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Advanced Concept of the National Airspace System of 2015: Human Factors Considerations for Air Traffic Control

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June 2007

DOT/FAA/TC-TN-07/21

U.S. Department of Transportation
Federal Aviation Administration

William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

NOTICE

Technical Report Documentation Page

1. Report No. DOT/FAA/TC-TN-07/21	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Advanced Concept of the National Airspace System of 2015: Human Factors Considerations for Air Traffic Control		**5. Report Date** June 2007
		6. Performing Organization Code AJP-6110
7. Author(s) Ben Willems, Human Factors Team – Atlantic City, ATO-P Anton Koros, Northrop Grumman Information Technology		**8. Performing Organization Report No.** DOT/FAA/TC-TN-07/21
9. Performing Organization Name and Address Federal Aviation Administration Human Factors Team – Atlantic City, ATO-P William J. Hughes Technical Center Atlantic City International Airport, NJ 08405		**10. Work Unit No. (TRAIS)**
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address Federal Aviation Administration Human Factors Research and Engineering Group 800 Independence Avenue, S.W. Washington, DC 20591		**13. Type of Report and Period Covered** Technical Note
		14. Sponsoring Agency Code ATO-P

15. Supplementary Notes

16. Abstract

During the next decade, all users and service providers within the National Airspace System (NAS) will experience profound changes. This report focuses on changes to the roles, responsibilities, and procedures for air traffic controllers during the transition and implementation of the new NAS. This report provides a description of upcoming enhancements for each system, human factors implications of these enhancements, and the effect of these new technologies and processes on air traffic controllers. The authors suggest that technology alone will not be able to support the increased capacity demands and that system designers will need to rely on a combination of technology and consideration of the human operators in the system. They conclude that the primary human factors considerations of these new technologies and procedures are in the areas of information processing, situation awareness, workload, errors, skill acquisition and maintenance, and new roles and responsibilities.

17. Key Words Air Traffic Controllers Human Factors Considerations National Airspace System	**18. Distribution Statement** This document is available to the public through the National Technical Information Service, Springfield, Virginia, 22161. A copy is retained for reference at the William J. Hughes Technical Center Library.

19. Security Classification (of this report) Unclassified	**20. Security Classification (of this page)** Unclassified	**21. No. of Pages** 49	**22. Price**

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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Executive Summary

Over the next decade, the National Airspace System (NAS) modernization will result in profound changes for all NAS users and service providers. The purpose of this report is to identify human factors implications of these new technologies and processes on air traffic controllers early in the development cycle. It is imperative that we identify changes to air traffic controllers' roles and responsibilities to ensure that we can meet the demand for air traffic services, while maintaining our unprecedented levels of safety. This report includes a description of upcoming enhancements for each element of the NAS, the human factors implications of these enhancements, and their anticipated effect on key human factors subject areas.

The Radio Technical Commission for Aeronautics (RTCA) predicts that by the year 2015, the NAS modernization will encompass enhancements to NAS management, airspace design, communications, navigation, surveillance, weather, as well as automation and the introduction of revolutionary vehicles (RTCA, 2002). Implementing these advanced concepts will result in profound changes for all users. Those of particular consequence to controllers will be aspects resulting from the use of information sharing, data link, automation, new and expanded procedures, and the introduction of revolutionary vehicles. Collecting, disseminating, and archiving all NAS information will promote comprehensive information exchange across all stakeholders. However, the system must be capable of filtering the enormous amounts of data to retrieve task relevant information. It is crucial that system developers determine exactly what information each user requires, what format is appropriate, and when to present this information. Perhaps the biggest challenge will be to determine what information *not* to display. Dynamically adjusting airspace sector boundaries may potentially negate much of the controllers' expertise, increase workload levels, and pose challenges to their ability to maintain Situation Awareness (SA). Migration from a voice-based to a digital communication system can result in loss of "party-line" information, inefficiency due to mixed-media types, increased "head-down" time, increased workload, and reduced SA. Flexible routing may undermine the controllers' ability to rely on situated cognition and dynamically change scanning behavior and hot spots. Automation tools will evolve to support the controllers' decision-making process. Principal human factors considerations include loss of separation skills due to increased reliance on automation, the challenge of developing and maintaining an accurate shared mental model of the system, and automation-induced complacency. The introduction of revolutionary vehicles will pose significant challenges to the integration of these vehicles into normal sector operations. Conflict alert systems will have to accommodate these revolutionary vehicles and aid air traffic controllers in separating traffic based on different separation standards. The introduction of new technologies and vehicles will also challenge controllers and require the implementation of new procedures, phraseology, and separation criteria.

The primary human factors considerations of these new technologies and procedures for air traffic controllers are in the areas of information processing, SA, workload, errors, skill acquisition and maintenance, and new roles and responsibilities. The NAS will have to perform some form of data fusion to avoid controller information overload, reduce workload, and promote SA. Future traffic loads, changes in traffic types, and changes in Air Traffic Control automation will challenge controller SA. Designers will need to create Decision Support Systems that minimize the potential

for negative effects such as automation-induced complacency, loss of SA, neglect of monitoring tasks, increase in workload, errors, and deficiencies in skill acquisition and maintenance. The introduction of these advanced automated capabilities will certainly lead to changes in the controllers' roles and responsibilities.

This report summarizes some of the primary human factors considerations that system designers should take into account when implementing changes to the NAS. As traffic levels increase, the automation process will need to provide controllers with the necessary tools to (a) alert them to situations that require their attention and (b) filter the data to provide what is required for decision making. Technology alone will not be able to support these increased capacity demands. To effectively meet these demands, we need to rely on a combination of technology and the human operators of the system.

1. INTRODUCTION

In an effort to support the high safety and efficiency standards demanded of the Air Traffic Control (ATC) system, the Federal Aviation Administration (FAA) has undertaken several activities to define the future evolution of the National Airspace System (NAS). One product depicting the NAS of the future is the *NAS: Concept of Operations and Vision for the Future of Aviation.* This product describes the vision of the Radio Technical Commission for Aeronautics (RTCA) and outlines the NAS evolution in the near term (up to 2005), mid term (2005-2010), and far term (beyond 2010) timeframes (RTCA, 2002). We based this Technical Note primarily on the RTCA document. However, we also present information from other planning documents such as the *National Airspace System Architecture 5* (FAA, 2003b); the *Target System Description* (TSD) presented by several representatives of the FAA Office of System Architecture and Investment Analysis, which is presently the Air Traffic Organization - Operations Planning Office of Systems Engineering (Bradford, 2004; Scardina, 2003); the *FAA Flight Plan* (FAA, 2003a); the *Blueprint for NAS Modernization: 2002 Update* (FAA, 2002a); and the *FAA's Operational Evolution Plan* (OEP) (FAA, 2002b). The Flight Plan links budget requests to the four goals of increased safety, greater capacity, international leadership, and organizational excellence. The Blueprint outlines the FAA's efforts for modernizing the NAS and improving NAS services through 2017. The OEP represents the shared commitment of the FAA and industry to meet the capacity needs over the next 10 years. The goal of these products is to introduce new technologies and procedures into the NAS, while continuing to maintain the system goals of safety, security, and efficiency.

In addition to the challenges of modernizing the existing NAS equipment, the FAA will face increases in air traffic as well as tighter budgets and staffing levels. Several areas of the NAS will experience profound changes. The most profound changes will be increased information sharing, automatic dissemination of flight plan and weather information, reduced reliance on ground and Navigational Aid (NAVAID) based routes, selectively reduced separation requirements, and the emergence of revolutionary vehicles with unconventional trajectories (RTCA, 2002). These differences represent important departures from today's system. Clearly, these new systems and procedures hold significant ramifications for all users including air traffic controllers, Technical Operations personnel, Flight Deck personnel, and the flying public. This Technical Note focuses on the human factors implications of these changes from the controllers' perspective.

We have organized this report into four sections. The current section includes the background and purpose of this document as well as the nature of air traffic controller tasks. In Section 2, we briefly describe the improvements that each element of the NAS is likely to experience in the next decade. In Section 3, we identify some of the major human factors implications of these changes on each NAS element. In Section 4, we address the upcoming changes and focus on primary human factors considerations.

1.1 Background

The NAS modernization represents profound changes for all NAS users and service providers. As the *NAS 2015 TSD CONOPS Analysis* document states, the NAS users include "any customer that uses the air traffic system, including commercial aviation, general aviation, commercial space transportation providers, and Department of Defense (DOD) aviation and space" (FAA, 2003c, p. 26). The modernization effort will affect air traffic controllers, Technical Operations personnel, airline support personnel, airport operators, and a myriad of other diverse groups. This Technical Note focuses on the human implications of technological changes to the tasks of air traffic controllers. We have organized this document in terms of NAS and management, airspace design, communication, navigation, surveillance, weather, automation, and revolutionary vehicles.

Modernization of air traffic services and the natural evolution of the NAS will have a significant impact on air traffic controllers' roles and responsibilities. This impact will be prevalent and may affect numerous controller activities. The following sections describe how the air traffic controller tasks will change in the future. This is important because it represents the basis for identifying critical human capabilities that may be vulnerable to changes in the NAS.

1.2 Purpose

The FAA is preparing for the substantial changes that the NAS will experience through 2015. These changes will encompass shifts in NAS users, services, systems, and processes. The purpose of this report is to identify potential changes in the future NAS and to examine their impact on air traffic controllers' roles, responsibilities, and workstations. It is imperative that human factors research address ATC implications of the evolving technologies in order to meet the demand for air traffic services and manage the risks in the future NAS to an acceptable level of safety.

1.3 Air Traffic Controller Tasks

In 1987, the FAA initiated a series of detailed task analyses investigating air traffic controller operations in an effort to define controller cognitive tasks (Alexander et al., 1989). Since then, the FAA and EUROCONTROL have conducted a number of ATC task and job analyses (Dittmann, Kallus, & Van Damme, 2000; Kallus, Barbarino & Van Damme, 1998; Kallus, Van Damme & Dittmann, 1999; Redding & Seamster, 1994). Table 1, which we adapted primarily from Kallus et al. (1999), provides an overview of core ATC task activities derived by various studies. The research presented in the table encompasses all air traffic domains (i.e., tower, terminal, en-route, and oceanic). Generalizing the tasks across domains is appropriate because research suggests that although the terminal environment is tactical in nature and en route strategic, the cognitive activities remain very similar (Dittmann et al.).

Table 1. Overview of Air Traffic Controller Tasks

Core Tasks Listed by Various Task Analyses	**A**	**B**	**C**	**D**	**E**	**F**
1. Maintain situation awareness	X	X	X		X	X
Build mental picture of traffic situation			X			X
Perform routine sector maintenance task				X		
2. Develop and receive sector control plan		X		X	X	X
Perform actions before aircraft arrives in sector				X		
Handle and process flight plan information			X			X
Manage air traffic within area of responsibility			X			
3. Make decision for control actions	X	X	X			
4. Solve aircraft conflicts	X	X				
Provide separation			X	X		
Conduct recognition and resolution of conflicts	X			X		
5. Provide tactical Air Traffic Management	X		X			X
Route aircraft through sector airspace/manage overflight/ re-route aircraft	X	X		X	X	X
Conduct aircraft movements				X	X	
Initiate/point out/transfer control		X		X	X	
Receive pointout/accept aircraft		X		X	X	X
Receive handoff/carry out handover from previous controller		X		X	X	
Initiate handoff/carry out handover to next controller		X		X	X	
Manage arrivals		X		X		
Manage departures		X		X		
Issue advisory/provide pilots & colleagues with all relevant info		X	X	X	X	
Issue safety alert		X				
Provide assistance in abnormal situations			X			
Manage airborne emergency				X		
Ensure correct coordination			X		X	
Conduct Radiotelephony (R/T) communication			X	X	X	
Manage pilot-initiated communication				X		
Perform actions after aircraft has left sector				X		
Conduct pre-shift briefing				X		
Handle/manage Flight Progress Strips	X	X		X		
Check technical equipment at working position	X		X			X
6. Complementary tasks			X		X	
Train			X		X	
Update working knowledge			X			
Supervise control room/team			X		X	
Coordinate with customers/users			X		X	
Manage sector/position resources	X				X	
Assess situational conditions	X				X	X

