En Route/TRACON Controller Common Function Information Requirements

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CAVEAT AND NOTICE TO READERS

Please note the following context regarding the purpose and historical nature of this document:

- **Not for Directives or Requirements:** This document is **not intended to show official directives or be used as a set of formal requirements**.
- **Historical Record:** This report was originally completed on September 30, 2016, and is being **published now solely as documentation for the historical record**.
- **NextGen Assumptions:** The analysis, recommended functions, and proposed timelines within this document assumed **NextGen capabilities and implementations based on the knowledge available at the time. Actual implementation post these analyses vary.**
- **FAA-Led Development:** The proposals herein operated under the assumption of an **FAA-led development process** for evaluating and integrating these workstation software capabilities.
- **Input for System Evaluation:** Because the technological landscape has evolved since its initial drafting, this document is **provided as input for evaluating systems**, such as common automation platforms.

1. Project Overview

The workstations in use by today's air traffic controllers were developed primarily to meet the requirements of the Air Traffic Control (ATC) domain in which they were implemented. Although the en route ATC domain and the terminal ATC domain share many required functions in common, such as air traffic surveillance, they have different required functions as well, such as with terminal's requirement to sequence parallel streams of arrivals into high volume, multi-runway airports. Today's en route workstation software was not designed to support all terminal functions and neither was today's terminal workstation software designed to support all en route functions. Not all the domain functions are the same because the controllers from those two domains perform somewhat different tasks using somewhat different procedures, and because the aircraft fly at different altitudes, speeds, and execute different profiles while under control of the controllers from the different domains. Furthermore, workstation software in use by controllers in the different domains often differ in their user interfaces even when the functions being fulfilled are the same. This is in part due to different contractors developing, somewhat independently, the workstation hardware and software used in each domain.

The implications of using unique workstation software in the different ATC domains include higher costs and inefficiencies with regard to training personnel, equipment acquisition, and system maintenance. Additionally, as some workstation software functions have been made available to controllers in only one domain, there may exist some as yet unrecognized benefits that can be gained by making those same functions available to controllers working in both domains. Although the design and implementation of new technologies associated with the Next Generation Air Transportation System (NextGen) could provide opportunities to reduce the differences between the domain workstations, without guidance the current trajectory of enhancing en route and terminal workstation software instead risks leading the FAA down a path toward further divergence.

The overall objective of this project is to provide human factors system development guidelines that identify incremental terminal and en route workstation software convergence opportunities throughout the NextGen mid- and far-terms. This guidance document provides human factors recommendations for the design and implementation of NextGen capabilities that could make controller workstations in both domains more similar in appearance and behavior. It also provides recommendations from FAA Human Factors for specific time periods when the implementation of proposed convergence items should occur based on scientific and technical data. The guidelines developed during this project for the terminal domain apply only to workstation software used in the Terminal Radar Approach Control (TRACON) operating environments and not to workstations used in air traffic control towers. Tower cab workstations and the tasks performed by tower controllers differ sufficiently from the controller workstations used in both the Air Route Traffic Control Centers (ARTCCs) and the TRACON facilities that they were deemed out of scope for this project.

The Common Information Requirements (CIR) project team worked with several Subject Matter Experts (SMEs) to identify functions associated with workstation software used by one domain that could provide benefits if made available to the other controller domain as well. Some of the functions examined as part of this analysis have been proposed as part of NextGen for implementation in either just the en route or just the terminal domain. This analysis examined some of the functions that were used in either just the en route or just the terminal domain prior to NextGen but would need to be made available to the other domain to support future NextGen-related functionality. Where the team identified functions for convergence across the two domains, we collected and documented recommended information requirements, in part to foster similarity between the two workstations.

