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Validating a Future Operational Concept for En Route Air Traffic Control

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Karen J. Viets
Dr. Celesta G. Ball

MITRE

Center for Advanced Aviation System Development
McLean, Virginia

MITRE Department Approval:

Diane E. Boone

MITRE Outcome Leader:

Wesley B. Link

Abstract

In an effort to accommodate predicted growth in air traffic, the Federal Aviation Administration (FAA) and the aviation community have developed a concept of operations for the National Airspace System (NAS) called Free Flight. This operational concept has been developed for the midterm timeframe (nominally a period of time that centers around 2005). The Center for Advanced Aviation System Development (CAASD) at The MITRE Corporation, which supported the concept development, has also identified a number of issues associated with both its implementation in the midterm timeframe and the evolution to the midterm timeframe. This paper describes CAASD's laboratory efforts to begin validating the portion of the concept that applies to the en route domain by examining issues associated with the evolution to the midterm. Favorable results for CAASD's initial (qualitative) validation efforts support the need for further (quantitative) validation activities that include more detailed analyses, further development of procedures and computer-human interfaces, and more rigorous exercises involving FAA field controllers.

Index Terms—Federal Aviation Administration, National Airspace System, Air Traffic Control, En Route, Midterm, Operational Concept, Free Flight, Validation

Preface

This paper was submitted for consideration by the Institute of Electrical and Electronic Engineers (IEEE) to be published in the *Transactions on Intelligent Transportation Systems, Special Issue on Automated Air Traffic Control Systems*.

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I. INTRODUCTION

The Federal Aviation Administration (FAA) manages and develops the National Airspace System (NAS) to support safe and efficient air traffic operations. To fulfill this responsibility, the FAA must research and analyze future air traffic projections of growth, as well as the ability of the NAS to handle those projections. This research and analysis helps the FAA gain insight into which procedural and automation improvements will be required to maintain NAS safety and efficiency as the traffic loads, patterns, and characteristics change. One key result of recent research and analysis was wide recognition that many NAS improvements are required to maintain safety and efficiency for the projected changes in traffic [1, 2, 3].

The FAA and the aviation community have developed a concept of operations called Free Flight that will accommodate the predicted growth in air traffic while maintaining safety and efficiency in the NAS [4, 5]. This operational concept has been developed for the midterm timeframe (nominally a period of time that centers around 2005) and builds on Free Flight Phase 1 (FFP1) capabilities that have been identified for implementation by 2002 [6].

The MITRE Corporation's Center for Advanced Aviation System Development (CAASD) supported the FAA in providing a more detailed description of the midterm operational concept for the en route domain of the NAS [7]. This detailed description includes a number of issues that must be resolved before the concept can be considered validated. In fiscal year (FY) 1999, CAASD began addressing these issues for both the midterm concept [8] and a possible evolution to the midterm [9].

This paper provides an overview of both the operational concept for the en route domain and the initial concept validation activities that were performed in FY 1999. A summary of the initial validation results is also provided, along with a brief description of the future activities necessary to complete the concept validation.

The CAASD validation activities described herein represent the beginning of a multi-year effort to fully validate the en route operational concept and its evolution. In this initial validation, qualitative (rather than quantitative) results were obtained to help the FAA define future validation activities. Favorable results for this initial validation support the need for further (quantitative) validation activities that include more detailed analyses, further development of procedures and computer-human interfaces, and more rigorous exercises involving FAA field controllers.

II. Overview of the Operational Concept for En Route Air Traffic Control

Today, NAS operations in the en route domain involve the NAS users as well as the FAA's en route service providers. The NAS users include pilots and flight dispatch personnel, such as those working with Aeronautical Operational Control (AOC) at the airlines[1]. The pilots and AOC personnel are interested in the safe and timely completion of their flights, and are involved in flight planning and execution, as well as in managing special situations, such as avoiding hazardous weather areas. In choosing a strategy for handling special situations, pilots and AOC personnel have different roles: pilots have specific knowledge of their own flights, and AOC personnel manage the entire fleet for their specific airline. NAS users generally have preferences about how to best handle their flights; because these preferences vary, they are best accommodated when the NAS users have ample freedom in flight decision-making.

The FAA's en route service providers include air traffic controllers and traffic management specialists, who are responsible for maintaining the safety and efficiency of the NAS, and are involved in flight planning, flight monitoring, and managing special situations. The controllers are responsible for maintaining adequate separation between aircraft, and between aircraft and Special Use Airspace (SUA). The controllers also respond to pilot requests, such as a flight plan change request to transition to a higher flight level for avoiding turbulence. The traffic management specialists perform more strategic tasks to improve the efficiency of the NAS, such as monitoring traffic flows, implementing flight restrictions, and rerouting air traffic to avoid hazardous weather areas. Because the en route service providers are responsible for all en route air traffic in the NAS, they make decisions to reroute or delay flights as necessary to maintain overall system safety and efficiency. In the future, an increase in collaborative decision making between the en route service providers and the NAS users will improve NAS efficiency by improving the balance of air traffic demand with system capacity, enabling efficient utilization of NAS resources.