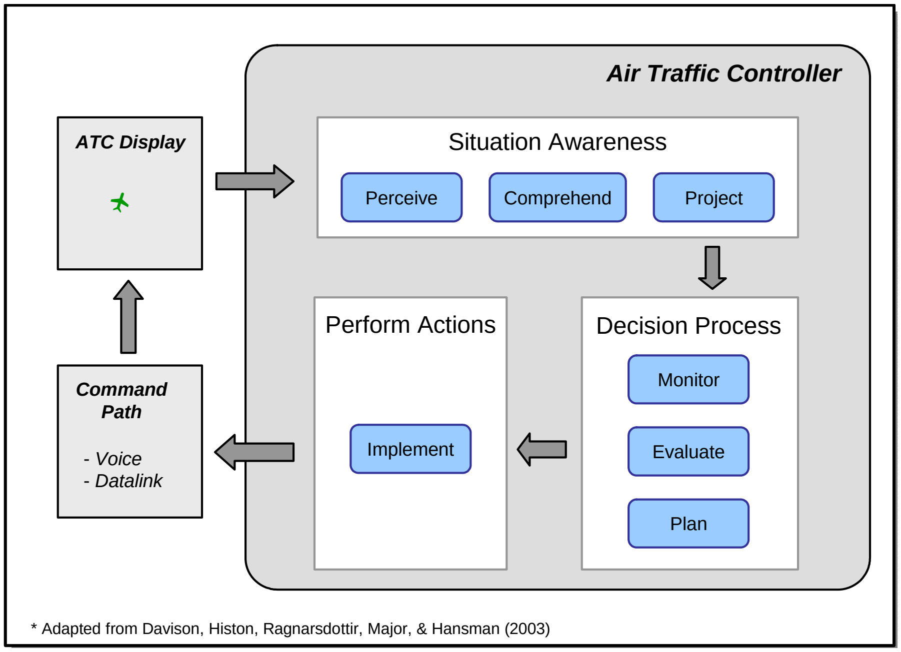
A = Alexander, et al. (1989) B = Redding & Seamster (1994) C = EATCHIP (1996)	D = Cox (1994) E = Glaser & Dahl (1995) (as cited in Kallus et al., 1999) F = NLR (1996) (as cited in Kallus et al., 1999)

Further research by Dittmann et al. (2000) suggests that the activities represent 7 task processes, 2 subprocesses, and 1 control process (see Table 2). Controllers typically perform a number of the activities in the order presented. For example, a controller will typically monitor aircraft progress, identify conflicts, develop solutions, and then issue ATC instructions (Activities 3, 4, 5, and 6). However, this order is subject to interceding events and the control process, which governs when controllers will switch their attention. The authors suggest that when controllers switch attention, they should set a mental reminder with a time window for returning to a higher priority task.

Table 2. Typical Air Traffic Controller Cognitive Activities

No.	Category	Air Traffic Controller Activity
1	Task process	Take over position/build mental picture
2	Control process	Prioritize scanning and actions/switch attention
3	Task process	Monitor aircraft progress/update mental picture and maintain situational awareness
4	Subprocess	Identify traffic conflicts
5	Task process	Solve conflict situations
6	Subprocess	Issue air traffic control instructions
7	Task process	Manage air traffic sequences
8	Task process	Assess weather impact
9	Task process	Manage workload and position resources (managing requests, assisting pilots, etc.)
10	Task process	Respond to system/equipment degradation

As the NAS evolves and the agency deploys new ATC systems, fundamental controller cognitive activities will certainly change. Therefore, it is important to understand how the controller will interact with the new NAS, so that we can identify and mitigate these adverse situations. Figure 1 identifies the basic controller cognitive activities; it is an adaptation of the generalized air traffic controller cognitive model developed by Davison, Histon, Ragnarsdottir, Major, and Hansman (2003). The authors developed the representation based upon Endsley's Situation Awareness (SA) model (Endsley & Rodgers, 1994). As Figure 1 illustrates, basic air traffic controller cognitive processes include SA, decision making, and performing actions. Each of these processes may be composed of several subprocesses. In SA, for example, air traffic controllers may *perceive* an aircraft's position on the ATC display, *comprehend* this information, and then *project* the aircraft's future position. Endsley and Rodgers refer to these subprocesses as level 1, level 2, and level 3 SA, respectively.



* Adapted from Davison, Histon, Ragnarsdottir, Major, & Hansman (2003)

Figure 1. Model of air traffic controller cognitive activities.

These processes/subprocesses are vulnerable to changes in automation, procedures, or other aspects of the NAS. For example, unless we apply good human factors principles, increases in traffic level or increases in display clutter either will contribute to the controllers' difficulty to perceive an aircraft or will contribute to the controllers' ability to project a future conflict. Increases in traffic level can also compromise the controllers' decision process. Implementing a plan is also vulnerable to the influence of new technologies and procedures. For example, research suggests that implementing ATC commands using the mixed-modality of voice and data link may increase transaction times as well as the likelihood for clarification of a clearance, but may be problematic because the electronic log does not reflect voice amendments (Dunbar, McGann, Mackintosh, & Lozito, 2001). These examples reflect a few of the potential implications of the new NAS on air traffic controllers. In this report, we review some of the most significant challenges likely to occur in the NAS by the year 2015, and we identify which controller activities are most vulnerable.

2. NATIONAL AIRSPACE SYSTEM IN 2015

The purpose of the TSD was to present long-term strategists with a state of the NAS in the year 2015 that they could use as a baseline from which to launch their evolution of the NAS. In this section, we present a synopsis of the RTCA document and the TSD vision. Some events have or will overtake the assumptions presented in the TSD, but we present them here to set the stage for the discussion of our human factors concerns with the projected evolution of the NAS.

The NAS will undergo a profound transformation during the next decade. The descriptions presented in the following sections reflect the consensus of the Free Flight Steering Committee as defined in the *NAS: Concept of Operations and Vision for the Future of Aviation* (RTCA, 2002). Among the critical components that RTCA recognizes in this vision is the fundamental need to develop technologies that support users by taking full advantage of their capabilities, while limiting the potential for error. We prepared this report to aid system designers in this process by identifying the implications for human performance as these new technologies and roles evolve.

> RTCA (2002) states the following:
>
> Our vision of the National Airspace System takes full advantage of globally harmonized, advanced aircraft, space, and ground capabilities. The future system maintains the importance of people, supported by automation, to manage operations. Through state-of-the-art communications, navigation, and surveillance and air traffic management enhancements, aircraft operate along more efficient auto-negotiated four-dimensional flight profiles that make the most efficient use of airport and airspace resources available. (p. v)

The NAS of 2015 will encompass sweeping changes across all flight domains (i.e., tower, terminal, en route, and oceanic). The System Wide Information Management (SWIM) system is a fundamental component in this enabling technology. This evolving capability will permit the NAS to react dynamically to changing capacity needs, weather, and other demands. By 2015, the SWIM system will support advanced automation, promote digital data sharing, promote common SA across all users, and enable system-wide collaborative rerouting and other resource allocation functions.

2.1 National Airspace System and Management

The underlying mechanism that will enable the comprehensive information exchange across all stakeholders in the NAS is the SWIM capability. Initially, SWIM will provide Traffic Flow Management (TFM) and other system constraint information. By 2015, it will archive all NAS information, support analyses and performance delivery assessments, and evolve into a self-monitoring, self-restoring system. This advanced system will provide access to information concerning movement of all NAS relevant traffic including ground vehicles, taxiing and airborne aircraft, Unmanned Aerial Vehicles (UAVs), and space vehicles. It will maintain real-time traffic movement, weather, arrival/departure/taxi schedule, airborne/surface surveillance, flight information, Automated Terminal Information Service (ATIS), status, TFM initiatives, infrastructure status, and other information. These data and the associated communication capability will facilitate coordination between decision makers and key players such as service providers, flight crews, flight operations centers, ramps, airport operators, and so on. Data sharing will support coordination and promote overall operational efficiency and safety. The collaboration of NAS users will drive service delivery priority.

By 2015, real-time changes in sectorization, traffic demand, and airspace assignment will determine the assignment of NAS infrastructure assets. The SWIM system will gather and distribute flight-specific data and aeronautical information (including planned flight trajectory coordination). Users will be able to access real-time NAS information such as current and predicted Special Use Airspace (SUA), infrastructure status, traffic density, and TFM initiatives. Decision Support Systems (DSSs) will use this real-time information for preflight planning and for ensuring efficient routing of airborne aircraft. Route changes will increasingly result from

NAS constraints and user-preferred profiles. Real-time trajectory updates will accurately reflect departure times, result in better traffic load predictions, and facilitate coordination between NAS users as well as the domestic and international service providers. The database of Controlled Flight into Terrain (CFIT) hazards will become increasingly comprehensive, so that it will include temporary structures and other important information. In addition, moving-map displays on the flight deck will show CFIT hazards in real time.

2.2 Airspace Design

Enhanced aircraft capabilities enable reduced separation through parallel Required Navigation Performance/Area Navigation (RNP/RNAV) routes. By 2015, multiple dynamic RNP/RNAV arrival and departure routes will be available in high traffic areas. Routes that are more efficient will be available with RNP/RNAV equipment. Traffic flow patterns in many terminal areas will incorporate Instrument Flight Rules (IFR) and Visual Flight Rules (VFR) transition routes. The NAS will dynamically modify terminal, en route, and oceanic airspace in response to demand, weather, and other system drivers. Real-time detection of wake turbulence and aircraft type criteria will determine appropriate separation standards.

2.3 Communications

One of the primary technological advancements in ATC communications by 2015 will be the widespread deployment of data link for all phases of flight. Pre-defined data link messages will be available for most situations (e.g., altitude clearances and frequency changes). Initially, it will provide position, flight profile information, aircraft status information, and accurate arrival and departure times. Data link will provide access to taxi routes, ATIS, automated clearance delivery, weather conditions (current, forecast, hazardous, etc.), all needed radio frequencies, and other information based on current location. The SWIM system will send some emergency communications automatically to both the pilot and controller to eliminate unnecessary time delays in relaying the message (e.g., wind shear and collision resolution advisories). Controllers will be able to allocate the reduced need for voice communications to monitor traffic and conflict resolution. The use of this technology will promote information exchange, shared SA, streamlined coordination, and a reduction in radio frequency congestion.

2.4 Navigation

During the next decade, an increasing number of aircraft will be equipped with satellite navigation and moving-map displays. Using enhanced satellite surface navigation, pilots will be able to taxi during reduced visibility conditions while relying solely on electronic means, such as enhanced/ synthetic vision moving maps or Cockpit Display of Traffic Information (CDTI). Pilots will use onboard electronic CDTI displays to avoid other air traffic. There will be an increasing usage of RNP/RNAV routes, which will result in more efficient airspace usage and improved performance during poor weather conditions. Aircraft will execute Flight Management System (FMS) departures, offset approaches, and parallel RNP/RNAV routes. The implementation of satellite navigation with vertical guidance will enable precision instrument approaches at all landing facilities. The RTCA predicts that these improved procedures and aircraft capabilities will eliminate the need for many speed and altitude restrictions (RTCA, 2002). Enhanced all-weather landing systems will permit multiple paths to final approach to maximize runway capacity.

2.5 Surveillance

In the near future, most aircraft will carry equipment for satellite navigation, data link, and other systems that provide position information to enhance controller, pilot, and vehicle operator SA. Data link will promote increased SA and safety by delivering traffic location information for presentation on moving map displays. All sources of ground surveillance data will be processed and shared to promote safety and prevent incursions. The tower situation display will show the airport, nearby airspace, data tags for all flights, and vehicles. Pilots will use flight deck displays to monitor separation and spacing from other traffic. During operationally advantageous and mutually agreed upon situations, controllers may choose to delegate flight separation responsibility to the flight deck. By 2015, most aircraft (including oceanic traffic) will be equipped to provide position and intent information as well as to receive position and intent data from other aircraft.

2.6 Weather

The RTCA notes that in the near term, equipped aircraft will receive graphical weather information such as current observations, pilot reports, and winds aloft information via data link (RTCA, 2002). As the NAS evolves, this information will be available in all phases of flight. By 2015, most aircraft will be equipped with moving map displays capable of presenting graphic and text weather information. Data link will provide current meteorological data, automated hazardous weather alerts, and surrounding traffic for presentation on moving map displays located on the flight deck. This will promote shared SA and minimize the likelihood of verbal miscommunications. Aircraft will be able to use these advanced integrated displays in low visibility conditions to taxi. Properly equipped aircraft and trained crews will be able to taxi solely based on electronic means. Vision enhancing devices will permit the flight deck to conduct more "visual-like" operations regardless of the weather conditions.