Where changes to either domain workstations were planned as part of NextGen, the CIR project team looked for opportunities to guide the changes to make controller workstation software interfaces from the two domains look and behave more similarly to each other. This project did not consider identifying potential changes to the workstations and workstation functionality not associated with a planned NextGen change. Although in theory there are potential cost savings to be had in training, acquisition, and maintenance if the two domain workstations were redesigned to have essentially all the same functions and identical interfaces, there are potential negative impacts associated with changing how controllers currently interact with their workstations as well. These negative impacts include those associated with controllers having to unlearn old task sequences and learn new sequences required to utilize the new workstation software. Extensive testing would be needed to understand the extent of the impact so that a determination could be made about whether the benefit of making the two domain workstations essentially the same would compensate for the potential problems controllers might experience when learning to utilize new functionality. This current project only looked for opportunities to make functions more similar when ATC SMEs agreed that there was a significant potential for operational benefits if the functions were brought to the other domain, such as reductions in the potential for error or in controller workload. Additionally, for these opportunities to continue to be considered for recommendation throughout the report, the expected impact to controller task performance associated with the proposed convergence changes either had to be judged to be relatively low or highly related to a change already planned to occur as part of NextGen.

2. Methods

As part of the project plan, the CIR project team conducted four phases of analysis (see Figure 1). The phases included an analysis to identify candidate functions for convergence, a two-part preliminary validation phase with ATC SMEs, a validation and knowledge elicitation phase with current air traffic controllers, and an analysis of NextGen implementation plans to determine where in the plans functions identified in this project might best be implemented.