The midterm operational concept enhances en route NAS operations by increasing the flexibility and freedom afforded to the NAS users and by improving the efficiency for performing en route service provider tasks. *NAS user flexibility and freedom* are improved by the following enhancements:

- Collaborative decision making – sharing operational information and decision-making responsibilities between en route service providers and NAS users.

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[1] Other users not explicitly discussed include personnel associated with military and General Aviation (GA) flights.

- Flexible scheduling – allowing NAS users to file flight plans based on their own preferences for departure and arrival times.
- Flexible routing – allowing NAS users to choose flight routes beneficial to their own operations, rather than routes that are preferred by the air traffic control system.

These enhancements facilitate strategic planning by NAS users and reduce the need for more tactical flight plan change requests during flight.

Efficiency for performing en route service provider tasks is improved by the following enhancements:

- Supporting increased NAS user flexibility – reducing the service provider workload for implementing flight restrictions and responding to user requests.
- Shifting service provider tasks from those that involve reacting to tactical situations to those that involve strategic planning – reducing the number of tactical control actions that become necessary for service provider implementation.
- Improving the supporting capabilities – improving the ability to perform accurate strategic planning and adjust to changing traffic patterns and loads, reducing the number of voice interactions, and expediting communication between NAS users and service providers.

These enhancements enable the service providers to handle increasing volumes of air traffic without proportionally increasing their workload.

Enhancements to the NAS operations that increase user freedom and service provider efficiency lead to reductions in the number of flight restrictions, voice interactions, and tactical control actions per flight, reducing the operational cost per flight and increasing the efficiency of NAS operations. These enhancements represent a departure from current NAS operations, employing principles of operation that are fundamentally different from those employed today. The concept described below for the FFP1 timeframe begins the evolution of the NAS towards this midterm operational concept.

The en route operational concept for both the FFP1 and midterm timeframes can be described by the roles and responsibilities of the en route service providers, the information flow among the en route service providers, and the capabilities required to support efficient en route operations. These three factors are briefly described below for the FFP1 and midterm timeframes, providing a high-level description of the operational concepts.

A. FFP1 Timeframe

In the FFP1 timeframe, the controller team for a portion of airspace called a sector includes a Radar controller (called the "R controller") and a collocated Flight Data controller (called the "D controller")[2]. The roles and responsibilities of the sector team include working together to resolve predicted problems[3] in the next 20 to 30 minutes, respond to user (pilot) requests, handle voice communications with pilots, and coordinate with adjacent sectors. In addition, traffic management specialists work to resolve predicted flow problems beyond 30 minutes, performing tasks such as planning flow restrictions and coordinating flight plan modifications to reduce the effect of hazardous weather and other special situations on the NAS.

Some of the key FFP1 capabilities supporting these en route service providers are the following:

- *Problem prediction, notification, and resolution* for D controllers using a Core Capability Limited Deployment (CCLD) version of CAASD's User Request Evaluation Tool (URET) [10, 11]. In the FFP1 timeframe, the D controller is notified of predicted problems and can use URET CCLD's manual trial planning capability to develop resolutions for those problems. The D controller can also use URET CCLD's automated replan capability to request that a trial plan be periodically checked until it no longer creates additional problems, at which time the D controller is notified that the trial plan is ready for implementation.
- *Automated (electronic) coordination* of problem resolutions (trial plans) among D controllers using URET CCLD.
- *Initial collaborative decision making* between traffic management specialists and AOC personnel.

Although there are other key capabilities associated with FFP1 [6], the capabilities listed above are building blocks for the capabilities associated with the en route concept for the midterm timeframe. A brief overview of the concept for the FFP1 timeframe, showing the

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2 The D controller is also referred to as the Radar Associate controller. In some sectors, there may be additional positions, such as Radar Coordinators, Radar Flight Data controllers, and Non-Radar positions, that are beyond the scope of this paper.

3 In the FFP1 timeframe, a problem is a predicted loss of separation between an aircraft and any one of the following: other aircraft, SUA, and terrain and obstructions.

types of communications among the NAS users and the en route service providers, is shown in Figure 1 (a)[4].