2.7 Automation

Cockpit displays will present information on aircraft position, airports, taxi routes, departure procedures, hazards, routes, Standard Terminal Arrival Routes (STARs), and other information. Moving map displays enhance pilot familiarity and promote improved planning and increased safety. Flight deck capabilities evolve to include ever-broadening implementations such as conflict alert logic and runway incursion information. These new capabilities promote safer operations in low visibility conditions on the airport surface because the moving map display can show the present position of aircraft. Departure and runway assignments will consider airline gate preference, congestion predictions, and taxi plan. The SWIM system will automatically coordinate with airspace automation to efficiently sequence ground traffic with projected traffic flow aloft.

> RTCA (2002) states the following:
>
> There is increased information sharing and collaboration among users and service providers. Collaboration includes information exchange plus shared and active user participation in decision making. For situations such as demand-capacity imbalances or severe weather, collaboration supports determine when, where, and how transitional route structures are established in airspace to resolve a short-term problem. Collaboration also supports strategic problem resolution. All parties have a shared situational awareness that is based on the best common information possible. (p. 8)

The DSS will use departure time, aircraft type, wake turbulence criteria, preferred departure route, traffic aloft, and other factors to efficiently sequence aircraft to the departure runway. The DSS will collect and process position and intent information transmitted by equipped aircraft. It will support gate-to-gate planning and interactively direct each aircraft based on current constraints that best meet user preference. Airborne flights will automatically receive updated flight plans. The routes will maximize safety and efficiency across all flight profiles (i.e., tower, terminal, and en route). The DSS will build these profiles based on the flight characteristics of all vehicle types including conventional aircraft, vertical take off and landing aircraft, UAVs, and spacecraft. It will assist in planning taxi sequences, arrival/departure spacing, balancing runways, and enable uninterrupted transitions from top of descent to the airport surface. The SWIM system will broadcast this information along with conflict prediction and resolution advisories to all stakeholders. Resolutions will incorporate use of improved RNP procedures to reduce congestion over waypoints and improve system safety and utility.

2.8 Revolutionary Vehicles

The RTCA forecasts that revolutionary forms of transportation will emerge and become increasingly common by the year 2015. They predict that the NAS will consist of UAVs, vertical take off and landing vehicles, tilt rotor aircraft, hypersonic vehicles, and space vehicles. This wide variety of aerospace vehicles will drastically increase the complexity of air traffic management. Some of these vehicles will certainly begin affecting the NAS in the near future; however, others will take much longer. UAVs, for instance, are already beginning to expand from military to civil applications. The FAA certified the General Atomics' Altair Predator UAV to operate in the NAS in 2005, and they have received several more applications for certification for these types of vehicles.

> RTCA (2002) states the following:
>
> The operation of Remotely Operated Aircraft (ROA) (i.e., UAVs) begins. Personnel situated in a ground facility operate these unconventional aircraft... Because these vehicles are unmanned, there are special airspace and navigation procedures that allow limited operation in the NAS. (p. 9)

In addition, Very Light Jets (VLJs) have already received certification to operate within the NAS. Several more jet manufacturers are pursuing certification for VLJs, and they report having orders for more than 2000 or these revolutionary aircraft. The RTCA (2002) envisions the deployment of spaceports by 2015; however, as they noted, these will initially occur in remote locations and, therefore, will represent minimal impact on existing airport operations.

3. HUMAN FACTORS CONSIDERATIONS FOR THE NAS OF 2015

Incorporating these advanced concepts and technologies within the NAS will hold significant human factors considerations for each of the systems. For example, by 2015, the NAS will reflect an increased reliance on Collaborative Decision Making (CDM), automatic dissemination of TFM information, non-verbal communications, and automation. The introduction of new and expanded procedures such as dynamic resectorization, reduced reliance on ground-based NAVAIDs, and the introduction of revolutionary vehicles will profoundly affect ATC.

3.1 National Airspace System and Management

3.1.1 Information Sharing

Among the most profound changes to the NAS by 2015 will be those afforded by the SWIM system. It will evolve to become a real-time repository and archive for all NAS information to promote comprehensive information exchange across all stakeholders. Initially, the FAA will leverage the new capability in support of CDM and TFM initiatives. One potential approach in support of CDM or any other air traffic function is to make all information available at all times to all users and at all locations. This approach may be effective within a narrow domain, but it is not realistic across all of the NAS. Although information sharing will be a positive change, air traffic controllers already experience a very high information load in the current NAS. It is crucial to determine what information should be available to controllers, as well as when and how to display that information. The projected increase in traffic will make it more difficult to determine what information *not* to display.

3.1.1.1 Increased Reliance on Collaborative Decision Making

Increased information sharing and collaboration among users will be possible in the near term, (RTCA, 2002). The FAA has supported CDM for some time now; a good example is the Post Operational Evaluation Tool (POET). Currently, the POET is in use to evaluate more efficient flight routings under different conditions including weather and traffic congestion. The CDM program can result in significant benefits by providing better communications between strategic service providers and NAS users (Ball, Hoffman, Knorr, Wetherly, & Wambsganss, 2000).

Human Factors Considerations

In the future, controllers and NAS users will share more information and collaborate more closely. The negotiation process will require dedicated attention from both service providers and users. To use the available bandwidth in support of these negotiations, air traffic service providers will need to decide what information to present. Another factor affecting success is ensuring that information sharing is part of operational priorities.

3.1.1.2 Automatic Dissemination of Traffic Flow Information

The RTCA expects that TFM will begin to provide information automatically to service providers and users. One of the promises of the automation in today's NAS is that traffic flow information would drive the supported decisions that air traffic controllers need to make on a daily basis.

> RTCA (2002) states the following:
>
> TFM information begins to be automatically provided to service provider ATC and user automation systems to facilitate the coordination and implementation of TFM initiatives. The service provider and users enter into TFM agreements based on the allocation of the available capacity that the affected resource (e.g., airport, airspace) in the form of a series of arrival intervals and an associated number of flights that may arrive in each interval. (p. 8)

The Traffic Management Advisor (TMA), for example, takes into account the arrival rates at an airport, weather conditions, and aircraft performance characteristics. The TMA uses that information to indicate to controllers how much time a metered aircraft needs to lose or gain to fit in an arrival slot. The TMA consists of two interfaces with ATC. The Traffic Management Unit (TMU) provides Traffic Management Coordinators (TMCs) with the ability to enter arrival rates and other information into TMA. The TMA in turn uses that information to provide controllers delay information in the TMA list that forms the second part. The User Request Evaluation Tool (URET) has a similar function when connected to the Center Routing Collaboration Tool (CRCT). Although URET would not necessarily display delay information, CRCT would transmit route changes that originate at the TMU or maybe even at the ATC System Command Center (ATCSCC). In the current system, a situation exists that is very similar to the prototype URET when it was first installed in Memphis and Indianapolis Air Route Traffic Control Centers (ARTCCs). Redundant entries are made to transmit information that is available in the Enhanced Traffic Management Systems; but the entries will need to be entered into the Host Computer Systems (HCSs) or sent by e-mail to the ARTCCs and then communicated to TMU personnel, ATC supervisory controllers, and finally to the sector controllers. Air traffic controllers perform many of the sequence of events by word-of-mouth. These events are, therefore, prone to error and are relatively slow. Currently, most of the technology is in place to support this flow of information. However, there may be little initiative to connect the pieces, eliminate the redundant data entries, and speed the dissemination process.

Human Factors Considerations

By 2015, the FAA anticipates having a complete data network in place for the distribution of air traffic flow information (i.e., SWIM). This new data intensive system will drive several human factors considerations. The SWIM concept will enable the availability of all data at all locations at any point in time. However, each user does not need to see all data at all times, or even in the same format. For example, system designers will need to determine what information a sector controller and a supervisor need, how this system will display the information, and whether sector information should be present on the Radar Controller Position (R-side), Data Controller Position (D-side), or both.

Another important question raised by the new network will be “Who is in control?” For example, when faced with weather or other traffic constraints, does the TMU, ATCSCC, or some other group decide which playbook is implemented and when? Do the sector controllers receive a message that indicates an aircraft has received a route change and gives the controller a deadline by which to implement the change? URET can send route changes to the HCS already, should it now display the flow related message and indicate if there are potential conflicts related to the flow request? If the intent is to reduce the implementation time of decisions made at the flow level, is the electronic system faster and more reliable than what controllers call “sneakernet” (i.e., handing down information by word-of-mouth)?

In the current system, a decision to implement a flow change may start at the ATCSCC and move its way down to the sector controllers through the TMU and the area supervisor. When the decision makers automatically disseminate traffic flow information to the sectors, it becomes important where and how that information will be available at the sector. To most sectors, the changes to flight plans will be transparent because it will look like the aircraft always intended to fly the received flight plan. For the sector that currently controls the aircraft and sectors that have already received flight plan data on the aircraft, however, the change may result in a change in the sector plan. Depending on the urgency of the change request, controllers will need to receive an alert that a flow-related request or change is available. For more strategic positions, such as the radar associate or a future multi-sector controller, it may be enough to show the change request in a list combined with an indicator that grabs the controllers' attention at an appropriate level. For tactical positions like the radar controller, such an indicator may need to be available at the aircraft representation level. The Research Development and Human Factors Laboratory enacted this potential solution in support of work performed for the National Aeronautics and Space Administration (NASA) En Route Descent Advisor (EDA) Computer-Human Interface (CHI) development effort. In this implementation, the researchers provided a status indicator at the edge of the full data block to indicate to a controller that an aircraft had flow constraints including metering requirements. The goal of the status indicator was to show controllers flow constraint information and to provide them with information about the level of urgency to respond to that information. For example, if the amount of time available to move aircraft to an alternative route is short, the status indicator may flash to draw the controllers' attention. This status indicator represents a rudimentary aid to controllers. However, an additional benefit of the indicator will provide controllers an efficient means to access detailed information (e.g., whether the system or an entity within the system has sent a request and the level of urgency of the request).

Some groups have recommended that TFM should send flow-related data directly to the flight deck. Although the dissemination of identical information to both the flight deck and the sector would increase shared SA, the advantage will only hold true when the sector controllers actively participate in that process. At EUROCONTROL, during the PHARE/PD3 simulations, the Multi-Sector Planner position could send a data-link message to an aircraft, but the aircraft could only make a change to the flight plan when it arrived at the sector border. The primary objective of this particular implementation was to introduce a change at a moment when an aircraft was between airspaces. It would still affect the next sector, if the controllers had to setup a plan for the aircraft before it entered the sector. A controller would stay involved if an external request came in to change an aircraft's flight plan that required approval prior to implementing changes to the NAS or sending messages to the aircraft.

3.2 Airspace Design

As with other aspects of the NAS, airspace design will undergo major modifications. The FAA intends to implement new concepts like dynamic resectorization, high altitude airspace Reduced Vertical Separation Minimum (RVSM), and user-preferred routes.

3.2.1 Dynamic Resectorization

The *Blueprint for NAS Modernization: 2002 Update* (FAA, 2002a), the *NAS: Concept of Operations and Vision for the Future of Aviation* (RTCA, 2002), and the *FAA National Aviation Research Plan* (FAA, 2000) identify dynamic resectorization as an integral concept in the NAS of 2015. Dynamic resectorization involves adjusting airspace boundaries to accommodate real-time traffic flow constraints such as weather, equipment outages, or other SUA needs. Presently, limited dynamic resectorization occurs in the NAS. The RTCA (2002) predicts that in the far term, airspace changes will occur dynamically in response to weather, demand, and user preferences.

This report also suggests that automated coordination aided by DSSs will result in real-time or near real-time sector boundary changes. The FAA anticipates that dynamic resectorization, when implemented in conjunction with full use of data link capabilities and new traffic management procedures and technology, will result in a reduction of analog voice communications and fewer communication frequency changes for en route aircraft (Vivona, 2000). However, dynamic resectorization requires additional research in terms of automation support requirements (Celio, 2003).

