participants in the ATM system interact or conflict.

One such example that has already arisen as a result of the expanded NRP involves crossing traffic around major airports. The implementation of the expanded NRP has made it clear that airlines would like to file flight plans that cause overflights to cross the preferred arrival and departure lanes at major airports. A classic example

of this arises with flights from Southern Florida to Minneapolis. With the introduction of the expanded NRP, the airline involved started filing such flights over Badger instead of over Iowa City-Waterloo. This put those flights in the departure lanes for traffic leaving Chicago O'Hare.

In the short run, the solution selected has been to deny requests for this user preferred route, or to vector such flights around the area once airborne. The net result is a significant loss of efficiency in terms of time and fuel. In this case, preliminary work with controllers and traffic managers suggests that the limiting factor is controller workload. Given traditional sectorization, this complex traffic pattern is too difficult for the controllers to deal with. Thus, solutions to eliminate this bottleneck must consider how to redefine sectors to reduce workload, how to provide tools that enhance controller capabilities (again reducing workload), or how to redefine the rules for the use of such airspace. (As an example, one controller suggested that if he were only required to maintain one thousand feet of vertical separation, he would be able to accommodate more aircraft in this situation.)

A similar situation arose involving East-West traffic over Chicago. Under the expanded NRP, airlines started filing flight plans for this traffic over arrival and departure lanes. To resolve this problem, Chicago Center created new high altitude sectors, allowing the NRP traffic to fly as filed. However, because there truly was a capacity limitation, in order to leave the NRP traffic untouched, arrivals and departures had to be restricted to lower than desired altitudes. The net result is that fuel is saved by the overflights, but extra fuel is burned by ascending and descending aircraft. As with the Badger example, the ideal solution would be to find a way to eliminate this capacity limitation.

The significance of such examples to the AATT Program is twofold. First, the airlines are already telling us by their actions where some of the important bottlenecks are that will need to be addressed by improved technologies or procedures. Second, such examples are a reminder that the aviation system includes competition for limited resources by users, and that there will continue to be a need for procedures whereby some "referee" decides what is "fair" or what is best for overall system safety and performance.

Recommendation 4: Systematically identify the types of situations where user preferences are likely to result in complex traffic patterns with crossing traffic, and explore solutions to eliminate the underlying causes of these bottlenecks. In addition, develop procedures to ensure safe, efficient, equitable handling of situations where such bottlenecks have not yet been successfully eliminated.

3.2 Conflicting Goals and Capacity Constraints: Cornerpost Loadings

Another capacity limiting situation that we have studied involves the overloading of cornerposts at an airport. A good example of this is the northwest cornerpost at DFW during peak hours. In the short run, providing AOCs with predicted loadings could help them to plan more effectively, avoiding expensive reroutings due to such overloading. In the long run, however, it would be preferable to reduce or eliminate the capacity limitation. Unlike the Badger example above, though, enhancing controller performance (in this case using tools like CTAS) only partially deals with the problem. Although capacity can be increased with such tools, another limiting factor then comes into play: runway availability given airline scheduling practices.

Recommendation 5: Explore solutions to reduce cornerpost loading problems that minimize inefficient routings or vectoring. Examine solutions that eliminate the underlying capacity constraints, as well as examining possible new decision support systems that make the most efficient use of the available capacity. (As one example, possibly add a new "strategic" component to CTAS for earlier prediction and resolution of cornerpost loadings.)

Our data suggest that situations involving conflicting goals and capacity constraints represent a very important class of problems. It is important to identify the full range of situations where conflicts like these can arise and to explore alternative solutions. Note that many of these solutions involve questions about how to support communication and coordination across different parts of the ATM system. Our data also suggest that these are quite challenging problems because they involve multiple parties and multiple goals. Careful studies will be needed to assess the feasibility of alternative solutions. Conceptual walkthroughs of these kinds of cases provide one approach to help evaluate potential solutions.

3.3 Changing Roles and Information Requirements

Changing roles by re-distributing authority (locus of control) has strong implications for the kinds of information and information displays needed to support these new roles. New ATM concepts change the roles of many of the people involved in the system. Under some current proposals under consideration, dispatchers will have more flexibility in route planning; flight crews will play a greater role in ensuring separation; and controllers will act more as monitors, making new kinds of decisions about when to intervene. If the changes created by these shifts in the locus of control, and in decisions concerning whether and when to intervene, are not accompanied by a corresponding shift in access to information, problems can arise.