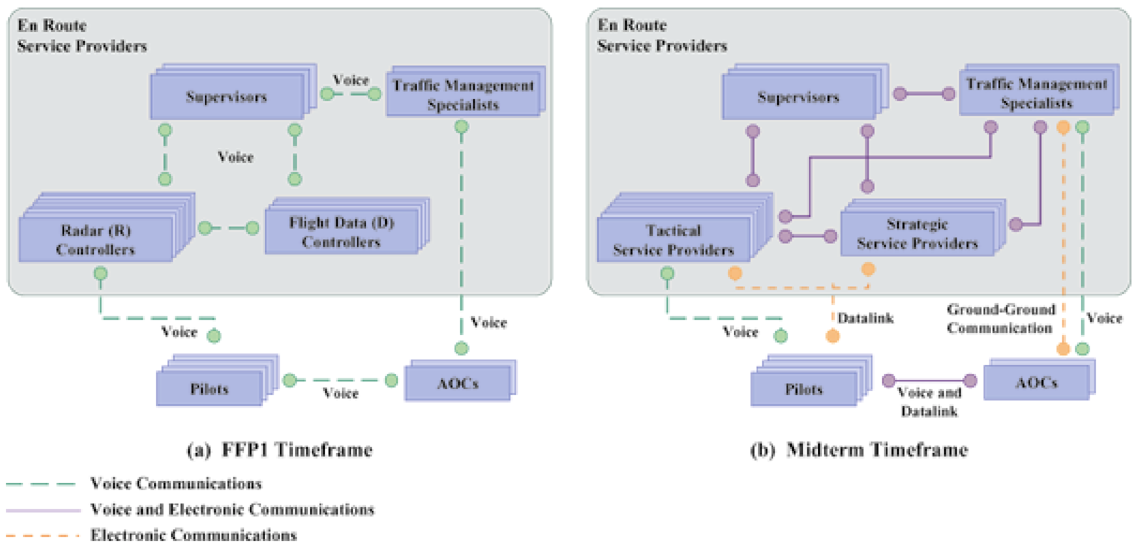

Figure 1. Concept Overview for FFP1 and Midterm Timeframes

As in today's NAS, two sector team configurations are available in the FFP1 timeframe for managing daily variations in air traffic patterns and loads. During periods of low to moderate traffic for a sector, an R controller can operate the sector alone. During heavier traffic loads, a collocated D controller can support an R controller in maintaining aircraft separation. As shown in Figure 2 [6], the R controller generally monitors the radar display and handles control actions of a more immediate nature, such as separation problems and user requests, as well as voice communication with pilots and coordination with adjacent sectors. The D controller helps the R controller as necessary.

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4 Although not shown in the figure, electronic communication called Voice Switching and Communication System (VSCS) exists between sector teams.

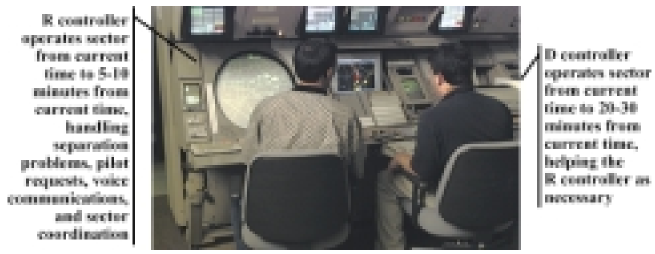

Figure 2. Roles for R and D Controllers in the FFP1 Timeframe

B. Midterm Timeframe

In the midterm timeframe, the en route service providers handling a sector of airspace include a tactical service provider and a collocated or non-collocated strategic service provider. The roles and responsibilities of these service providers include working in different time intervals to resolve predicted problems[5], respond to user (pilot) and traffic management specialist requests, handle voice and electronic communications with pilots, and coordinate with other sectors. The traffic management specialists perform tasks such as collaborating with AOC personnel, modifying flight plans to reduce the effect of hazardous weather and other special situations on the NAS, and electronically communicating flight plan change requests to the appropriate strategic service providers for implementation.

Some of the key midterm capabilities supporting these en route service providers are the following:

- *Problem prediction, time-based notification[6], and resolution* for the tactical and strategic service providers. In the midterm timeframe, the tactical and strategic service providers are notified of their assigned predicted problems and can use either the manual or automated trial planning capabilities, as well as the automated replan capability, to develop problem resolutions.

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5 In the midterm timeframe, a problem is a predicted loss of separation between an aircraft and any one of the following: other aircraft, SUA, complex traffic airspace, terrain and obstructions, or hazardous weather areas. It is also used to refer to a predicted failure of an aircraft to comply with a traffic planning constraint.

6 In the midterm timeframe, problems are allocated based on the amount of time before the problem is predicted to occur. With time-based problem notification, the tactical service provider is responsible for resolving tactical problems (such as in the next 15 minutes) and the strategic service provider is responsible for resolving strategic problems (such as from 15 to 40 minutes from the current time).

- *Automated coordination* of problem resolutions (trial plans) among tactical and strategic service providers.
- *Electronic air-ground communications (datalink)* between the tactical and strategic service providers and the pilots.
- *Enhanced collaborative decision making* between traffic management specialists and AOC personnel.

Although there are other key capabilities associated with the midterm [7], the capabilities listed above are enhancements to the key capabilities described for the FFP1 timeframe. A brief overview of the concept for the midterm timeframe is shown in Figure 1 (b).

Using the midterm capabilities that support the tactical and strategic service providers[7], five sector team configurations [7] become available for managing daily variations in traffic patterns and loads (Figure 3). During periods of the lowest traffic load for a sector, a tactical service provider can operate the sector alone. As the traffic load increases, a non-collocated or collocated strategic service provider can serve as a multi-sector strategic service provider by supporting two or more tactical service providers, as appropriate, to manage the traffic variations and maintain NAS efficiency. During the highest traffic loads, a collocated or non-collocated strategic service provider can support a single tactical service provider (similar to today's sector configuration in which a collocated D controller supports an R controller). In this case, the strategic service provider performs strategic tasks that decrease the tactical service provider's workload, creating an environment in which the tactical service provider can handle all of the tactical problems and user requests. As shown in Figure 4, the tactical service provider generally monitors the radar display and handles control actions of a more immediate nature. The strategic service provider handles strategic problems and requests from the traffic management specialists.