Human Factors Considerations

In a simulation of lateral inter-facility dynamic resectorization, en route controllers recorded slightly lower workload ratings and higher SA ratings in dynamic resectorization scenarios (Hadley, Sollenberger, D'Arcy, & Bassett, 2000). However, further research into the impact of vertical boundary adjustments is essential as the concept becomes more prevalent and expands to accommodate more constraints. These new situations will certainly hold significant implications for the controllers' tasks. Today's controllers develop expertise in airspace over a period of years, and they learn to rely on the airspace and route structure to aid decision making (Stein, Della Rocco, & Sollenberger, 2006). The authors report that en route air traffic controllers take approximately 3 years to develop the pattern recognition that supports this sector-specific expertise. Dynamically adjusting sector boundaries in combination with permitting user-negotiated flight paths may potentially negate much of this expertise and pose challenges to the controllers' ability to maintain SA. Unlimited dynamic resectorization will require that we immediately notify controllers of sector boundary and radio frequency changes affecting their airspace. Air traffic controllers will need to gain and maintain SA of acquired traffic without exceeding their workload capabilities. System designers will need to provide an effective means of presenting real-time boundary and altitude shelf adjustments to the affected controllers, supervisors, and facilities. Human factors research provides some guidance for the effective implementation of the dynamic resectorization concept. Stein et al. offers the following recommendations:

- Add structure and constraints to the resectorization process. For example, block altitudes and inhibit crossing traffic, so that the controllers' responsibility is limited to just the affected flow. This will limit the likelihood of an adjacent controller clearing an aircraft into the new airspace.
- Implement dynamic resectorization only in areas in which the active controller has knowledge of the airspace, obstacles, and other airspace constraints.
- Ensure adequate training and practice with dynamic resectorization.

3.2.2 High Altitude Airspace RVSM and User-Preferred Routes

The RTCA expects that the introduction of Domestic Reduced Vertical Separation Minimum (DRVSM) and User Preferred Profiles at high altitudes will be possible in the near term. The use of RVSM and user-preferred routes are both highly researched topics. Several locations outside of the Continental United States already support RVSM while user-preferred routes are already possible above 29,000 ft.

RTCA (2002) states the following:

> The high-altitude airspace permits aircraft operations along user-preferred profiles from entry through cruise to final exit. Entry to and exit from the airspace are based on preferred profiles for climb and descent. Within that airspace, aircraft operate closer to their optimum altitudes by increasing the available flight levels using 1,000 rather than 2,000 foot separation. (p. 9)

The user-preferred routes are still limited to cruise segments only, and do not cover preferred climb and descent profiles, because aircraft still need to conform to airspace Standard Operating Procedures (SOPs). For accommodation of Domestic RVSM, the FAA will need to adopt new or adapted ATC procedures to accommodate military and humanitarian flights, transition non-RVSM certified aircraft through DRVSM airspace, take into account mountain wave and turbulence, and accommodate new decision-support tools.

To some extent, the National Route Plan already supports user-preferred routes. Pilots can fly these routes as long as they file the route before departure. Currently, aircraft cannot maneuver without requesting clearance from ATC. It is not clear, from the RTCA document, whether the pilot will be able to fly preferred profiles for climb and descent autonomously or whether the ATC will still need to give the pilot permission.

Human Factors Considerations

Modifications to the en route airspace will require major changes in controller route structure and raise complexities of fleet diversity and separation responsibility when accommodating user-preferred climb and descent profiles.

The introduction of DRVSM will change the airspace structure that en route controllers have worked with for several decades. With the amount of exposure to the cardinal altitudes used in the existing airspace, controllers expect aircraft to enter and exit their portion of airspace at certain altitudes. Over time, controllers have incorporated the vertical buffers that maintain 2,000 ft separation into their aircraft separation strategies. The change to new separation standards above 29,000 ft may seem trivial, but it can affect controllers in situations where their workload increases and they reach back to reflex-like behaviors learned through experience. Although controllers will adapt to the new separation standards, they may have trouble in the interim period.

Air traffic controllers will need to accommodate non-DRVSM-certified aircraft in DRVSM airspace. This means that controllers will need an indication that an aircraft is DRVSM certified and is flying using DRVSM procedures. Although this may be possible by providing that information on the Flight Progress Strips (FPSs) or URET Aircraft List, this will not suffice for tactical decision making. The FAA has proposed to incorporate a non-RVSM indicator in the en route Full Data Block (FDB) to provide this information to controllers. The FDB, however, is rapidly expanding away from the familiar stimulus that controllers have learned to process efficiently. It is not clear how the attachment of more and more data to the FDB will affect controller visual scanning and situation assessment. Scanning of the ATC display and listening to radio communications form the only source controllers have to maintain SA.

In the current NAS, pilots can only execute maneuvers after they have received permission from ATC. The notable exception is a Traffic Alert and Collision Avoidance System (TCAS) advisory that can override ATC instructions. If an aircraft can execute a preferred climb or descent profile above 29,000 ft, the controller needs to be aware of that intent. Even if controllers do not have to deal with frequency congestion, calls from pilots to indicate that they will execute preferred climbs or descents will not provide the controllers with a reference on the radar display to indicate the aircrafts' status. In the future NAS, pilots will be able to execute user-preferred climbs and descents, which will raise issues such as who is responsible for maintaining separation during that maneuver. These issues will include questions if this will require the controller to provide separation assurance during the maneuver by keeping other aircraft out of the path of the aircraft or if a controller will interrupt a preferred profile if other aircraft may cause it to lose separation.

3.3 Communications

The NAS of the future will gradually migrate from a voice-based to a digital communication system. By 2015, many aircraft will support data link. This advanced form of communication will support digital exchanges between ground-based systems and aircraft. It is one of the key advanced concepts identified by the RTCA (RTCA, 2002). In addition, the RTCA (2002) indicates that data link will support several services including ATC clearances, airport information, current and future weather, Notice to Airmen (NOTAM), SUA status, updated charts, as well as the current position of other aircraft. Leveraging data link will provide several benefits including improved shared SA, the ability to better anticipate the needs of other users, a common context upon which to negotiate, and accessibility to an ever-growing repository of data (FAA, 1994; Farley, Hansman, Endsley, Amonlirdviman, & Vigeant-Langlois, 1998). However, data link raises important implications for the role of controllers such as the use of mixed media, workload, and SA.

Human Factors Considerations

The FAA and several researchers have already begun to investigate the effects of data link communications on controller performance (Dunbar et al. 2001; Farley et al. 1998; Hansman & Davison, 2000; Lozito, Verma, Marin, Dunbar & McGann, 2003; Office of the Inspector General [OIG], 1999). Although the widespread introduction of the data link technology offers significant benefits, their research underscores the importance of addressing some potential human factors challenges. For example, users may lose "party-line" information as the NAS transitions from radio communications to electronic messaging. Transaction times may be longer in a mixed media environment when there is time pressure. Pilots and controllers may experience difficulties reviewing communications that employ a combination of voice and data link clearances. The FAA recognizes that voice communications play a large role in current controller and pilot interactions; therefore, transitioning to data link represents important safety considerations and is a significant challenge (OIG, 1999). This report acknowledges that the new technology requires a fundamental change in the way controllers and pilots communicate. It raises important workload, "head-down" time, and party-line considerations. A mix of data link and non-data link traffic introduces the potential for confusion and additional workload for both controllers and pilots. Controllers may spend more head-down time composing, reading, or responding to data link messages. Pilots may lose the benefit of the party line. Currently, they can tune to a frequency and monitor controller instructions and responses from other pilots. In particular, the OIG report suggests that the FAA focus attention and resources on developing (a) new ATC procedures for using data link; (b) training programs for controllers and pilots; and (c) new data link equipment for displaying and sending messages.

3.4 Navigation

The NAS of 2015 will experience enhancements in the area of navigation. These changes will include a reduced reliance on ground- and NAVAID-based routes and the implementation of RNAV routes for satellite airport traffic.

3.4.1 Reduced Requirement to use Ground- and NAVAID-Based Routes

The introduction of new technologies in surveillance and the cockpit will make it possible to rely less on ground-based NAVAID-defined routes. Although this may benefit our users, it will remove some of the structure that controllers have used for many years; most of the potential human factors issues evolved from that reduction in structure. By the 2015 timeframe, the NAS is likely to support aircraft equipped to accommodate flexible routings independent of ground-based systems as well as aircraft reliant on ground-based elements of the current NAS.

Human Factors Considerations

A reduction in the requirement to use ground and NAVAID-based routes may affect controllers because of the potential loss of structure in the flow of traffic. The more flexible routes will still require a transition of traffic to a structured flow into an airport. A potential change in the role of ATC includes less involvement in determining what route an aircraft needs to follow. There will be an interim period where only some aircraft will be able to navigate without ground and NAVAID routes that may require controllers to integrate them with aircraft that still rely on ground-based system. Air traffic controllers have spent considerable time learning their airspace, and they have developed certain expectations of traffic that flows through their sectors. To qualify as a radar controller in an area, controllers will take one or more years after academic training to pass certification. During that time, developmental controllers will develop several skills. Our findings in studies using eye tracking suggest that part of that learning process involves perceptual learning (i.e., the acquisition and processing of information displayed on the radar display becomes automatic and effortless). Another aspect of the learning process involves understanding the peculiarities of the airspace – controllers become situated (Clancey, 1997; Kirshner & Whitson, 1997) and will acquire skills involving situated cognition.

Situated cognition occurs when an environment remains relatively stable and the user learns to recognize subtle cues that give them an almost intuitive feel for an answer to a particular problem. Klein (1997) refers to this as recognition primed or naturalistic decision making; in such cases, a controller sees a situation and knows the answer. Much of the Recognition Primed Decision Making (RPD) translates to recognition of patterns or structures in a situation. When allowing more flexible routing, such predictable patterns may no longer exist. We are uncertain whether the change from scanning “hot” spots for potential problems to scanning the airspace as a whole for potential issues will increase controller workload.

By 2015, we may begin to notice that the roles of the traditional en route R-side, D-side, and tracker have changed in both nature and purpose. As we introduce more decision-support tools, the D-side, for example, may no longer serve as the “housekeeper” and “extra set of eyes” for the R-side, but may become strategic in function. Likewise, the tracker’s role may also change. A possible redistribution of duties may also demand additional adjustments to tool capabilities and CHI presentations.

3.4.2 RNAV Routes for Satellite Airport Traffic

The RTCA predicts that RNAV routes will be in use to move traffic to satellite airports while avoiding arrival and departure routes for the primary airport. Although RNAV routes have been in existence for many years, few controllers or pilots have experience with them. RNAV routes are useful to aircraft equipped with navigation systems enabling them to fly virtual waypoints. The FMS can then fly an aircraft accurately over a predefined 4D flight path, (i.e., to ensure that the aircraft will be within an accepted tolerance, at a point in space, and at a precise time). An RNAV route can include heading, speed, and altitude changes. Potentially, RNAV equipped aircraft can fly a precision approach without interaction with the pilot and controller. Air traffic controllers have, depending on the FMS used for the RNAV implementation, the possibility to modify speeds and other parameters without taking the aircraft off the RNAV route.

> RTCA (2002) states the following:
>
> Aircraft arriving at and departing from satellite airports in and around terminal areas are provided assistance to remain clear of the primary airport’s arrival and departure routes without undue delay. Within each terminal airspace area, there are predefined overflight Area Navigation (RNAV) routes for IFR and VFR operations that also avoid the primary airport’s arrival and departure routes. The routes are not straight line paths in situations where primary airport arrival and departure routes dedicate otherwise. (p. 8)

Human Factors Considerations

The implications of remaining clear of the primary airport’s arrival and departure routes are reductions in workload, frequency congestion, and the need to monitor progress of those aircraft. These benefits will, however, be accompanied by a change in SA.

In highly congested airspace, controllers spend considerable amounts of time maneuvering aircraft, stopping them at altitudes, and reducing their speeds as required by SOPs or Letters of Agreement (LOAs) with other facilities. The availability of RNAV routes and aircraft that can fly them can reduce controller workload in several ways. An aircraft flying an RNAV route means that a controller avoids issuing a large chain of clearances to move that aircraft along a predefined flight path. This can drastically reduce the use of the radio to contact the pilot.