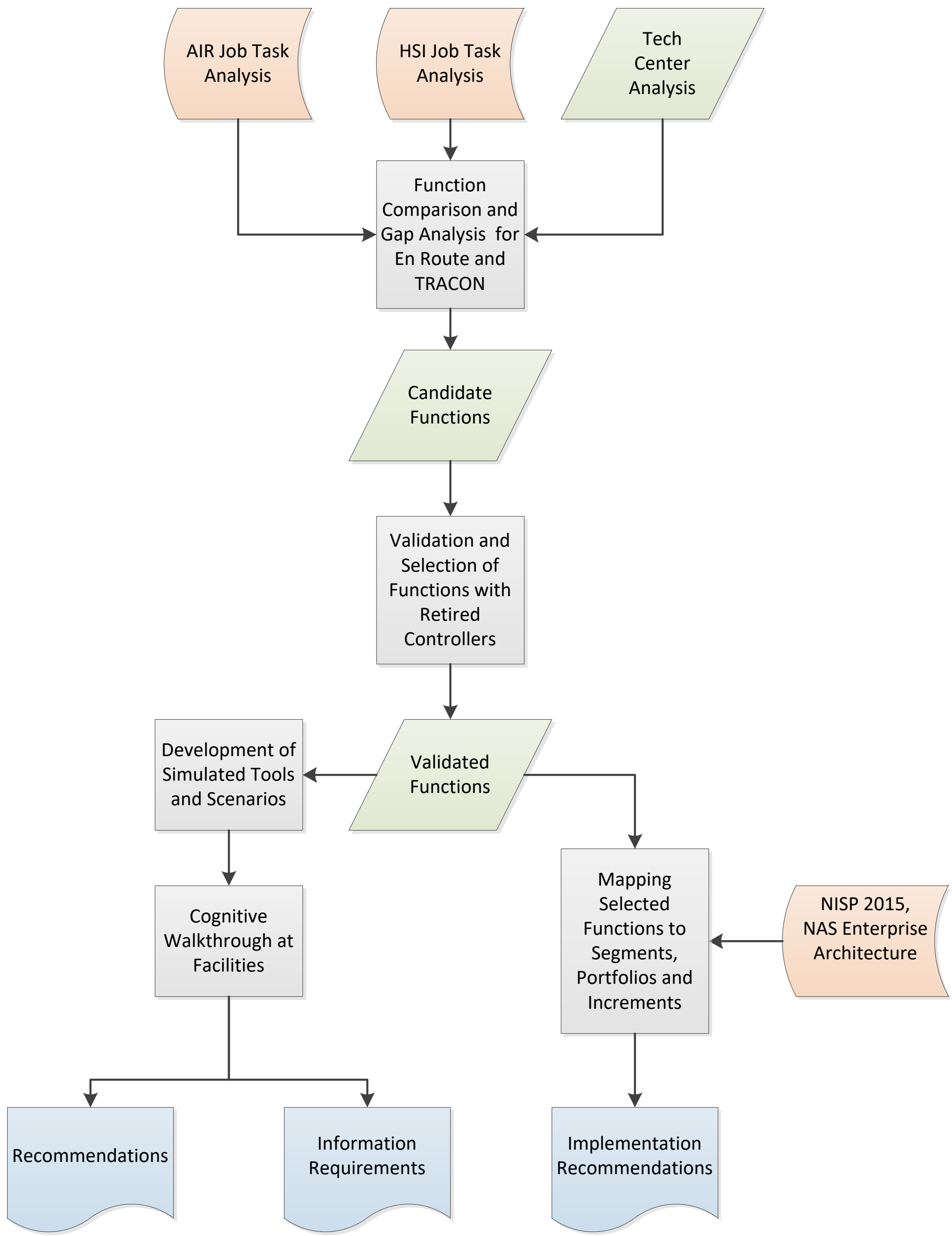

Figure 1. En Route/TRACON Controller Common Function Information Requirements project method

2.1 Identification of Candidate Functions

The project team conducted literature reviews, comparisons of ATC task analyses, and ATC SME interviews to identify current and NextGen related en route and terminal workstation software functions that are potential candidates for convergence. In particular, the project team identified the following:

- Functions that currently exist in both domains, but where the implementations of tools to accomplish the functions are substantially different (such as indication of aircraft ADS-B equipage) and where planned NextGen changes provide opportunity to reduce the differences.
- Functions that currently exist solely in one domain or are planned as part of NextGen to be implemented in one domain but not the other, and where the second domain might benefit if the functions from the first domain were added to their workstation (such as a data block drop down menu for changing flight data on the terminal primary display).
- Functions that do not currently exist in either domain, but where proposed NextGen improvements could bring changes to both domains (such as Data Comm.) that present opportunities for convergence.

The literature review included ATC task analyses (Krokos, et al. 2011a; Krokos, et al. 2011b; Smith, et al., 2011), NextGen description and planning documents (FAA, 2011; FAA, 2015), and papers describing research on potential future workstation design (Friedman-Berg, et al., 2010; Valencia and Allendoerfer, 2008; Willems, et al., 2008, Willems and Heiney, 2002, Willems, et al., 2002; Zingale, et al., 2010). Furthermore, researchers visited organizations known to conduct related NextGen human factors research including the FAA William J. Hughes Technical Center (WJHTC), the MITRE Corporation Center for Advanced Aviation System Development (CAASD), the NASA Ames Research Center, MIT Lincoln Labs, Volpe National Transportation Systems Center, and the FAA Civil Aerospace Medical Institute (CAMI), for the purpose of gaining a current understanding of potential future ATC systems.

A careful comparison of en route and terminal task analyses was conducted. Recent task analyses have either focused only on one controller domain or else lacked the specific fine-grained details needed to conduct a thorough comparison for display design purposes. For example, Human Solutions Incorporated (HSI) conducted a fine-grained task analysis for en route operations in 2011 but did not complete similar analyses for any of the other controller domains. Also in 2011, American Institutes for Research (AIR) conducted a job analysis that covered all controller domains but did not collect the type of fine-grained details such as task elements, tools, or task frequency and criticality ratings needed to perform the required comparisons for this project. Therefore the project team worked with retired controller SMEs to create a translation matrix between the AIR and HSI documents and add the details to the AIR job analyses needed to allow them to be used for comparison. Through the development of the translation matrix, we were able to map 1643 out of 1704 task elements from the HSI analysis to all 352 tasks of the AIR en route job analysis. By mapping task elements to tasks, we were also able to effectively translate all HSI's functions (9) and sub-functions (36) to AIR's activities (11) and sub-activities (42). Two retired terminal controllers were enlisted to provide more detailed information to AIR's terminal job analysis. Four retired terminal controllers provided frequency and criticality ratings to the terminal tasks in the same fashion that they were provided by HIS's SMEs for the en route task analysis. Note that the additional detail was added only for tasks performed by controllers working in the TRACON environment and not the tower cab environment. The resulting task analysis comparison between terminal and en route domains was used by the project team to identify activities, sub activities, and tasks potentially suitable for convergence.