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7 In addition to the capabilities described for the strategic service provider in the midterm concept [7], CAASD is currently developing a concept for a multi-layer planning capability that will support the resolution of strategic problems involving more than one sector of airspace.

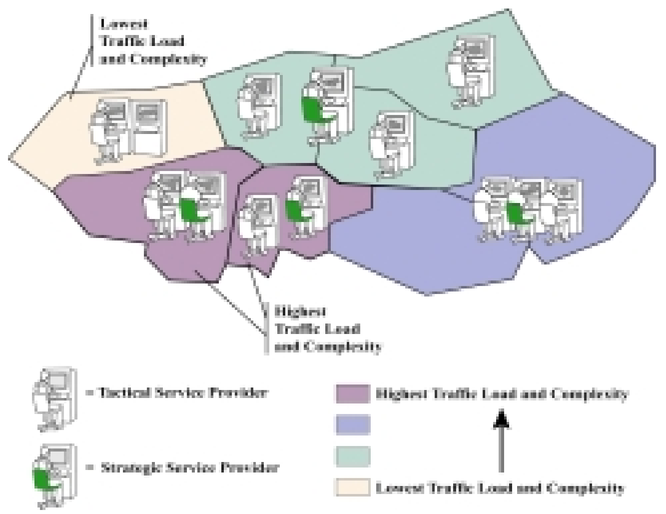

Figure 3. Sector Team Configurations for the Midterm

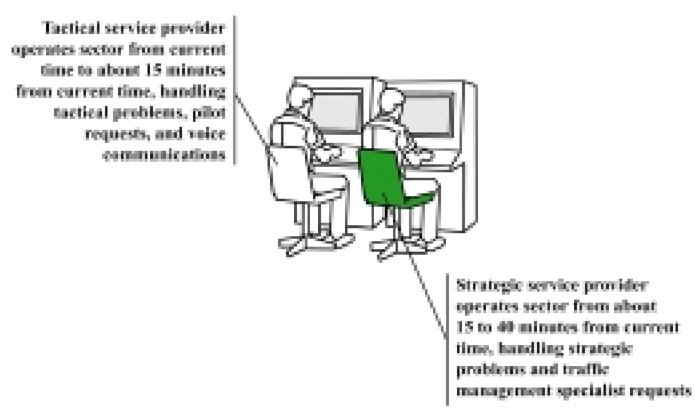

Figure 4. Roles for Tactical and Strategic Service Providers in the Midterm Timeframe

III. Overview of the Initial Operational Concept Validation

The midterm en route operational concept outlined above describes improvements needed in the areas of problem prediction and resolution, complex traffic airspace, traffic planning constraints, hazardous weather, information exchange, and sector workload management. The improvements described for these areas are central to the FAA development process and, once validated, will drive NAS development in the evolution from the FFP1 timeframe to the midterm timeframe. CAASD began validating midterm operational concepts in FY 1999 by choosing validation exercises that address some of the initial improvements.

The areas of needed improvements are summarized below, along with the validation exercises that were chosen for FY 1999, the laboratory environment, and the evaluation process.

A. Areas of Needed Improvements

The areas of needed improvements to be addressed during the ongoing validation of the midterm concept are briefly described below:

- *Problem prediction and resolution* – reducing or eliminating route and altitude restrictions to accommodate NAS user preferences, such as more direct routes, will change traffic patterns and loads in the sectors. Enhanced capabilities for problem prediction and resolution[8] are required to help the sector team maintain safety in the NAS.
- *Complex traffic airspace* – increasing the accommodation of user preferences can increase the complexity of dynamic air traffic flows. A capability for predicting the time and the location of potentially complex traffic airspace allows time for collaboration between the NAS users and the en route service providers, as well as for adjusting the air traffic facilities (such as the sector team configurations) to best accommodate the changing traffic flows.
- *Traffic planning constraints* – potentially complex traffic airspace can require the use of traffic planning constraints, such as reroutes and metering restrictions, to reduce the level of airspace complexity. Capabilities for (1) helping the traffic management specialists to identify aircraft-specific constraints[9], (2) electronically coordinating

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8 Problem resolutions are generally problem-free for up to 20 minutes, reducing the number of controller and pilot actions required for a flight.

9 In today's system, traffic planning constraints cannot be issued on an aircraft-specific basis and inevitably affect more flights than necessary.

these constraints (called traffic management specialist requests) with the sector team, and (3) checking these constraints for problems before implementation enable the sector team to efficiently implement these requests without causing additional problems.

- *Hazardous weather* – because NAS users wish to avoid hazardous weather areas in favor of more penetrable weather areas, capabilities for identifying and characterizing weather areas allow the sector team and the traffic management specialists to create more accurate flight plans that better accommodate user preferences.
- *Information exchange* – because the verbal exchange of information can result in misinterpretations and the information required for effective decision making is not always available, improved methods of exchanging, collecting, and disseminating information are needed.
- *Sector workload management* – increasing levels of future traffic loads and complexities will increase the number of traffic planning constraints that result in delays for the NAS users. Capabilities for managing sector workloads by varying sector team configurations allow the en route sector team to better handle the traffic variations, reducing the number of traffic planning constraints and the resulting delays.