When an aircraft flies an RNAV route, that aircraft must have RNP certification. This increases the controllers’ confidence that an aircraft will accurately fly the assigned route. Once a controller assigns an aircraft an RNAV route, the controller has a reduced need to monitor conformance of that aircraft, thereby reducing the cognitive load caused by the monitoring task. To use RNAV routes, controllers and pilots must know about their existence and be able to make them visible. Controllers must know which aircraft have RNAV certified equipment and have an indication that the aircraft is in fact using it to fly an RNAV route. As mentioned in the introduction, different FMSs allow different changes to the RNAV route before they will abort the RNAV mode and give aircraft control back to the pilot. At the workstation, the situation display, therefore, needs to indicate that an aircraft is RNAV eligible maybe similar to the Controller Pilot Data Link Communications (CPDLC) session indicator. Furthermore, the situation display needs to indicate whether an aircraft is flying an RNAV route, and the limitations a controller may have, before the FMS will abort the RNAV mode.

If RNAV routes of the future include programmed altitude, heading, and speed changes, then controllers will need procedures that permit them to assign an aircraft to an RNAV route without their intervention, unless it is required to maintain separation. Aircraft on the same RNAV route could fly as “pearls on a chain.” For example, once a controller indicates that an aircraft has permission to fly the RNAV route, it will be a matter of spacing aircraft in time over a fix on the RNAV route and separation can be maintained. The FMS for each of the aircraft will fly the preprogrammed route and controllers will not need to monitor aircraft for conformance, and the separated aircraft will maintain separation on an RNAV route.

To enable procedural changes that take advantage of RNAV routes and FMS capabilities, the SWIM system must provide the controller with information about FMS capabilities as well as FMS status. A system like Aeronautical Data Link may be able to provide that data to the SWIM system, which in turn will disseminate that data to the controller workstation.

Once FMS RNAV capabilities and status are available over the SWIM system, automation can take advantage of that data by displaying relevant information to the controller. If the ground automation can communicate with the FMS, temporary RNAV route controllers may be able to create conflict-free flight paths that will meet metering requirements. Controllers can use such capabilities to reduce frequency congestion and to reduce the need for monitoring the progress of individual aircraft.

3.5 Surveillance

The agency has mentioned enhancement of surveillance as a support system as a key enabler for meeting several of its safety goals. Technologies suggested as enhancements are Automatic Dependent Surveillance - Broadcast (ADS-B), Traffic Information Service - Broadcast (TIS-B), and Flight Information Service - Broadcast (FIS-B) (FAA, 2003a). To accurately determine the location and predict the flight path of aircraft, the NAS needs a denser network of communications between aircraft that can support ground control as well. Guichard, et al. (2005) suggests that one of the technologies considered to fulfill that need is ADS-B.

The surveillance tasks of controllers and pilots include many additional sources and products. In the En Route Automation Modernization program, for example, the conflict alert algorithms run on the surveillance data processor. Other products include weather-related reports such as convective hazards and icing forecasts (Uhlarik & Comerford, 2003). The introduction of additional surveillance sources with higher update rates and increased accuracy can enable a reduction in separation standards and share separation responsibility between ground-based control and pilots; some examples of supporting efforts are the Airborne Collision

Avoidance System and the Airborne Separation Assistance System working groups within the International Civil Aviation Organization (ICAO, 2005). These enhanced surveillance systems could also form the foundation for conformance monitoring assistance (Reynolds, Hansman, & Li, 2003).

Human Factors Considerations

ATC human factors concerns related to surveillance mainly fall into two groups. First, the availability of additional surveillance sources will affect the display of information on the ATC display systems. Second, the availability of surveillance information on the flight deck and the ground systems may result in issues of shared SA and potentially shared responsibilities.

Availability of additional surveillance data on the ATC display systems will result in issues related to asynchronous update rates of surveillance sources and the need for controllers to know rules that apply to aircraft based on the use of different surveillance sources. Currently, the safety nets that assist controllers in maintaining safe separation between aircraft rely heavily on radar update rates. The introduction of asynchronous 1-second update rates for ADS-B, for example, can potentially result in the automation system issuing conflict alerts for a pair of aircraft that phase in and out of conflict just because one aircraft has a slower update rate. One suggested solution to circumvent the issue of synchronization of updates is to use data fusion, in which an algorithm would use multiple data sources and make an accurate estimate of the current location of an aircraft. Controllers report that they need to know the last true-track update for an aircraft. However, currently, the digital systems used by air traffic controllers do not provide the age of the track data. When a digital system displays a track update, the controllers no longer know whether that position is fresh or up to 4.8 seconds old (in the terminal environment) or even 12 seconds old (in the en route environment). A fusion or tracker algorithm could still display the last update, but it could also show the calculated position of the aircraft.

Shared SA and responsibilities become an issue when the flight deck and ground control both have similar, but not necessarily identical, information available. An example already exists for aircraft that carry onboard radar to detect weather ahead of them. The information that controllers have on their displays is not as fine-grained as the information that these pilots have available. When controllers and pilots communicate about weather, they do not have a shared awareness of the situation. In a similar fashion TIS-B and FIS-B will provide pilots with information that may not correspond with the information controllers have available.

3.6 Weather

Weather is a significant factor affecting NAS safety and efficiency. The NTSB reported that, in 2000, weather was the most frequently causal factor cited for aircraft accidents by U.S. air carriers in the environmental category (NTSB, 2001). In fact, the *FAA National Aviation Research Plan* reports that weather accounts for approximately 23 percent of all aviation accidents annually and costs the country an estimated $3 billion for accident damage and injuries as well as delays and unexpected operating costs (FAA, 2000). The plan indicates that the NAS must undergo major changes to improve the accuracy, display, and timeliness of weather information and to improve the ability of controllers and pilots to use that information safely and efficiently. As with all systems, system designers will need to address several human factors considerations when developing and implementing the wide variety of new technologies.

Human Factors Considerations

The current NAS does not support transitional route structures to resolve relatively short-term situations. Several groups have proposed “route objects” that a service provider could provide to route aircraft around weather disturbances. Presently, when weather creates a non-nominal situation, controllers will vector each aircraft around the weather disturbance. Often, controllers do not enter these vector maneuvers into the HCS as an amendment to the flight plan. To be effective, automation tools will require up-to-date weather and re-route information. For example, it will be essential that controllers enter routing around weather into the system, so that the DSS will base resolutions on complete and accurate information. Air traffic controllers note that in today’s system, entering updated flight plan amendments are workload intensive and require clearances for each maneuver, which contributes to frequency congestion. A potential solution to reduce this workload is to modify the system, so that controllers have the option to re-route subsequent aircraft around the disturbance using a similar trajectory. Providing the ability to create transitional airspace structures would reduce controller workload, increase SA, reduce frequency congestion, and provide more accurate data for the automation systems. In turn, using this improved data as input, the system could better identify and predict potential issues, thereby enhancing decision support.

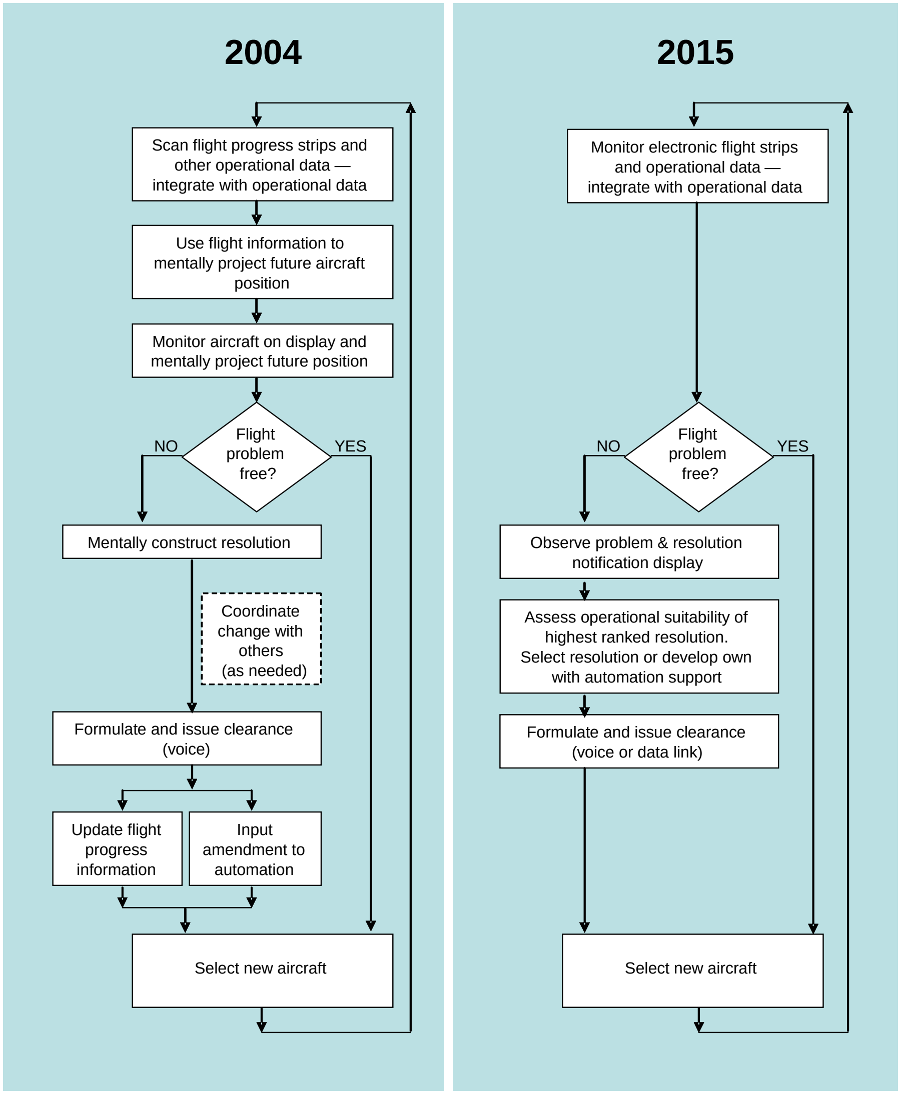
3.7 Automation

Many of the ATC automation functions have augmented the abilities of controllers or removed routine tasks. An example of the former is the use of vector lines to indicate the direction of flight. Controllers often use vector lines as a crude conflict probe by extending the vector lines to see where they can expect aircraft to be within several minutes. A good example of the latter is the automatic handoff function that reduced the need to manually handoff aircraft that were flying on flight plan and were going to cross the sector boundary.

Much of the FAA’s automation effort has focused on replacing mental functions with automation tools, often leaving controllers with the routine tasks such as data block movements and making or taking handoffs. Automation could also serve to support controllers by providing information as it is needed in the decision-making process. Presently, controllers often indicate that automation tools perform well under nominal conditions, but these tools perform poorly when weather conditions are adverse. The question is whether the tools are performing poorly under those conditions or whether the data provided to the tools is incomplete or incorrect.

If the number of aircraft in a sector increases between 2.5 to 3.5 times the current traffic loads as predicted, we can no longer expect a controller to maintain full SA of all aircraft in a sector at all times. While our current maximum Monitor Alert Parameter in the en route ATC environment allows controllers to be responsible for 18 aircraft (at most) in large sectors, a controller in the 2015 environment may be responsible for 45 to 63 aircraft if staffing levels and sector sizes stay the same. Increases in traffic volume will require the use of automation to aid controllers in processing the substantial amounts of data.

This means that future controllers will assure aircraft separation by intervening only by exception (RTCA, 2002). This new approach will implicitly change the way controllers perform their tasks and introduce significant human factors considerations. Figure 2 contrasts specific differences of how controllers resolve potential separation violations today versus how they may accomplish it in the year 2015.



* Adapted from Celio (2003, Figure 4-1)

Figure 2. Air traffic controller activities in predicting and resolving anticipated problems.

As Figure 2 illustrates, some activities will no longer exist when controllers manage traffic in 2015. They will not necessarily use flight information and current position to project aircraft position mentally to identify potential conflicts, as they do today. Automation will identify if a flight is problem free. Automation will also change the way in which conflict situations are resolved. Instead of mentally constructing the resolution, in the future, controllers will observe a conflict resolution display and select the most operationally suitable option. This new way of operating holds significant implications for controller SA, for maintaining conflict resolution skills, and for recovery from automation failures. In this new role, controllers would essentially become managers instead of actively developing solutions to conflicts.