The CIR project team identified the functions associated with the tasks considered most suitable for convergence. Next, the project team decomposed the functions into the methods with which they are accomplished at ATC workstations. These methods were then compared to determine if terminal and en route controllers perform the functions in a similar way. The project team used workstation instructional documents, when possible, but also relied on retired controller input for this determination. Furthermore, again working with SMEs, the project team assessed which common en route and terminal functions, currently differing in the tools and methods used to carry them out, were potentially suitable candidates for convergence in the NextGen time frame.

2.2 Preliminary Validation of Candidate Functions

To validate each of the identified functions, the team developed a series of simulated automation tools. These simulated tools were used as a mechanism to capture the concept of common functions across the en route and terminal domains for controller SMEs. Each of the simulated tools and their associated functions were reviewed by SMEs via an iterative process. During each phase of this process, all SMEs had the option to recommend adding or removing a simulated tool or function. During the rare cases where there were strong differences of opinion, the rationales for the opinions were discussed until a consensus was reached.

During the process four information sharing sessions were held to acquaint controllers with the other domain's workstations. The two domain-based groups were split for the first and second sessions as the project team delivered information about terminal workstation to three retired en route controllers and about the en route workstation to three retired terminal controllers. The third session was used to present simulations of NextGen tools to both groups together. During each of these sessions, each group was prompted to identify advantages and disadvantages of each of the different tools presented to them. For each session, the retired controllers were asked to answer the following questions for each tool presented:

1. Will this tool be useful in your current operational environment?
2. What part is the most useful? And why?
3. What part is the least useful? And why?
4. Under what conditions (e.g., small vs large sector, busy vs light traffic, high vs low altitude sector, etc.) will this tool be most useful?
5. If the tool is not useful, what type of additional information/functionality would you like to see in your workstation to accomplish the same objective?
6. Will this tool be useful in a NextGen operational environment?

During the fourth and final session, presentation of NextGen tools was completed and a round table exercise was conducted to develop rankings and priorities for all the functions represented. All information was provided via Power Point slides that included videos and figures explaining the functions and tools. The retired controllers were provided with briefing materials before each session.

During the second part of the preliminary validation phase, the results of the previous convergence analysis were further validated, this time presenting the materials to human factors, system engineering, and program management SMEs. Although nuances in simulated tools were discussed, this group of SMEs concurred with the retired controller SMEs regarding which tools should be presented to current controllers as part of the cognitive walkthroughs.

Table 1 presents the functions identified during the first and second phases of the project along with the rationale behind why the functions should be given consideration.