3.3.1 Airlines and Flight Planning

One of the major problems with the current system is that the ATM system often has no access to information about the impact of its decisions on airline business concerns. As a result of this separation of authority and information, many of the decisions made by traffic managers and controllers are based solely on considerations regarding traffic flows and separation. Even when two solutions to a traffic problem are equally acceptable in terms of safety and traffic flow management, FAA staff generally do not have the information necessary to select a solution that is preferable to an airline in terms of its business concerns (Smith, McCoy and Orasanu, 1995).

As a response to such problems, the FAA has been shifting the locus of control to the airlines where possible. One example is with the expanded NRP, where (subject to certain constraints) the airlines are now allowed to file the routes that they prefer. The assumption is that, since the airlines have the information about their business needs, they are in a better position to make such decisions (with the ATM system then monitoring these flights to detect and deal with any potential safety or system capacity constraints). On the other hand, although the airlines have information about their own business priorities, they have only limited information about air traffic bottlenecks. As a result, they must make decisions based on inadequate information. (Appendix B provides an illustration of this in a scenario documented by a traffic manager for RTCA Working Group 5.) As several airline air traffic coordinators and dispatchers have commented in our studies:

- "Under the expanded NRP, it's like shooting ducks in the dark."
- "The problem with the expanded NRP is that there's no feedback to the AOCs. Nobody's getting smarter. Someone has to be responsible for identifying and communicating constraints and bottlenecks."
- "It used to be that weather was the biggest source of uncertainty for flight planning. Now it's the air traffic system."

Thus, whoever is given the authority to make strategic decisions about routing flights needs access to *all* of the pertinent information. The implication is that, when exploring future designs for the aviation system, one of the most important questions to be considered is how to effectively distribute and display the information needed to support decisions.

3.3.2 Flight Crews and Separation

This same general issue arises in a tactical setting because of proposals to give flight crews more authority to change routes and altitudes while enroute. How do changing roles for flight crews and controllers affect who should have access to what types of information for tactical air traffic control decisions?

If, in a free flight environment, pilots are sometimes given responsibility for maintaining separation, then they and any available support software will have to play part of the role that controllers currently play, while still dealing with their current responsibilities (keeping in mind that, under current proposals, controllers

will at a minimum still be monitoring the situation). They will have to detect potential conflict points in a timely fashion, generate solutions, and coordinate their actions with other aircraft.

Various studies of controllers indicate that there are a number of complex factors that they consider, including weather, the intentions of other aircraft, available contingencies, and positional uncertainty. In addition to considering the implications of these factors for their own flight, this new environment will require pilots to think about these factors as they impact surrounding aircraft. Interesting new patterns of communication will also be required, as there will no longer be a single authority approving route and altitude changes. Furthermore, pilots will have less knowledge than controllers currently do about typical traffic patterns in particular sectors (since pilots won't see the same sector day after day), potentially making the cognitive demands on flight crews even greater.

Thus, our research has raised provocative questions about the roles of flight crews, controllers and support software in such an enroute free flight environment. It is clear that careful consideration must be given about who should have access to what information, about how wide a "field of view" each participant should have, and about how this information should be displayed.

3.3.3 Controllers as Exception Handlers

Some of the new ATM concepts currently being considered suggest that, in certain circumstances, controllers will act as monitors, detecting problems and intervening only as necessary to resolve specific concerns. This new role has considerable implications for how controllers should obtain information. Examples of statements by controllers during our data collection help illustrate the complex issues that must be considered in proposing future system designs:

- "In adverse weather, communication occurs between controller and flight crews as needed. We ask: 'When are you going to turn?' and they say: 'I can't because weather is there.' In that case I need to do something with someone else. If I can get him out of the way, I do it. The decision and evaluation process is 10 to 20 fold more complex as no structured game plan exists. It constantly changes as their needs change in each mile they go."
- "For me to have the big picture or overview I need to know intent. Not knowing where the path is can be a problem. If I change your true path and another plane turns quickly, then we're back into trouble."
- "In free flight, nothing is preset. You will have to scan all the time. In the current system [there are] conflict points where [you expect] flows to cross on a daily basis. They are the spots you concern yourself with. You focus on conflict points. But in a free flight environment, everything is a focus point."