While the FY 1999 validation exercises described below begin to address some of the improvements in the areas of problem prediction and resolution, and information exchange, future validation activities are required to completely examine these and the remaining improvements.

B. Validation Exercises

The FY 1999 validation exercises begin to address some of the improvements associated with the midterm operational concept. These exercises are described below for the R-side capabilities evolution and the multi-sector strategic service provider evaluations.

1) R-Side Capabilities Evolution

URET, one of the new capabilities to be provided in the FFP1 timeframe, helps the en route sector team in managing user requests for flight plan changes and in handling problems with other aircraft and with SUAs. However, the functions, displays, and interface devices associated with this capability are logically and physically dedicated to the D-side (D controller) position. The R controller can access URET and its capabilities only through the D-side: by requesting the D controller to perform a particular task, by physically turning attention to the D-side displays to scan for information, or by physically handling the D-side interface devices when the D-side position is not staffed.

The question arises whether the R controller should have direct access to URET and its capabilities via the R-side displays and interface devices. The capabilities that might benefit the R controller include the following:

- *Improved access to flight data on the R-side* – automatic display of a subset of flight data, without paper flight progress strip posting or marking.
- *Improved access to problem prediction information on the R-side* – automatic display of the problem list and the associated data block indicators representing information about predicted problems up to 20 minutes in the future.
- *Availability of flight planning capabilities on the R-side* – including manual trial planning, automated replan, and automated coordination of problem resolutions between and within sector teams[10].

This set of R-side capabilities was implemented in a laboratory setting and a companion set of operating guidelines was developed for use in evaluations. A limited evaluation (one exercise) was carried out in July and August of 1999, using former controllers as evaluation subjects and considering all of the above capabilities, with the exception of automated coordination.

In the R-side capabilities exercise, three evaluation sessions were completed, each of which consisted of two scenario runs. For each run, data was collected for two sectors that were staffed only by R controllers. As a result, there were twelve single-sector sets of data collected from this particular exercise.

The specific question motivating the evaluation was "Can direct access to problem prediction (and its associated capabilities) via R-side displays and interactions benefit air traffic control?" The evaluation specifically examined procedures (How should the R controller interact with the new capabilities?) and information requirements (What information should be available to the R controller to facilitate the use of the new capabilities?).

Resource limitations prevented the inclusion of baseline runs to represent current NAS operations without the additional capabilities. Comparisons to current NAS operations were based on the subjective judgement of the evaluation subjects obtained during the validation exercise.

2) Multi-Sector Strategic Service Provider

Two capabilities that serve as building blocks for the multi-sector strategic service provider concept were chosen for beginning the validation in FY 1999: the automated

10 In the FFP1 timeframe, automated coordination is only provided among D controllers.

coordination of problem resolutions (trial plans) from the strategic service provider to the tactical service provider, and the time-based allocation of responsibility for resolving predicted problems (time-based problem notification). A phased approach was used in defining the validation exercises to facilitate the comparison of these new capabilities to an FFP1 baseline. This approach also helps address the evolution from the FFP1 timeframe to the midterm timeframe.

The three validation exercises for the initial multi-sector strategic service provider evaluation in FY 1999 are briefly described below:

1. *FFP1 baseline capabilities in two sectors that are staffed by two R controllers and two D controllers* – baseline of the FFP1 capabilities, which support only the D controller, using a sector team configuration available in FFP1. In this exercise, two adjacent sectors were operational, each of which was staffed by an R controller and a D controller. The baseline capabilities provided for the D controller included the following: (1) problem prediction and notification, (2) manual trial planning for problem resolution, (3) automated replan, and (4) automated coordination of trial plans among D controllers.

2. *Initial advanced capabilities in two sectors that are staffed by two tactical and two strategic service providers* – operation with several advanced capabilities, which support both the tactical and the strategic service providers, using the same sector team configuration as was used in the FFP1 baseline exercise. As in the previous exercise, two adjacent sectors were operational, each of which was staffed by a tactical and a strategic service provider. The capabilities provided for each position included (1) problem prediction and time-based notification[11], (2) manual trial planning for problem resolution, (3) automated replan, and (4) automated coordination of trial plans from strategic service providers to tactical service providers (as well as among strategic service providers).

3. *Initial advanced capabilities in two sectors that are staffed by two tactical service providers and one strategic service provider* – operation of the same advanced capabilities as in the previous exercise, using a sector team configuration in which the strategic service provider operates more independently and supports more than one sector. In this exercise, two adjacent sectors were operational, each of which was staffed by a tactical service provider; a single strategic service provider supported

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[11] The tactical service provider only received notification of problems predicted to occur within the next five minutes, while the strategic service provider received notification of all of the problems predicted to occur in the next 20 minutes.

both of these sectors. The capabilities provided for each position are the same as the capabilities provided for the positions in Exercise 2.