Table 1. Candidate Functions from the Preliminary Validation Phase

Candidate Function	Domains for which this would be a New Function	Rationale for Decision
Prevent occlusion of flight data blocks.	Both	New technologies and procedures associated with NextGen will likely lead to an increase in the amount of information displayed on the data block. In some cases, controllers will need to graphically interface with the data blocks to support new functions. To accommodate the new amount of information displayed, the size of the data blocks may increase, leading them to be more likely to overlap. At the same time, there will be a more frequent need to access text and icons on the data block. Managing data blocks has already been identified as the most frequent activity controllers perform (Willems & Heiney, 2002; Willems, Heiney, & Sollenberger, 2002). Therefore, the need to assist the controller in separating the data blocks becomes more important to avoid confusion and errors.
Provide visual indication of current flight non-conformance with route (RNAV, OPD) restrictions in a readily detectable format compatible with the manner used to display conflict alerts in STARS.	Both	The implementation of RNAV routes and Optimized Profile Descent (OPD) procedures introduces a need for more precise aircraft conformance monitoring. This common function could assist controllers in the timely identification of aircraft that do not adhere to published lateral and vertical route restrictions.
Provide visual indication of aircraft ADS-B capability on the primary display in readily detectable, non-textual format.	Both	Implementation of NextGen technologies and procedures requires new methods to convey target information and position. Each domain displays targets in different manner even though some embedded information points to the same aircraft/tracking attributes. Due to the use of different separation criteria and other new procedures enabled by Automatic Dependent Surveillance Broadcast (ADS-B) capabilities, controllers will need to be able to distinguish between ADS-B equipped and non-ADS-B equipped aircraft at a glance. Using a new symbol to replace the target symbol for ADS-B aircraft in

Candidate Function	Domains for which this would be a New Function	Rationale for Decision
		both the terminal and en route domains will allow controllers to quickly distinguish ADS-B capability and will foster similarity between the terminal and en route workstations. As the en route environment will be transitioning to a new symbol that represents location via a target fusion technique, a potential opportunity exists to implement this change.
Provide the ability to manipulate flight routes using a graphical user interface on the primary display to reduce controller workload and potential for error.	Both	On the primary En Route Automation Modernization (ERAM) display, en route controllers can access a data block drop down menu to input minor aircraft route changes. More complex changes require en route controllers to use an ERAM Decision Support Tool (EDST), which is located on a secondary display. Without the assistance of a D-side, R-side controllers must divide their attention between both the primary and secondary displays to input complex route changes such as airborne reroutes. Controllers working at terminal workstations do not have even the tools that the en route controllers currently have when it comes to performing airborne reroutes. Terminal controllers who use STARS make data entries to the National Airspace System (NAS) using a keyboard with an alphabetical key layout (as opposed to the QWERTY keyboard used by en route controllers). Currently terminal controller tasks do not require them to make as many data entries as en route controllers. For example, unlike en route controllers, terminal controllers do not make a data entry each time they instruct an aircraft to change altitude. TRACON sector controllers can ask a controller at a Flight Data position to enter the reroute information or else they can pass the rerouting task on to an en route controller to complete, when traffic load does not permit them the time necessary to enter the reroute information on the tools they have available at the sector today. This function would reduce the workload and potential for errors associated with performing airborne reroutes for both en route and terminal controllers.

Candidate Function	Domains for which this would be a New Function	Rationale for Decision
		For terminal controllers it would allow them to perform more reroutes themselves than is possible today. This would particularly be helpful to terminal controllers handling satellite or departure separation operations. This, in turn, would improve coordination between terminal and en route controllers and pilots and improve the predictability of flights in the system needed to maximize the potential benefits of NextGen planning tools.
On the primary display, introduce a GUI function that enables controllers to execute controller-pilot interactions via Data Comm for clearances such as altitude and frequency changes.	Both	Data Comm can reduce voice communications on sector radio frequencies, reduce workload associated with handoffs, and reduce the potential for certain types of communication errors. Data Comm is related to technologies that might reduce workload as well for such tasks as uploading lengthy route clearances or broadcasting the same information to more than one aircraft.
Provide additional weather information related to lightning strikes and icing.	Both	NextGen proposes improvements to the weather information provided to controllers. Controllers could use this type of information to better advise pilots to avoid unsafe areas.
Provide additional precipitation severity information in a format similar to that of STARS.	En Route	NextGen proposes improvements to the weather information provided to controllers. Currently en route workstations provide precipitation severity information in three levels while STARS provides six. Considering the potential benefits for training, implementation costs, and shared situation awareness, the CIR team proposed presenting en route controllers with a six level precipitation severity display.
Provide persistent visual indication of aircraft to aircraft and aircraft to terrain conflict information in a readily detectable format similar to that used in terminal.	En Route	Losses of separation have been attributed to circumstances whereby the conflict alert in en route is no longer displayed while a conflict still exists. Besides providing a persistent visual indication of conflict, the conflict alert presentation in STARS has other features that human factors principles would describe as improvements over the way conflict alerts are presented currently on en route workstations. Considering the potential benefits for training, implementation costs, and shared situation awareness, we presented en route