Thus, there are a number of tasks and situations that must be dealt with to enable enroute free flight in situations involving multiple aircraft or unpredictable weather patterns. Furthermore, it is clear that such complex factors cannot be

adequately handled by an autonomous machine agent in the foreseeable future, thus requiring that any tools developed be explicitly designed to support and enhance decision making by flight crews and controllers.

Recommendation 6: Identify the information and decision making requirements associated with new roles within proposed new ATM concepts. One tool for doing this is scenario-based walkthroughs that increase in level and scope of fidelity as the AATT project matures. The results will be an important input for the development of new technologies as true decision support systems.

3.4 Coordination During Transitions in Level or Locus of Control

Another characteristic of many of the proposed future concepts for ATM is flexibility. Under these proposals, flight paths and plans should be adjusted dynamically to best meet the rapidly changing demands and circumstances of the air traffic environment. ATC should intervene only when circumstances demand; otherwise individual operators should be able to plan flights and manage flight paths as they see fit based on their perspective and goals.

This flexibility creates demands for coordination in several ways. For example, flight crews and ground controllers will have joint responsibility for positive separation. Locus of control will shift as circumstances demand. For example, traffic density in terminal areas will require transitions from free flight rules to greater control by ATC and its supporting computers. How will these transitions be made smoothly? One of the major challenges for a more flexible and less centralized traffic management environment is the need to be able to handle transitions in locus or level of control in order to cope with highly dynamic and unpredictable factors such as weather, emergencies and system failures. How will people recognize when circumstances create the need to shift locus of control? How will people communicate the change in management strategy and transition to the a new form of control? What are the alternative levels of control? Are there intermediate levels between full ATC control and full enroute free flight?

Several of the scenarios we developed include situations where the locus or level of control needed to change in order to accommodate an event or environmental condition, thus allowing us to explore issues in successful coordination and cooperative problem-solving. Such transitions require highly effective coordination and communication between different people in the system and different computer based support systems. We also included a variety of elements that complicated communication and coordination, using these elements as probes to trigger discussion among the participants in the meeting about how to avoid or cope with such problems by means of new procedures, technologies or protocols.

3.4.1 Paradigms for Distributed Control

There is a variety of paradigms for distributing control. It is useful to consider three distinct paradigms as anchor points for exploring possible strategies in ATM. An actual system is likely to be based on intermediate strategies or a mixture of these. The first is "control by directive", where an agent in the ATM system (a controller, for example) simply issues an instruction which is to be followed (unless there is some overriding concern that prevents this). The second is "control by permission", in which the ATM system initially specifies a solution, but will consider and sometimes give permission to requests for alternatives submitted by system users. A third is "control by exception", in which system users are allowed to select and act on their own solutions or plans, which are then monitored by the ATM system for potential problems as these plans are enacted.

Within these paradigms there are a number of important variations that need to be carefully considered. For example, one extreme version of "control by exception" is to restrict interventions to localized, reactive responses by the ATM system. Under this variation, the ATM system would leave flights alone until and unless serious safety or system capacity problems were imminent. The assumption is that the users would generally select plans that avoided such situations so that interventions by the ATM system would be infrequent, functioning only as a backup safety net. Under another variation, the ATM system might play a more proactive role, dynamically setting certain constraints and communicating these constraints for the users to consider when they are comparing alternative plans. This could include examples like constraining the number of flights allowed to arrive at a particular airport when weather has impacted its operations, or curtailing enroute free flight in sectors with complex or high density traffic patterns. A third alternative would be for the ATM system to communicate a constraint by listing an explicit set of options for selection by the user. A fourth would be true collaborative control, where the users and the ATM system jointly assess the situation and consider alternatives.

Numerous human factors issues arise in considering these alternatives:

- How do we ensure adequate involvement of various participants so that they maintain situation awareness, including continuous awareness of who is in control?
- How do we ensure adequate training and involvement of various participants so that they develop and maintain necessary skills?
- How can technology support the individual performance of controllers, dispatchers, pilots and traffic managers (assessing situations and monitoring for problems; generating and selecting from alternative solutions)?
- How will workload be predicted and managed given greater variability in the behavior of the system?
- In situations where there are goal conflicts, how do we ensure that adequate "refereeing" occurs (especially if the conflict has safety implications)?
- What types of roles should be assigned to participants so that, where appropriate, effective cooperative problem-solving will occur?