These three exercises illustrate examples of the FFP1 baseline concept, an interim concept that retains the one-to-one strategic-to-tactical service provider ratio using several advanced capabilities, and a potential sector team configuration (multi-sector strategic service provider) that becomes available with the implementation of these advanced capabilities.

Each of these exercises was completed once, using one of the scenarios developed for the R-side capabilities evolution exercise. Data were collected from each staffed position during each of the three exercises.

Some of the validation questions to be addressed involved how the concepts affect the manner and efficiency of the following: (1) service provider response to increasing sector workload, (2) coordination between service providers, both within and between sectors, (3) problem resolution, and (4) service provider response to pilot requests.

C. Laboratory Environment

The laboratory used for the evaluations was built upon an emulation of the Host Computer System (HCS) dynamic simulation (DYSIM) capability [12]. As shown in Figure 5, the laboratory provided two en route sectors, each with two staffed (evaluated) positions: the Radar, or R-side, position for use by R controllers and tactical service providers, and the Radar Associate, or D-side, position for use by D controllers and strategic service providers.

- The R-side position included a keyboard, trackball, and DSR-like[12] display. The HCS interface allowed access to all of the HCS functions used by today's controllers, plus access to new functions and displays representing the new capabilities to be evaluated. However, the interface remained "Host-like," using quick action keys (QAKs), functions displayed in the R-CRD (Controller Readout Device), tabular lists, indicators in the full data block, and the route readout display.
- The D-side position included a URET keyboard, mouse, and Sony 2K x 2K display, but did not include a functional DSR keyboard. As a result, the D-side position could interface with the HCS only through URET, and could not amend flight plans (except to activate a URET trial plan) or accept handoffs using the normal HCS interface.

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[12] DSR (Display System Replacement) is a program to upgrade current controller displays using newer technologies.

The R-side capabilities evolution evaluation used only the R-side position at each sector, while the multi-sector strategic service provider evaluations also used the D-side positions.

In addition to the R-side and D-side positions, two “sim (simulation)-pilot” positions were staffed to represent all of the pilots, and an all-other R-side (“sim-controller”) position was staffed to represent all of the other sector controllers that would communicate with the staffed R-side and D-side positions. The execution of an exercise was managed from a separate position called session control, which allowed an analyst to start, pause, and stop the exercise, and provided real-time output for monitoring the progress of the exercise.

New supporting laboratory capabilities were developed for the evaluations to enhance the standard DYSIM capabilities and to augment the existing System Analysis Recording (SAR) capabilities [13]. The automated data collection capability captured information about predefined events and stored the data for off-line post-processing and analysis. Although the automated data collection capability was used for both the R-side capabilities evolution and the multi-sector strategic service provider evaluations, the voice recording capability shown in Figure 5 was used only for the R-side capabilities evolution evaluation.

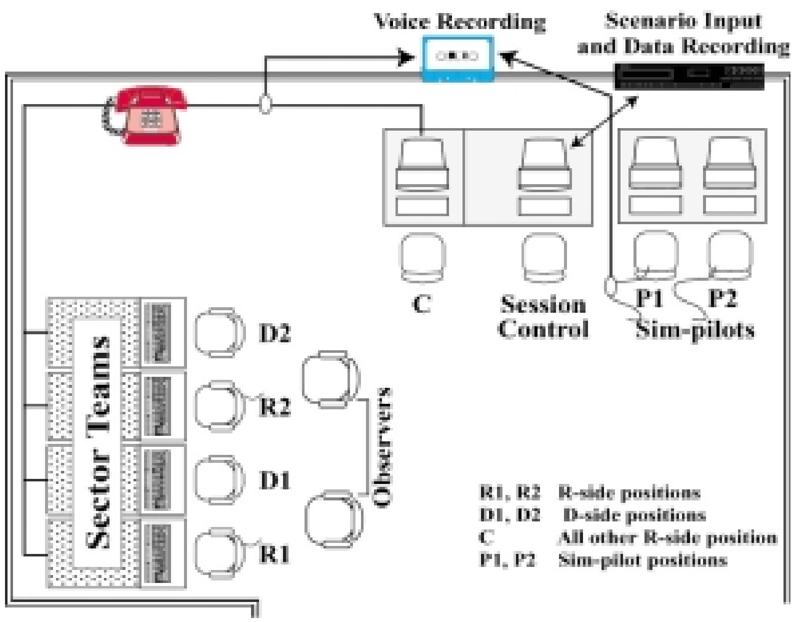

Figure 5. Laboratory Environment

D. Evaluation Process

The evaluation process consisted of three distinct but related phases:

- Planning and preparation
- Evaluation activities
- Post-processing and analysis

In preparing for the evaluation, two adjacent sectors in the Memphis Air Route Traffic Control Center (ARTCC, or Center) were evaluated. These sectors controlled a mixture of traffic consisting of overflights, arrivals, and departures. A third sector represented all other sectors below, beside, and above the two evaluation sectors.