Candidate Function	Domains for which this would be a New Function	Rationale for Decision
		controllers with a conflict alert display that looks similar to the display of conflict alerts in STARS but in the ERAM environment.
Indicate flight ownership status in readily detectable, non-textual format.	En Route	Indication of ownership needs to be unambiguous and easily determined. Incidence of errors in the en route domain suggests that making small text changes in a screen full of moving text boxes isn't always sufficient. STARS in the terminal environment uses color to indicate ownership. Considering the coloring convention has been in use for over a decade and considering the potential benefits for training, implementation costs, and shared situation awareness using the same convention in en route would present, we proposed presenting en route controllers with an ownership indication that looks similar to the display of ownership used in STARS.
Provide the user with information that calculates a safe and efficient sequence or spacing plan based on wake turbulence and given routes and display the information in a graphical format.	En Route	Many of the benefits associated with NextGen rely on the predictability of flights within the system. Decision aids such as these create the potential for greater predictability throughout the system.
Enable computer mediated, controller to controller coordination for point-outs.	En Route	This function, offered spontaneously by a retired en route controller, is similar to a type of coordination provided in the terminal domain. Like Data Comm., it has the potential to reduce workload associated with communications but communications between controllers rather than between controllers and pilots.
Facilitate flight data entry on the primary display in a way that reduces workload and potential for entry errors.	Terminal	Terminal controllers who use STARS make data entries to the NAS using a keyboard with an alphabetical key layout (as opposed to the QWERTY keyboard used by en route controllers). Currently terminal controller tasks do not require terminal controllers to make as many data entries as en route controllers are required to make. This is likely to change as NextGen will

Candidate Function	Domains for which this would be a New Function	Rationale for Decision
		require both terminal and en route controllers to make more data entries so as to offer more flexibility and predictability for flights. This function would reduce the workload and potential for errors associated with performing data entry for terminal controllers. It would allow terminal controllers to enter data more efficiently and more frequently than is possible today. This, in turn, would improve coordination between terminal and en route controllers and pilots and increase the predictability of flights in the system.

2.3 Final Project Validation and Knowledge Elicitation Phase

At the conclusion of the preliminary validation phase, each of the tools and related functions were validated by current air traffic controllers via cognitive walk-throughs. Results from the cognitive walk-throughs were used to identify potential human factors requirements and design recommendations.

This phase took place in the field at or near en route and terminal facilities in the continental United States. A series of part task simulations was conducted using I-Sim simulation software developed by Kongsberg Geospatial and installed on two laptop PCs (one for the controller to interact with and one for an experimenter/pseudo-pilot) with 17" monitors and a Coretron keyboard representative of the kind used in the en route domain. The project team took the simulated tools to four locations: Dallas, TX, Minneapolis, MN, Atlanta, GA, and Houston, TX. At each location the team met for approximately 8 hours with a current terminal controller who had current experience working in TRACON operations and a current en route controller on two different days. These eight controller SMEs interacted with automation tools and display features, chosen as examples of the candidate functions, during short simulated air traffic scenarios under the corresponding platform for the domain (terminal or en route). The meetings with these eight controller SMEs were arranged through collaboration with FAA facility managers and bargaining unit representatives. The four en route controllers had between 8 and 26 years of experience as en route controllers with an average of 20.5 years of en route experience. The four terminal controllers had between 8 and 24 years of experience as terminal controllers with an average of 15.5 years of terminal experience.