> Kallus et al. (1999) states:
>
> Monitoring without action is one of the weaker skills in human information processing and is also a risk factor in the sense that in the event of equipment failure the air traffic controllers are unable to take over in a procedural or semi-automated way. (pp. 9-10)

Controllers will experience difficulty maintaining the traffic picture if they will have a monitoring role. Figure 2 underscores the increased reliance on data link in the future. The increasing number of aircraft equipped with data link capability, the growing need to minimize radio frequency congestion, and the requirement to implement a technology that allows controllers to communicate with the high number of traffic traveling through their sector will drive this increased reliance. Leveraging automation to implement flight amendment inputs and update flight strip information will reduce controller workload demands. However, this reduced demand will not be sufficient to offset the SA demands of future traffic levels.

Human Factors Considerations

Principal human factors considerations of future automation include increased reliance on automation, the challenge of developing and maintaining an accurate shared mental model of the system, and the need to develop advanced conflict probe algorithms. The automation that we have started to introduce during the last decade does not attempt to remove routine tasks to free up time for the primary ATC task, but it attempts to augment and, to some extent, replace some of the higher cognitive functions of controllers. Not only does this kind of automation potentially change the controller into a monitor of traffic instead of an active controller of traffic, but it may also take away that part of the controllers' job that provides them the most job satisfaction. High traffic density and passive control, both characteristics of the future NAS, may degrade controller conflict detection performance (Metzger & Parasuraman, 2001). Furthermore, without a way to ensure that controllers will stay current in taking over (assisted or not) control of the traffic in their sector, their skill set will degrade and may no longer be available when needed. Newly hired controllers may never have the opportunity to develop these skills. If we automate the higher cognitive functions, we will leave controllers with those tasks wherein humans perform badly (i.e., repetitive menial tasks and monitoring).

Many opportunities exist to provide controllers with assistance that removes repetitive and routine tasks. Some require changes in the interface design, while others require a different use of the data that has already become available through the automation tools that we are currently introducing in the field. More direct access to information, when and where needed, can reduce the amount of time that certain tasks take (e.g., when using a trackball to slew over to a window to change a vector line). Our user community is well aware of the time issue and has made changes to make data retrieval and data entry more direct (e.g., by insisting that knobs are necessary in the terminal environment or by introducing a special keypad in the en route environment). Better use of available data can reduce the number of calls that controllers need to make to pilots (e.g., by providing a calculated *indicated* airspeed, controllers may not need to request indicated airspeed from the pilot). In a similar way, data about the state of aircraft can provide the system with ways to augment controller perception. For example, by enabling emphasis on all aircraft that share a certain property, such as altitude, controllers could quickly scan those aircraft instead of searching for them among a field of several distractors that have the same format.

The use of a mixed fleet also means that Conflict Alert will need to be intelligent enough to detect potential loss of separation on mixed separation standards. We will need to change the separation standards themselves to include DRVSM to DRVSM aircraft standard separation as well as one for DRVSM to non-DRVSM aircraft. Air traffic controller behavior will need to incorporate scanning for potential loss of separation using these new rules. Future automation tools must accurately predict loss of separation between a wide range of aircraft type and equipage. They must then present this information in a meaningful way to controllers in the form of advisories. The algorithm must incorporate the separation standard that applies to a particular aircraft pair, including distinguishing between aircraft with certification for RNP, DRVSM, or other specialized routes and those that do not have certification.

3.8 Revolutionary Vehicles

In the future, controllers will need to separate several revolutionary types of vehicles, each demonstrating unique performance characteristics. Traffic will include UAVs, VLJs, space vehicles, and tilt rotor aircraft. UAVs and VLJs will be the forerunners of these revolutionary aircraft and will pose significant challenges to the efficient flow of traffic within the NAS because of their unique flight characteristics.

3.8.1 Unmanned Aerial Vehicles

The DOD UAV roadmap states that “the most recognized contemporary issue concerning UAVs is how to safely integrate unmanned flight into the NAS, which since its inception has been geared for manned flight” (DOD, 2001, p. 56). UAVs, or ROA, will become increasingly common.

> RTCA (2002) states the following:
>
> These unconventional airborne vehicles are operated by personnel situated in a ground facility… Because these vehicles are unmanned, there are special airspace and navigation procedures that allow limited operation in the NAS. These procedures tend to be by exception and are locally coordinated between the service provider and the ROA operator. (p. 9)

Although there are some concerns, in the near term, there will be little impact on controllers. Presently, the NAS ROA operations are very limited but they provide insights on how ROA operators will interact with controllers. The FAA certified the Altair to operate in the NAS airspace in 2005, and they have received applications for certification for several more of these vehicles.

Human Factors Considerations

The communications mechanism and the unique range of behavioral characteristics for these types of aircraft will pose challenges for the air traffic controller. One of the biggest differences between ROAs and conventional aircraft is that the operators play a role similar to controllers, but they have direct control over one or more aircraft. We will need to resolve how controllers will communicate with the remote operator before allowing ROAs into the NAS. Whom should a controller contact if an ROA has to comply with a clearance? Wickens and McCarley (1995) note that another potential human factors consideration is the effect of delays in response to ATC instructions. They report response delays of a varying number of seconds, and controllers may have greater difficulty in compensating for these delays than they do with aircraft exhibiting a fixed response characteristic. They also suggest that without human presence on UAVs, operators may maneuver UAVs with characteristics that are very different from passenger or human piloted aircraft. Therefore, it may be important for controllers to distinguish UAVs easily from other vehicles in their sector. Additional considerations include whether communications phraseology, ATC separation, controller roles and responsibilities, and emergency procedures should be different from those for other types of vehicles.

3.8.2 Very Light Jets

VLJs (or micro jets) are already certified to operate within the NAS. In 2006, the FAA certified the Eclipse 500 and Cessna 5140 for business and personal use (FAA, 2006). The Eclipse jet carries up to four passengers, is capable of a cruise speed of 375 knots (694 km/h), and has a maximum altitude of 41,000 ft (12,497 m). More than 10 jet manufacturers are pursuing certification for VLJs, and they report receiving orders for more than 2000 of these revolutionary aircraft. The FAA predicts that as many as 4,500 VLJs will enter the NAS in the next decade (Wall, 2005). VLJs raise important ATC considerations because of the (a) number of these types of aircraft that are expected to enter an already congested airspace and (b) flight characteristics of these types of aircraft.

Human Factors Considerations

The emergence of VLJs and UAVs in the NAS, combined with the projected growth in the number of regional jets, will pose significant challenges to controllers in terms of the volume of traffic. As a result, controllers may be responsible for up to 3 times the traffic they are currently managing. In addition, these 4 to 6 passenger vehicles represent significant performance differences from existing passenger jets. The NBAA training guidelines for VLJs delineates some of the unique issues in terms of wake turbulence, jet blast, and pilot unfamiliarity with high altitude operations (e.g., weather, jet stream, physiological effects, and procedures). These will certainly hold implications for ATC. Wall (2005) reports that VLJs are seen as particularly troublesome because of their speed and the fact that they fly at the same altitudes as many standard passenger aircraft. The differences in airspeed and climb/descent rates between existing and revolutionary traffic such as VLJs and UAVs will make it particularly challenging to merge these types of traffic efficiently.

3.8.3 Space Vehicles

The presence of SUA is not new to NAS. Until recently, the controller received SUA status through the supervisor. On the old M1 consoles, controllers used a “grease pencil” to draw the SUAs on the scope to indicate that the area was hot. On the current DSR displays, controllers have the ability to use electronic drawing features to indicate that a particular area is an SUA and is hot. Existing automation tools like URET already have the capability to schedule SUAs to go hot and will probe for aircraft that have a trajectory that enters a hot SUA. Currently, someone still enters the SUA schedule manually. With a SWIM system in place, facilities and government agencies may be able to automate the entry of SUAs and their schedules.

The main difference between the SUA that is currently used in the NAS and the volume of airspace needed for separation assurance from space launch/reentry site is the restricted volume of airspace that may move dynamically depending on the vehicle's predicted flight path, the type of fuel used, and the impact of the weather.

- An example of how the predicted flight path will affect the protected volume of airspace is a vertical takeoff requiring a smaller SUA for a shorter period than a reentry.
- An example of the impact of the type of fuel used is the aggressive nature of solid fuels used in space travel. When a vehicle with solid fuel reenters earths' atmosphere, a large area of airspace may be required to separate it from other traffic.
- Depending on the weather, the plume of air may shift orientation. The SUA may need to shift dynamically to avoid needing a larger SUA.

Human Factors Considerations

The primary human factors of controlling airspace with the presence of space vehicles include the novel aspects of SUAs and the integration of space vehicles into normal sector operations. Several groups have studied dynamic resectorization to accommodate changes in airspace because of weather or traffic demands. These studies based the resectorization on predetermined boundaries and switched these boundaries depending on conditions. An SUA that needs to behave like a weather area to represent the plume of airspace that the spacecraft requires is more dynamic and less determined than that. It is essential, however, that the controllers involved at the boundaries of that SUA have the capability to visualize that airspace to prevent aircraft from entering the restricted area. This may require integration of models of spacecraft debris and exhaust to ensure safety and efficiency. The conflict probe that is currently available in the NAS (URET/CCLD) can already probe for aircraft to airspace conflicts and has the capability to schedule SUA to go hot. That function is currently only available on the D-side position. To update the SUA shape and status dynamically, the airspace adaptation would need to change dynamically for predetermined pieces of airspace as well as for dynamically changing borders. Currently, this is not possible in the NAS.

Depending how well we can predict the behavior of space vehicles, we may also see a transition from dedicated large scale SUAs to a space vehicle that just has different separation requirements, but is otherwise treated as another aircraft. To incorporate space vehicles in normal sector operations, we need to determine what minimum separation standards are necessary to maintain a safe and efficient flow of traffic. The conflict alert system, conflict probe, and conflict resolution advisories will need to accommodate the presence of space vehicles and aid the controllers in separating traffic from them. It may take additional training to accomplish this task effectively, because controllers currently have certain expectations of the behavior of aircraft. The behavior of space vehicles may not fall within these expectations.

3.8.4 Tilt Rotor Aircraft

The RTCA predicts that NAS users will begin to operate tilt rotor aircraft in the near term, (i.e., before the end of 2005). The use of aircraft that can takeoff and land vertically, but operate similar to fixed-wing aircraft while en route, results in the presence of aircraft display dynamics that are different from what a controller expects from fixed-wing aircraft. RTCA (2002) states, "In the initial years of operation, tilt rotor aircraft operations tend to be few, localized, and follow traditional traffic flow. However, as additional commercial uses are found for these vehicles, new operational applications capitalize on their inherent capabilities." (p. 9)

Human Factors Considerations

In addition to the changes noted for the previous vehicles, tilt rotor aircraft will present key challenges because of their unconventional transition states. Air traffic controllers will need to learn the new aircraft dynamics at a perceptual level to be able to identify takeoff and landing states quickly and to learn and use new terminology and procedures. Other important considerations include effectively integrating these unique flight characteristics into conflict probe algorithms to minimize false alerts.

Although controllers learn some behavior characteristics of aircraft from written material during their initial training, much of their knowledge about aircraft behavior during all phases of flight must originate in perceptional learning. During day-to-day operations, controllers work repeatedly with aircraft that implicitly display their dynamic characteristics on the radar display. Under these conditions, perceptual learning will occur in an unsupervised fashion. It is not clear at this point how much time controllers need to complete this learning process. After perceptual learning has occurred, projection of expected aircraft behavior will be fast and effortless. Until controllers reach that point, projection of aircraft behavior will be conscious, slow, and arduous. The introduction of a new class of aircraft with very different dynamic characteristics than current fixed-wing aircraft will require controllers to "over learn" that behavior before they can incorporate them into the mental projection of their airspace effortlessly. When tilt rotor aircraft are in a sector, during the time that controllers are still learning the behavior characteristics of these machines, controllers will need to commit more effort and resources to these aircraft, which will result in a reduction of available resources for the conventional aircraft in the airspace.

Once controllers have acquired the expertise to accommodate the dynamics of these new aircraft, we can capitalize on the fast and effortless processing of the controllers' behavior. This requires controllers to distinguish these aircraft from conventional fixed-wing aircraft easily. Existing automation will need to provide that information to controllers in a primitive way (i.e., at the perceptual level) for controllers to be able to apply their newly acquired expertise.