Traffic scenarios were generated from actual flights flown on 28 April 1999 to contain the following: (1) traffic flowing through and around the two selected sectors of Memphis Center and (2) user requests to represent earlier climbs to cruise altitude and shorter, “direct to destination,” routes (sim-pilots were trained to make these user requests as the flights called in “on frequency” to the appropriate sector). Three scenarios were used: a training scenario with a low traffic load to allow time for the subjects to practice using the new capabilities, and two evaluation scenarios with varying traffic loads (low to high) to evaluate the new capabilities under higher traffic conditions.

Training materials were then created to familiarize the evaluation subjects with the laboratory capabilities. Four evaluation subjects were recruited from CAASD staff and trained in DYSIM and new capability operations with the Memphis airspace. Of the four subjects, two were retired en route controllers, two had previous experience as military air traffic controllers, and one had previous experience as a tower, terminal, en route, and military controller. CAASD staff were recruited and trained to staff the other (support) positions during the exercises, including five sim-pilots and two sim-controllers. Four of the sim-pilots were licensed pilots. One of the sim-controllers was a former terminal controller, and the other was a trained FAA controller who was awaiting placement in a Center.

After the requisite training, the test subjects participated in the actual evaluation activities. Data were collected electronically as well as by observation during the exercises. After each session, the evaluation subjects were interviewed to obtain more detailed feedback about the new capabilities and the operational guidelines provided for using these capabilities. Post processing and data analysis were then performed and the results were documented [8, 9].

IV. SUMMARY OF RESULTS FOR INITIAL VALIDATION

Because the initial validation produced limited data, it is more appropriate for suggesting ranges, magnitudes, or interdependencies between different data items than it is for drawing any specific conclusions. Any insight into event relationships must be considered preliminary because the number of exercises was limited, the traffic scenarios did not represent the full level of expected 2005 traffic volume or routings, and the participating evaluation subjects had limited training with the proposed capabilities.

The results of these evaluations were qualitative rather than quantitative, but they support the need for further investigation, as well as provide valuable insight and direction for future validation activities. The results of the R-side capabilities evolution and the multi-sector strategic service provider exercises are summarized below.

A. R-Side Capabilities Evolution

In the R-side capabilities evolution exercise, all of the evaluation subjects recommended that each proposed capability (improved access to flight data and problem prediction information, and access to flight planning capabilities) become an R-side capability. Using the problem prediction and notification capability, subjects were aware of problems earlier and took action sooner to resolve the problems. The subjects stated that the problem resolution (manual trial planning) capability was useful in evaluating user requests and in resolving problems. They stated that automated replan is useful in handling user requests, and additional uses should be investigated (such as when the controller intends to issue a clearance--for any reason--and is currently unable to do so, possibly because the controller is busy with other tasks).

All evaluation subjects agreed that the information provided by the new capabilities was adequate. Subject comments included implications for workload in a tactical environment, including the following:

- A possibly negative impact in facilities where there is a heavy reliance on flight progress strip marking as non-verbal coordination through a potential increase in verbal communications between the R and D controllers.
- A possibly negative impact through a potential increase in workload for the R controller, resulting from the use of trial planning for user requests.
- A possibly positive impact through a decrease in communications with other sectors because of automated replan.

Recorded data from the limited evaluation show that controllers reacted differently to the same traffic and initial scenario conditions, making different tradeoffs between resolving problems and satisfying user requests. In addition, controllers adjusted their workload by accelerating or delaying the initiation and acceptance of handoffs. Although each subject conscientiously handled problems and user requests, even trying many approaches when necessary, the use of the new capabilities was reduced in favor of familiar capabilities as the traffic and its associated workload increased. How much of this response was a result of limitations in training is not known, but the subjects' willingness to use the capabilities was certainly strong.

The exercise conditions represented by the R-side capabilities evolution evaluation were most similar to the conditions represented by the second multi-sector strategic service provider exercise, with both the tactical and the strategic service providers being given problem notification and planning capabilities. The conditions differed in that the R-side evaluation did not include automated coordination, but did include problem notification for the R controller up to 20 minutes in the future. Under the multi-sector strategic service provider exercise conditions, the tactical service provider received problem notifications only up to five minutes in the future. The data from the R-side evaluation were examined for insight into whether R controllers working alone used planning capabilities to resolve problems with a lead time of less than five minutes and whether an R controller (without automated coordination) receiving a problem with a lead time between 5 and 20 minutes waited to resolve the problem until one of the aircraft was controlled by the sector.

The data from all of the R-side evaluation runs were aggregated, contrasting when a problem was posted with when it was resolved, whether trial planning was used, and where the aircraft were when problem resolution and trial planning occurred. Problems were separated into two time intervals: short-term problems (2 to 5 minutes) and long-term problems (5 to 20 minutes), depending on the lead time when they were posted. Problems posted with less than two minutes' lead time were ignored in this analysis.

The following insights were obtained:

- There were no cases in which a short-term problem was posted before either aircraft had entered the sector receiving the notification. This result suggests that the subject controllers were effective in ensuring that aircraft were problem-free at least five minutes into the future. In fact, there were no problems with a lead time of less than 8.8 minutes posted at a sector before either of the aircraft involved in a problem entered the sector.