- How do we ensure that adequate mutual understanding develops regarding each participant's goals, capabilities and constraints?
- How can new technologies support the communication of intent under both normal and contingency conditions?
- What types of tools should be developed to support cooperative work (e.g., tools to enhance a shared model or common ground; tools for graphic communication)?

The conceptual walkthroughs conducted to date provide initial results pertinent to these questions (details will be found in our technical reports which are in preparation). For example, the rules defining when a controller will be charged with an operational error for violation of minimum separation standards will have an impact on when controllers will consider it necessary to intervene, asserting more positive control on the aircraft they are monitoring. In regard to this issue, one of the controllers we studied indicated that if controllers would be charged with operational errors when there is a violation of separation standards between aircraft operating under free flight rules, then controllers will not be able to wait for the individual airplanes to sort out situations. Controllers will have to intervene and take control before such situations develop very far, rather than trusting the flight crews to find resolutions on their own.

In short, although our research on coordination during transitions in the level or locus of control has begun to identify some of the factors that should be taken into account and to suggest some initial solutions, there is a great deal of work left to be done to understand the impact of alternative control paradigms on individual performance, as well as on cooperative and (in some cases) competitive group performance.

Recommendation 7: Coordinated activity and cooperative problem-solving will be fundamental issues in the implementation of the proposed new ATM concepts currently under consideration. The AATT program needs to assess the potential impact of alternative methods of control and coordination on individual, group and overall system performance and to explore the design of tools for computer-supported cooperative work.

3.4.2 Communication Requirements During Transitions in Locus of Control

An environment where both pilots and controllers have joint or overlapping responsibility raises several important issues about communication. For example, there is the potential for one party to act without adequate prior communication. Knowledge of intent may be difficult to maintain in these circumstances, yet knowledge of intent may be the critical information needed to anticipate potential problems. How will controllers monitor for potential problems if they cannot assume that they know the intentions of the aircraft they are monitoring? Thus, information on pilots' and controllers' intentions, decisions, and actions needs to be

gathered and distributed very quickly to ensure that all affected parties are aware of changes in a timely fashion.

Similarly, once controllers recognize the need for intervention, how will they communicate this to all of the affected aircraft, providing assistance or asserting positive control over these aircraft and then returning them to free flight after the problem has been resolved? The pilots and controllers who participated in our studies agreed that successfully handling such situations in the future ATM system will require context-dependent, flexible and operator-controlled selection of communication media, protocols, and strategies, while recognizing concerns about potential new demands on visual attention imposed by the introduction of additional displays.

Given the many competing demands for visual attention that already exist for both pilots and controllers, it will be critical to provide them with big picture, status-at-a-glance displays that allow for parallel processing of various kinds of information. For example, the case of a transition from enroute free flight to a more controlled environment potentially requires message acknowledgments by a large number of affected crews. These acknowledgments cannot be handled solely via voice communication as the controller may have to use the voice channel for issuing urgent clearances. Most controllers consider DataLink the medium of choice for those acknowledgments. But the particular implementation of digital communication for this purpose could create user problems. For example, users did not want to have to keep track of acknowledgments by referring to and monitoring a separate chronological message list. Instead, one possible solution proposed by some controllers is to visually code affected radar targets and their datablocks to indicate whether an acknowledgment has been received by the DataLink system. The goal would be to indicate acknowledgment in a way that would support pattern recognition.

In summary, overall, communication demands, procedures, and technologies in the context of future highly flexible ATM operations are likely to differ considerably from those in the current highly standardized and more centralized ATC system. More insight is needed into the effects of introducing digital communication on the coordination between and among ground-based and airborne operators.

Recommendation 8: Examine scenarios where there are transitions in method or locus of control to help assess the design of communications technologies and procedures. Specifically, the design of protocols and interfaces for a digital communication system needs to be reviewed and adapted to future ATM operations, since designs have been driven for the most part by the demands and characteristics of the current air traffic control system. One important goal is to avoid overloading visual attention during demanding situations and to enhance system transparency so that users can

focus on what and to whom they want to communicate rather than focusing on the interface codes and commands needed to monitor and send messages.