To merge vertical takeoff and landing aircraft into existing traffic, new procedures are necessary. The procedures will need to include requirements of phraseology, separation criteria, and eligibility of aircraft for vertical takeoff and landing.

The current conflict alert and conflict probe algorithms base their predictions on the characteristics of fixed-wing aircraft. With the introduction of aircraft that are capable of vertical landing and takeoff, these algorithms need to account for such behaviors.

3.9 Summary of Human Factors Implications of NAS Enhancements

As discussed, the new NAS will have far-reaching implications for air traffic across all domains and users. Table 3 summarizes some of the key enhancements and their potential impact.

Table 3. Implications of Advanced Concepts on Air Traffic Control

Air Traffic Domain	Key Enhancements	Human Factors Implications
Tower	Data link disseminates route of taxi and flight clearances, airport information, other aircraft locations, and weather conditions.	• Information processing (e.g., what information needs to be presented? how can the display be designed to avoid clutter?) • Situation Awareness (SA) (e.g., what impact does the system have on users' SA?)
	Decision support systems (DSSs) sequence traffic and provide taxi clearances and runway assignments based on assigned gate, traffic congestion, traffic flow aloft, weather and other instrumental variables.	• Information processing (e.g., how should this information be displayed? how do system designers avoid clutter?) • SA (e.g., does the system promote user SA, especially when there is increased reliance on DSS tools?) • New roles and responsibilities (e.g., how do DSS and data link change user-system interactions and information processing?) • Errors (e.g., does the system provide a means to avoid and recover from errors?)
	All stakeholders receive surface aircraft and vehicle location information.	• Information processing (e.g., what information does each user need? how do system designers avoid display clutter?) • SA (e.g., does this information promote SA?) • Workload (e.g., does the system require additional physical actions or mental effort?)
	Enhanced navigation and total airport surveillance enable zero-visibility operations.	• SA (e.g., does the system promote user SA?) • Information processing (e.g., what information is needed to support these types of operations?)
Terminal	DSSs deliver optimum flight profiles and efficient traffic flow for arrivals and departure transitions to and from high altitude anchor points.	• Skill acquisition and maintenance (e.g., do users acquire and maintain sequencing skills? how do users recover from a DSS system failure?) • New roles and responsibilities (e.g., how do users interact with the DSS?) • SA (e.g., does the system promote and maintain user SA?)
	Flight decks receive negotiated routes based on system-supported coordination.	• SA (e.g., does the system promote a shared SA between the controller and pilot?) • Workload (e.g., does this process require additional controller workload?)
	Precision instrument approaches and departures, even in poor visibility conditions, are available at almost any location due to satellite navigation, vertical guidance capabilities, and virtual vision devices on the flight deck.	• Information processing (e.g., what information is needed to support these types of operations, and how do system designers avoid clutter?) • New roles and responsibilities (e.g., do controller roles and responsibilities change during these operations?)

(table continues)

Table 3 (continued). Implications of Advanced Concepts on Air Traffic Control

Air Traffic Domain	Key Enhancements	Human Factors Implications
Terminal	Pilots monitor current position using moving map displays.	• SA (e.g., does the system promote a shared SA between the controller and pilot?) • Workload (e.g., does the shared controller/pilot SA reduce workload?)
	Separation standards are reduced because of changes to ATC procedures and improvements in turbulence and wake vortex avoidance.	• New roles and responsibilities (e.g., what effect do these new procedures have on controller performance? can controllers recover from a DSS failure?)
	Enhanced all weather landing systems allow for multiple final approaches which maximizes runway capacity.	• Workload (e.g., does the system maintain reasonable controller workload levels?)
En route	DSSs including conflict probe, resolution advisor, and automatic trial planning maximize traffic safety and efficiency, especially in low-density airspace.	• Skill acquisition and maintenance (e.g., do users acquire and maintain sequencing skills? how do users recover from a DSS system failure?) • New roles and responsibilities (e.g., how do users interact with the DSS?) • SA (e.g., does the system promote and maintain user SA?)
	An increasing number of en route facilities use time-based metering.	• New roles and responsibilities (e.g., what effect does this have on the controller task?)
	Separation standards are reduced as a result of technological improvements such as improved surveillance and navigation capabilities.	• Skill acquisition and maintenance (e.g., how do users recover from a system failure?) • Errors (e.g., do these technological improvements help mitigate and recover from errors?)
	Data link provides en route ATC clearances and real-time weather, NOTAMs, charts, SUAs, and other data.	• Information processing (e.g., what information needs to be presented? can controllers readily locate needed information from mixed communication types?) • SA (e.g., what impact does the system have on users' SA?)
	Sector boundaries are adjusted dynamically to meet traffic, weather, SUA, and other constraints.	• SA (e.g., can controllers effectively maintain SA as sector boundaries are dynamically adjusted?)
	An increasing number of users are able to use high altitude auto-negotiated and automatically loaded routes when their preferred route is not available.	• SA (e.g., does the system promote SA? how does the system notify the controller of reroutes?)

(table continues)

Table 3 (continued). Implications of Advanced Concepts on Air Traffic Control

Air Traffic Domain	Key Enhancements	Human Factors Implications
Oceanic	Lateral and longitudinal separations are reduced for all aircraft equipped with advanced navigation and performance equipment.	• New roles and responsibilities (e.g., what changes do these reduced separation standards have on controller roles and responsibilities?) • Information processing (e.g., what is the best means to present aircraft equipage information?)
	ATC operational en route and international procedures are harmonized.	• New roles and responsibilities (e.g., how do the new procedures impact controller performance?)
	ATC receives automated position updates from all oceanic traffic via data link.	• Information processing (e.g., what information needs to be presented? how can the display be designed to avoid clutter?)
	As in all other domains, DSSs monitor the flight domain, analyze constraints, and auto-negotiate flight amendments to maintain safety and promote efficiency.	• New roles and responsibilities (e.g., what effect does increased reliance on DSS tools and automation have on controller performance?) • Skill acquisition and maintenance (e.g., do controllers acquire and maintain sequencing skills? how do users recover from a DSS system failure?) • SA (e.g., does the system promote a shared SA?)
System-wide	Traffic levels increase from today's levels. Predictions range from +33% to +350%.	• Information processing (e.g., how can the display be designed to avoid clutter?) • Workload (e.g., are workload levels acceptable?) • New roles and responsibilities (e.g., will controllers need to rely on DSS tools to maintain separation?) • SA (e.g., can controllers maintain SA at these traffic levels?)
	New forms of transportation will emerge and become increasingly common. The RTCA predicts that the NAS will consist of vertical take off and landing vehicles, tilt rotor aircraft, hypersonic vehicles, and UAVs.	• New roles and responsibilities (e.g., will controllers need to rely on automation to separate these types of vehicles? what changes will need to be implemented to their current roles and responsibilities?) • SA (e.g., what impact does the mix of traffic have on controllers' SA?)
	Data link provides clearances, weather, NOTAMs, charts, SUAs, and other data.	• Information processing (e.g., what information needs to be presented? how can the display be designed to avoid clutter?)

4. DISCUSSION

RTCA (2002) summarizes the expected changes in the NAS from a technological perspective. We have presented our assessment of how these changes may affect the human operators of the ATC system. We also have concerns that cut across all technological changes presented in the RTCA vision and the TSD. In addition, we have identified issues that human factors research needs to address to ensure that the controller workforce can operate the NAS of 2015 in a manner that equals or exceeds the current levels of safety and efficiency. These issues revolve around expected increases in traffic levels, information, fleet diversity, and automation. The primary human factors considerations of these new technologies and procedures are in the areas of information processing, situation awareness, workload, errors, skill acquisition and maintenance, and new roles and responsibilities.

4.1 Information Processing

One of the integral aspects of the NAS of the future is the availability of all data for all users at any point in time. Although the increased availability of data provides the NAS with greater flexibility, it does not mean that we need to display all data everywhere. Researchers state that operators in the battlefield today report being unable to process all the data presented to them in the limited time available (Duggan, Banbury, Howes, Patrick, & Waldron, 2004). They have proposed data fusion as a means to reduce workload and promote operator SA. Depending on the function of the controller workstation, only a subset of the available data may be necessary to execute that function. The FAA planning documents do not sufficiently detail how to filter the data to provide an operator with only the data needed, or the format needed, to support efficient information processing. It is likely that a DSS will perform much of the information processing. In the current ATC environment, we have already introduced several elements to the ATC workstations that have changed the interface significantly without understanding what that change will do to the situation assessment capabilities of the operator. Especially in the ATC environment, availability of data in an appropriate format is essential to support a safe and efficient flow of traffic. Seemingly, small changes can have a dramatic effect on the way operators monitor the data provided on their displays. For example, a recent study has shown that the introduction of the TMA list on the DSR displays will change the way controllers scan their displays for information. The TMA-list is already available in ARTCCs that use the Center TRACON Automation System (CTAS) to support time-based metering into certain airports.

Increased diversity in the air traffic fleet causes some of the concerns described in the previous sections. In the current environment, controllers know what behaviors to expect from certain aircraft types because they have worked with them for several decades. The introduction of new aircraft types will require air traffic controllers to integrate the characteristics of these aircraft into their procedural knowledge. By not introducing aircraft that had drastically different characteristics, for quite some time, we do not know how long it will take controllers to predict how these aircraft will work.

The introduction of other separation standards and the RTCA document suggest that we will move to DRVSM and 3 nautical miles (nm) of separation everywhere. This may be our goal, but is it realistic to expect that these standards will apply to the full fleet? In 2015, it is likely that we will still have many aircraft that do not meet the requirements necessary to apply these reduced separation rules. Even if we provide air traffic controllers with indications of what separation standard applies, we will leave the controllers with the decision if two aircraft should meet the 3 nm or the 5 nm separation standard.

The introduction of new technologies and procedures (ADS-B, RVSM, and RNAV, etc.) will require that we inform the controllers about what equipment is available on an aircraft and whether that equipment is in use. Simply adding indicators to the aircraft representation will result in a format that contains a dense set of information and result in more clutter rather than reducing it. Even if we assume that controllers eventually will adapt and process all the data, we do not know how long it will take them to absorb the information automatically. Instead of attempting to display more information, the increase in traffic will require that we decide what we need to display to the operator because there will be too much traffic to display all available data on all aircraft.

4.2 Situation Awareness

Future traffic loads and changes in ATC automation will challenge controller SA. Predictions of air traffic levels in 2015 vary widely and range from 33% to as much as 250-350%. Some air traffic controllers suggest that using current procedures and systems, an increase of even 33% would saturate ATC facilities during busy periods and make it necessary to limit the number of aircraft entering the facility's airspace. Differences introduced by novel aircraft with unique characteristics will challenge a controller's ability to project aircraft positions (level 3 SA). The increase in traffic level and types of traffic will continue to expand into the near future; therefore, it is imperative that the FAA deploy effective automation and procedures that enable controllers to maintain good SA despite these changes.

As we introduce shared separation into the NAS, there will be fewer predictable conflict points within a sector, which will increase the controllers' level of effort to maintain awareness of potential conflicts. Research indicates that automated systems can result in neglect of monitoring tasks (Endsley, 1997; Willems & Truitt, 1999).

4.3 Workload

Air traffic controller workload is another important consideration in the NAS of the future. It includes visual complexity components such as searching a busy visual display for targets; it includes cognitively demanding tasks such as identifying potential conflict pairs; and it includes motor tasks such as issuing clearances.

In the steadily increasing traffic levels of the future, controllers will require highly reliable conflict detection capabilities to aid in the safe transition of aircraft through the NAS. As we reduce predictable conflict points, the controllers' level of effort to maintain awareness of conflictions will increase. One problem posed is dynamically predicting the level of traffic at which the controller will begin to lose effectiveness, as a minimum, taking into account a variety of factors such as wind, weather, traffic flows, and procedures. It will be at this point that the intervention of automation will become necessary to assist the controller in maintaining awareness and providing services such as route, altitude, flow, and conflict resolution advisories.