- In 90% of the cases when a short-term problem was posted (and resolved) after at least one aircraft entered the sector, the controller resolved the problem without using trial planning. This result might suggest that R controllers prefer not to use trial planning (or prefer to use more familiar capabilities) to resolve short-term problems.

- In every case when a long-term problem was posted and resolved before either aircraft entered the sector, the R controller did not use trial planning. These problems (23% of all problems posted) were posted with an average lead time of 13.1 minutes, but were resolved, on average, within 3.1 minutes of initial posting. Because automated coordination was not available, coordination in all cases was verbal. This result might suggest that the R controller did not want to create coordination workload in addition to the workload caused by manual trial planning, but raises the question of whether automated trial planning or automated coordination could make trial planning more attractive in such cases.

- In about 29% of the cases when a long-term problem was posted before either aircraft entered the sector, but resolved after at least one aircraft had entered the sector, the R controller had used trial planning. In each case, the aircraft for which the trial plan was built had not yet entered the sector. The problems for which trial planning was used had a longer average lead time (16.9 minutes) than those resolved without trial planning (13.0 minutes) and took longer, on average, to resolve (12.9 vs. 7.9 minutes, see bullet below).

- In about 17% of the cases when a long-term problem was posted (and resolved) after at least one aircraft entered the sector, the controller had used trial planning. However, when trial planning was used, the location of the aircraft being trial planned (inside or outside the sector) did not seem to be important.

- Problems that were resolved using trial planning took longer on average to resolve than problems resolved without trial planning. Whether the longer resolution time was due to the difficulty of the problems, the difficulty of trial planning, the presence of higher-priority activities, or some other unknown factor cannot be determined from the data.

- During each evaluation run, R controllers built between four and six trial plans for each 10 user requests. This result might suggest that controllers were more willing to use trial planning when the time pressure was less, since user requests were made upon frequency check-in at the sector and did not involve problems with current flight plans. A small number of requests per run resulted in more than one trial plan as the controller tried to “come close” to satisfying a request that could not be cleared exactly as requested.

The qualitative results described above support the need for further investigation of the R-side capabilities evolution through the use of more rigorous validation exercises performed by FAA field controllers.

B. Multi-Sector Strategic Service Provider

The results of the analysis for the multi-sector strategic service provider exercises suggest that the additional capabilities of time-based problem notification to the tactical and strategic service providers and automated coordination from the strategic to tactical service providers were generally feasible. The results also suggest that the new sector team configuration, in which one strategic service provider served as a multi-sector strategic service provider by supporting two tactical service providers, was feasible. The qualitative results obtained from these exercises support the need for further investigation of the associated capabilities through the use of more rigorous validation exercises performed by FAA field controllers.

Post-exercise interviews were performed and although detailed results could not be obtained for the time-based problem notification capability (due to limited controller exposure and training), much feedback concerning strategic-to-tactical automated coordination was obtained. All of the evaluation subjects considered the automated coordination from strategic service provider to tactical service provider to be potentially useful; in fact, there was agreement that automated coordination from the strategic to the tactical service provider should be recommended as a midterm capability. In addition, the following observations were made:

- While most evaluation subjects found that the information provided in the automated coordination request was adequate, suggestions were made for improving the description of the clearance given for lateral maneuvers.
- There was agreement that the use of automated coordination would change the way the tactical and strategic service providers interact by limiting the verbal communication, and therefore might compromise the ability of the tactical and strategic service providers to work as a team in managing the sector's traffic.
- Most evaluation subjects thought that automated coordination would have little impact on service provider workload, with the decrease in verbal communication offsetting the additional workload associated with entering and responding to requests.

V. Future Validation Activities

The FY 1999 exercises accomplished the first steps towards evaluating the evolution of R-side capabilities and validating the proposed en route sector team operational concept. Favorable results for CAASD's initial (qualitative) validation efforts support the need for further (quantitative) validation activities that include more detailed analyses, further development of procedures and computer-human interfaces, and more rigorous exercises involving FAA field controllers. The capabilities chosen for validation are considered essential building blocks for future concept validation exercises that CAASD plans to conduct with FAA field personnel. As CAASD's operational concept validation work continues, further details for each of the planned exercises will be developed in a manner similar to that used for these initial exercises, and results will be provided.

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Glossary

AOC	Aeronautical Operational Control
ARTCC	Air Route Traffic Control Center
ASD	System Architecture and Investment Analysis
ATP	Air Traffic Plans
AUA	Air Traffic Systems Development
CAASD	Center for Advanced Aviation System Development
CCLD	Core Capability Limited Deployment
CRD	Controller Readout Device
D	Flight Data
DSR	Display System Replacement
DYSIM	Dynamic Simulation
FAA	Federal Aviation Administration
FFP1	Free Flight Phase 1
FY	Fiscal Year
GA	General Aviation
HCS	Host Computer System
IEEE	Institute of Electrical and Electronic Engineers
NAS	National Airspace System
QAK	Quick Action Key
R	Radar
SAR	System Analysis Recording
SIM	Simulation
SUA	Special Use Airspace
URET	User Request Evaluation Tool
VSCS	Voice Switching and Communication System