Recommendation 9: Evaluate the potential for graphic communication tools for pilot--controller communications to coordinate interactions concerned with short-term flight plan modifications, weather phenomena and other potential hazards. Shared graphic tools are examples of computer-mediated cooperative work tools that could support transitions in locus of control, enhance shared situation awareness among flight crew, controllers and others, and support new controller roles to monitor and intervene only when needed.

3.5 Additional Specific Recommendations

Recommendations 4-9 deal with specific areas of concern that have been identified as part of our research, including issues dealing with conflicting goals and capacity constraints, changing roles and information requirements, coordination during transitions in the level or locus of control, and communication requirements during transitions in the locus of control. There are a number of other specific recommendations that we have developed which arise from the interactions of these major categories of issues. These are listed below.

Recommendation 10: Based on those scenarios that we have studied to date, we recommend research on the human factors implications of a number of technologies -

a. To support pre-flight planning by AOCs, predictive tools need to be developed to collect, analyze, disseminate and display air traffic bottleneck forecasts (analogous to weather forecasts) and to support plan generation. Even with the introduction of the expanded NRP, this is one of the major requests by dispatchers. ("What we really need to make good decisions is NRP forecasts to help us decide where traffic congestion is likely to cost us time or fuel.")

b. To support tactical planning (while a flight is enroute), similar tools need to be developed to help pilots and dispatchers detect and deal with traffic and weather conflicts. Such tools need to support the flight crew and dispatcher in considering complex factors such as the intentions of other aircraft and the availability of alternatives to deal with possible events. (A major question in designing these tools is how to provide an adequate field of view to support the detection and evaluation of developing situations.)

- c. Tools need to be developed to provide information about the availability of special use airspace to support both strategic and tactical planning by flight crews and AOCs.
- d. Tools need to be designed to provide controllers with the information needed to monitor for potential problems, so that the controller can intervene in a timely fashion to help avert a potential loss of separation or provide advice on how to deal with a developing situation. This includes information about the intentions of flights. (This need to display intent may call for changes in aircraft flight management systems as well.)
- e. Some situations will be too complex to allow enroute free flight. Tools must be designed to display the information necessary to help controllers and traffic managers to detect such situations, and to somehow communicate to AOCs and flight crews those sectors that have been permanently or temporarily designated as "controlled" or non-free flight areas. (This is similar to issues currently faced in dealing with special use airspace.)
- f. All of the above tools would help controllers, dispatchers, pilots, and traffic managers to deal with real-time problems as they are developing. Equally important are tools that provide feedback on performance. Tools need to be developed to help assess the success or failure of the strategies that various parties are applying, so that they can learn and improve.

Finally, there are a number of areas where current ATM procedures need careful investigation, looking for opportunities to provide the airlines with greater flexibility to accommodate their business needs. To make these feasible, it is likely that additional tools for computer-supported cooperative work need to be developed and studied.

Recommendation 11: Develop tools to support, and study the impact of, new ATM procedures that give the airlines more flexibility to deal with their business concerns, while ensuring safe and effective overall use of system capacity. Such procedures should deal with concerns about ground delay programs, severe weather routes, slot-swapping and runway assignments.

4. SUMMARY

The purpose of this report has been to provide an early indication of the conclusions we have reached based on our empirical studies under the AATT Program. This set of recommendations should therefore be viewed as preliminary, and incomplete. As we continue our data analysis, we may refine some of these recommendations, and identify new ones.

Generally speaking, however, our major theme is that it is important to evaluate new technologies early in the design process, and to do so in terms of the broader context of coordination and cooperation among the multiple agents within the aviation system. In conducting such evaluations, there are a number of factors that need to be considered, including:

- Processes, policies and procedures under which the system will be operated
- Information that needs to be made available to various participants
- Methods and technologies for distributing this information
- Methods and technologies for supporting individual performance
- Methods and technologies for supporting effective distributed, cooperative problem-solving

Finally, it is critically important that we understand how different support technologies will influence human performance in the context of different situations or scenarios, especially scenarios where significant capacity constraints must be dealt with, and scenarios where transitions in the locus of control must be handled.