Controllers recognize radio communication limitations as one cause of their inability to handle a substantially higher level of traffic. Radio frequency congestion is a known issue across air traffic domains. En route controllers at several en route centers have acknowledged its importance (FAA, 1994), and it continues to represent one of the three most prevalent complexity factors facing tower controllers today (Koros, Della Rocco, Panjwani, Ingurgio, & D'Arcy, 2003). Programs such as the CPDLC system can reduce the frequency congestion drastically by introducing electronic alternatives to verbal communications. Expanding the number of available radio frequencies does not alleviate the limitations of the human operator. Verbal clearances are sequential and, therefore, controllers can only control as many aircraft as they can issue clearances in an uninterrupted stream of utterances. In busy facilities, both the terminal and the en route domain, controllers will often be so busy issuing verbal clearances that it is difficult for pilots to insert their responses to the clearances. Presently, this occurs in busy en route facilities including Miami, Jacksonville, Chicago, Houston, New York, Boston, and Cleveland (FAA, 1994). The acknowledgment of a pilot’s initial call when entering a sector and the instruction to switch frequency when the aircraft leaves the sector (hi-and-goodbye) makes it necessary for the controller to issue clearances to at least two times the number of aircraft coming through the sector. The introduction of a system that can separate these clearances and many others from the verbal channel can free up resources considerably.

Initially, the introduction of digital communication such as CPDLC between air and ground operators may provide a window of increased availability of resources; the predicted increase of traffic will quickly close that gap, which will confront controllers with other limitations. The use of a CPDLC-like system can enable controllers to offload their verbal channel (voice) by making communications available using the motor channel (input through the keyboard or other devices). Some solutions may make use of the knowledge that the system has about airspace and associated frequencies and create an automated communication process that, unless interrupted by a controller, automatically hands off aircraft and switches frequencies to the next sector. Instead of manually accepting aircraft and instructing frequencies when the circumstances are normal, the future NAS needs to only require this by exception.

In addition to issues related to frequency congestion, limitations to controlling a large number of aircraft exist because controllers can only address (either verbally or electronically) a limited number of aircraft. Alternatives that enable controllers to issue instructions to groups of aircraft can provide a means to alleviate the need to address all aircraft individually. In the next section, on the concerns related to an increase in information available to controllers, we will further address the ability to reduce the need to address aircraft individually.

4.4 Errors

Controllers in the current and future NAS will perform the six basic ATC tasks that Alexander, Alley, Ammerman, Hostetler, and Jones (1987) established:

1. Perform situation monitoring.
2. Resolve aircraft conflicts.
3. Manage air traffic sequences.
4. Route or plan flights.
5. Assess weather impact.
6. Manage sector and position resources.

Human errors in any of these tasks can lead to a reduction of system safety, efficiency, and capacity. To minimize the impact of changes to the NAS structure, the volume and complexity of traffic, and the introduction of automation on human error, the system must support operators in those areas that are most prone to operator mistakes. The source of operator errors can range from failure to detect, remember, misinterpret, or apply incorrect action following an event (Isaac, et al, 2002). When the volume of traffic increases, controllers will rely more on automation and will no longer expect to have a full awareness of the situation under their control. Therefore, it is imperative that we help controllers find the information easily and provide them with a safety net. These safety nets may be part of the automation systems. Existing examples of tools that attempt to counteract potential failure to detect information are the conflict alert and conflict probe. An example of a mechanism that has received research attention is the *monitor alert*. A monitor alert would warn a controller when an aircraft is out of conformance (i.e., started a maneuver that does not conform to what the system expected the aircraft to perform). Although a monitor alert exists in the form of a subtle change of position symbol in the en route environment, in the future, we may need to provide more advanced tools. Examples of recent changes that support controllers in remembering events and information are the annotation on the fourth line of the full data block in the DSR system and a non-RVSM indicator to help air traffic controllers remember that a particular aircraft cannot use RVSM rules.

4.5 Skill Acquisition and Maintenance

The introduction of advanced automated air traffic systems and capabilities hold substantial implications for controller performance. Systems that do not adequately address user needs may engender automation-induced complacency, deficiencies in skill acquisition and maintenance, as well as several other negative repercussions. Research suggests that individual differences in the potential for automation-induced complacency, boredom proneness, and cognitive failure may further complicate things (Prinzel, DeVries, Freeman, & Mikulka, 2001).

A justified concern exists among operational personnel that with the introduction of more automation tools, current skills will erode and possibly disappear altogether. Although this concern is valid, it is not realistic to assume that the current ATC system can revert to non-automated operations while maintaining the same volume and complexity of air traffic. It becomes more important to determine how, with the help of automated systems, controllers can most efficiently acquire the skill needed to safely and efficiently handle the projected traffic levels and can recover from system failure.

4.6 New Roles and Responsibilities

The controller workstation of the future will almost certainly require more dependency on highly automated and reliable conflict detection capabilities. As noted earlier, besides increased traffic volume, increased flexibility in flight paths will result in many more converging paths and, ultimately, less predictability and potential conflicts may occur. As we further reduce the structure in the airspace, the controllers' level of effort to maintain awareness of conflictions will logically increase. One problem posed is dynamically predicting the level of traffic at which the controller will begin to lose effectiveness, as a minimum, taking into account a variety of factors such as wind, weather, traffic flow, and procedure. It will be at this point that the intervention of automation will become necessary to assist the controller in maintaining awareness and providing services such as route, altitude, flow, and conflict resolution advisories.

The increased route flexibility may require improved abilities to communicate complex and dynamic route strings to the aircraft. Input methods must be streamlined and intuitive using the minimum of verbiage or actions. Digital transfer of information with graphical displays on the flight deck could prove to be a highly efficient method of communicating complex and rapidly changing routes. This would be especially true when no existing route exists, such as during deviations around weather.

The improved route flexibility and the ability to communicate that information rapidly could virtually eliminate the need for vectors. Vectoring is a non-precise method of navigation and even more so in areas of shifting winds and wind shear. With a dense, flexible, and rapidly communicable route structure, a controller may actually assign the precise ground track without the need for interpretation or potential for misunderstanding. With this ability, amended procedures could accommodate reduced separation; for example, controllers could reduce the airspace required to separate aircraft in parallel streams.

In the current system, controllers receive information about an aircraft and its route as soon as the FPS arrives. When the FPS is not (yet) available, a controller can obtain aircraft information by requesting a flight plan readout. Once the aircraft is in the sector, the sector controllers are responsible for its safe and efficient flight through the sector airspace. When TMU or ATCSCC decides that a flow needs to change, they are telling the controlling sector to change their plans to incorporate the flow changes. However, the sector controllers are still responsible for these aircraft. Therefore, controllers will need the flexibility to modify the flight path within their sector, when necessary. This type of request differs from a request made by an adjacent sector in that it is not up to the discretion of the controller to approve or deny the request.

The FAA has already begun drafting new procedures that will provide controllers with guidelines for handling a fleet with mixed DRVSM capabilities. The Future En route Workstation will need to provide controllers with information about aircraft DRVSM capabilities and status. To provide controllers with a safety net that performs at a minimum as well as the Short Term Conflict Alert available in the current HCS/DSR environment, the STCA algorithms will need adjustment to accommodate DRVSM. We will need to modify algorithms of automation tools that use current separation standards to accommodate a fleet with mixed DRVSM capabilities. The possibility that pilots can execute user-preferred climb and descent profiles may require drastic changes in procedures that will affect the division of responsibilities for separation assurance between air traffic controllers and pilots.

5. RECOMMENDATIONS FOR FUTURE RESEARCH

The changes to the NAS will have far-reaching implications to the roles and responsibilities of controllers. The following list outlines some key research questions that designers must anticipate when implementing future automation systems.

1. How will increases in traffic levels affect
    a) *information processing* (e.g., how can the display be designed to avoid clutter);
    b) *workload* (e.g., are the resulting workload levels acceptable);
    c) *reliance on and use of automation*; and
    d) *SA* (e.g., can the air traffic controller maintain SA at these traffic levels)?

2. How will the increase in traffic diversity affect
    a) *the controllers' ability to apply multiple separation standards*; and
    b) *the controllers' ability to integrate new aircraft types into the existing traffic flow* (e.g., slower VLJs or UAVs into a stream of heavy passenger jets)?

3. How does increased reliance on DSSs (including automatic conflict detection, resolution, trial planning, and time-based metering) affect
    a) *conflict detection, resolution, and sequencing skills*;
    b) *recovery from a DSS system failure*; and
    c) *the need for integration of the decision-support functions?*

4. How does providing auto-negotiated and automatically loaded routes to aircraft affect
    a) *how controllers maintain awareness of current and projected aircraft positions*; and
    b) *the way the system needs to notify air traffic controllers of changes in aircraft intent?*

5. How does the availability of emerging navigation and surveillance capabilities affect
    a) *how the system provides air traffic controllers with information about the capabilities and state of aircraft and the applicable procedures*;
    b) *limitations of the FMS to handle deviations from standard procedures*; and
    c) *information when these capabilities are degraded?*

6. How will using data link to provide ATC clearances, real-time weather, NOTAMs, charts, SUAs, and other data affect
    a) *shared SA between pilots and air traffic controllers*;
    b) *recovery from loss of the availability of data link services*; and
    c) *air traffic controller expectations of aircraft capabilities* (e.g., controllers may attempt to send a data link message to a non-equipped aircraft assuming that the aircraft will comply)?

7. How will dynamically adjusting sector boundaries to meet traffic, weather, SUA, and other constraints affect
    a) *how controllers maintain SA as sector boundaries change*; and
    b) *workload as a result of communications, point-outs, or changes in procedures?*

6. CONCLUSIONS

As the *NAS: Concept of Operations and Vision for the Future of Aviation* recognizes, it is essential that NAS changes take a human-centered approach (RTCA, 2002).

> RTCA (2002) states the following:
>
> Human factor analyses and human-in-the-loop simulations determine the appropriate allocation of service providers, users, and automation system tasks. Moreover, issues such as situational awareness, workload, and computer-human interface (CHI) design are resolved by incorporating human factors and operational assessments throughout the NAS (including flight deck) design and validation process. (p. 6)

It is necessary to include human factors into the individual development and acquisition programs, but it is not sufficient to ensure that air traffic service providers and their customers will be able to use the resulting system in a safe and efficient manner. In this report, we have attempted to summarize some of the implications that changes in the NAS will have upon air traffic controllers, but more importantly, we have tried to identify key human factors considerations that researchers and system designers must address when implementing these new technologies. For example, it is essential that the air traffic controller interface with the display system and integrate all information to ensure manageable workload and SA. As traffic levels increase, air traffic controllers will not have a complete awareness of the traffic situation in their airspace. Automation will need to provide controllers with the necessary tools to alert them when a situation needs their attention as well as to filter the data they need for decision making. Technology alone will not be able to support the increased capacity demands. To meet these demands, we need to rely on a combination of technology and the human operators of the system.

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Acronyms

ADS-B	Automatic Dependent Surveillance - Broadcast
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
ATIS	Automated Terminal Information Service
CDM	Collaborative Decision Making
CDTI	Cockpit Display of Traffic Information
CFIT	Controlled Flight into Terrain
CHI	Computer-Human Interaction
CPDLC	Controller Pilot Data Link Communications
CRCT	Center Routing Collaboration Tool
DOD	Department of Defense
DRVSM	Domestic Reduced Vertical Separation Minimum
D-side	Data Controller Position
DSS	Decision Support System
EDA	En Route Descent Advisor
FAA	Federal Aviation Administration
FDB	Full Data Block
FIS-B	Flight Information Service - Broadcast
FMS	Flight Management System
FPS	Flight Progress Strip
HCS	Host Computer System
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NAVAID	Navigational Aid
NOTAM	Notice to Airmen
NTSB	National Transportation Safety Board
OEP	Operational Evolution Plan
OIG	Office of the Inspector General

POET	Post Operational Evaluation Tool
RNAV	Area Navigation
RNP	Required Navigation Performance
ROA	Remotely Operated Aircraft
R-side	Radar Controller Position
RTCA	Radio Technical Commission for Aeronautics
RVSM	Reduced Vertical Separation Minimum
SA	Situation Awareness
SOP	Standard Operating Procedure
SUA	Special Use Airspace
SWIM	System Wide Information Management
TFM	Traffic Flow Management
TIS-B	Traffic Information Service - Broadcast
TMA	Traffic Management Advisor
TMU	Traffic Management Unit
TSD	Target System Description
UAV	Unmanned Aerial Vehicle
URET	User Request Evaluation Tool
VFR	Visual Flight Rules
VLJ	Very Light Jet