The controller SMEs received an orientation to learn about the airspace and traffic characteristics. En route controllers interacted with tools using a generic en route sector and terminal controllers interacted with tools using a generic TRACON sector. Following the airspace orientation, a quick review of the workstation was conducted to familiarize participants with the simulation system. SMEs then received orientation on the simulated tools being examined. At the end of this orientation, the SMEs were given time to interact with the simulated tools while controlling simulated air traffic.

After using the simulated tools, the controller SMEs took part in a structured interview whereby the researchers asked questions about the usefulness and usability of the tools. A paper and pencil questionnaire was administered to the SMEs as well, for the purpose of collecting usability scores for each tool. Blank copies of the interview questions and the usability questionnaires are included in Appendix A and Appendix B.

Each function presented to the controller SMEs is enumerated below along with a description of the simulated tool used as an example of how the function could be fulfilled. We were not able to collect data during the cognitive walkthrough phase regarding the computer mediated point-out function or the additional weather information function due to having a limited time available with controller SMEs. It is important to note, however, that these functions remained on the list of recommended functions after the preliminary validation phase and thus merit further consideration for future research. Ulf Ahlstrom (2008) presented example ways to display this type of additional weather information.

2.3.1 Prevent occlusion of flight data blocks

Two tools were simulated as examples of how flight data block occlusion could be prevented: Automatic Data Block Offset, and Drag and Drop Data Blocks.

Automatic Data Block Offset (ADBO) is a concept that has been investigated in the Future En Route Workstation Study (FEWS) (Willems et al., 2008) and has also been investigated by EUROCONTROL (Project HRS/HSP 006, 2000). ADBO consists of automatic orientation of the flight data block to prevent overlapping and help to declutter the radar display. In the Standard Terminal Automation Replacement System (STARS), terminal controllers already have an automated full data block (FDB) offset algorithm that prevents overlapping of data blocks (Willems, 2008). The en route environment does not have a similar tool.

Controllers were presented with a simulation of a tool similar, but not identical, to the one developed for FEWS. The simulated tool moved data blocks in a slow, smooth motion whenever they were about to overlap with either each other or an aircraft target to prevent occlusion. If a controller manually moved a data block, this suppressed the automatic data block moving capability until a controller turned it back on for that aircraft. This simulated tool, however, did not feature all the capabilities explored for FEWS. For example, the simulated tool did not use intelligent algorithms to set the initial position of the data blocks when they first appeared on the screen, using controller-designated positioning rules. It also did not include the feature of moving data blocks just enough not to overlap. Instead, it moved data blocks to the nearest compass position. Controllers thought that if a tool had both of these features it would be an improvement over the tool we showed them as an example.

The simulate drag and drop data blocks tool allowed the controllers to click on a data block and drag it to any location they desired. The line that connects the data block with the target would stretch as necessary to continue to indicate the target to which the data block referred. Today controllers are given 16 positions relative to a target where they can move a data block. These positions are selected by a series of keystrokes.

2.3.2 Provide visual indication of current flight non-conformance with route (RNAV, OPD) restrictions in a readily detectable format compatible with the manner used to display conflict alerts in STARS.

As an example of this function, the CIR project team simulated a tool similar to MITRE CAASD's Automation for Monitoring RNP/RNAV Operations (AMRO). Our tool displayed an alert in line 0 of an aircraft's data block for aircraft assigned an RNP/RNAV route that violated conformance criteria for that route (see Figure 2). The alert was presented in red and consisted of two letters; one letter indicating it was in violation of conformance, and a second letter indicating the type of violation; speed, altitude (shown on the left in Figure 2), and lateral heading (shown on the right in Figure 2).

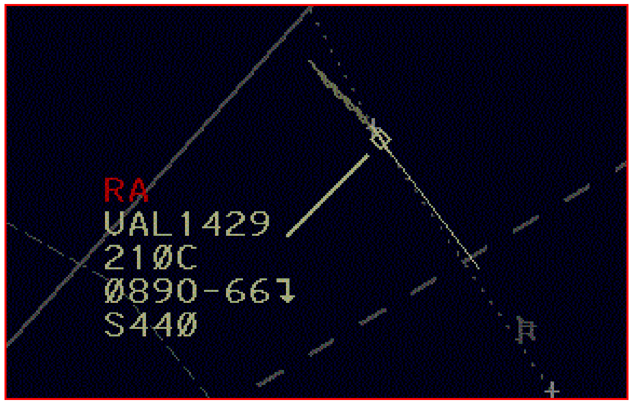

Figure 2. Red altitude conformance violation alerts in line 0 of en route data blocks.

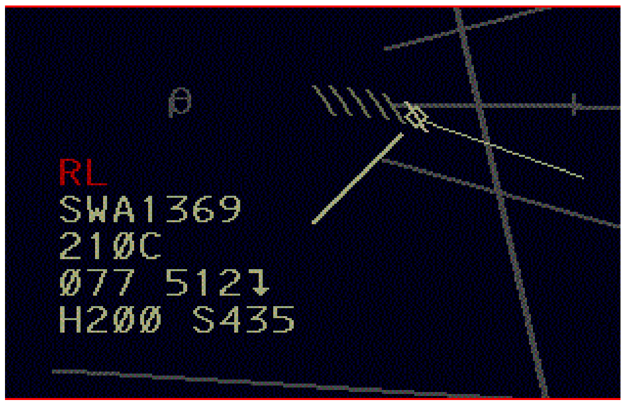

Figure 3. Red heading conformance violation alerts in line 0 of en route data blocks.

2.3.3 Provide visual indication of aircraft ADS-B capability on the primary display in readily detectable, non-textual format.

In our simulation we replaced the target (and track symbols for en 4oute) with a theoretical new fused target and track symbol for aircraft that were ADS-B equipped. The new symbol was a green colored chevron that pointed in the direction the aircraft was currently headed. This symbol is similar to symbols explored by Friedman-Berg, Allendoerfer & Deshmukh (2010). If an aircraft was ADS-B In equipped, the chevron was also enclosed in a green circle. An example of the new symbol is provided in Figure 3.

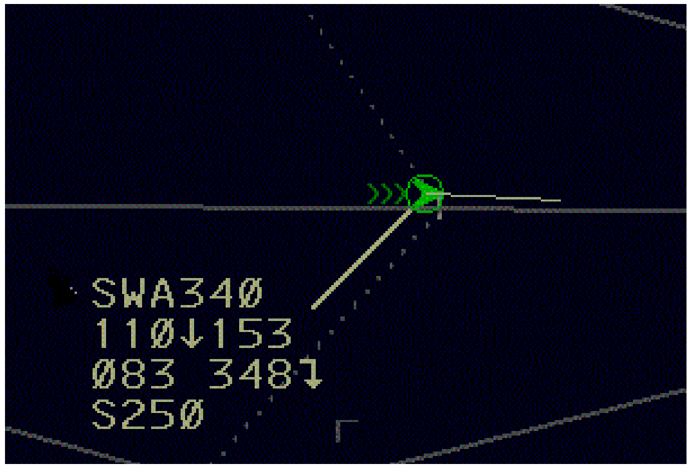

Figure 4. Chevron symbol denoting ADS-B equipage and aircraft directionality information.

2.3.4 Provide the ability to manipulate flight routes using a graphical user interface on the primary display to reduce controller workload and potential for error.

To allow controllers to manipulate flight routes, the CIR team provided them with a Graphical Route Tool. The objective of this tool is to allow controllers to perform rapid recalculation of routes in real time. It uses equal line segments along a route to adjust the delay or speed of an aircraft in order to meter over a fix (see Figure 4). A controller can call up an aircraft's route and, using the track ball, grab parts of the route and drag them to other locations. New flight legs can be dragged to any lat long or snapped to the nearest fix. As the new route is created, a description of the route is automatically displayed to the controller such that they can read it to a pilot using voice communications or uplink the new route to the flight deck via Data Comm.

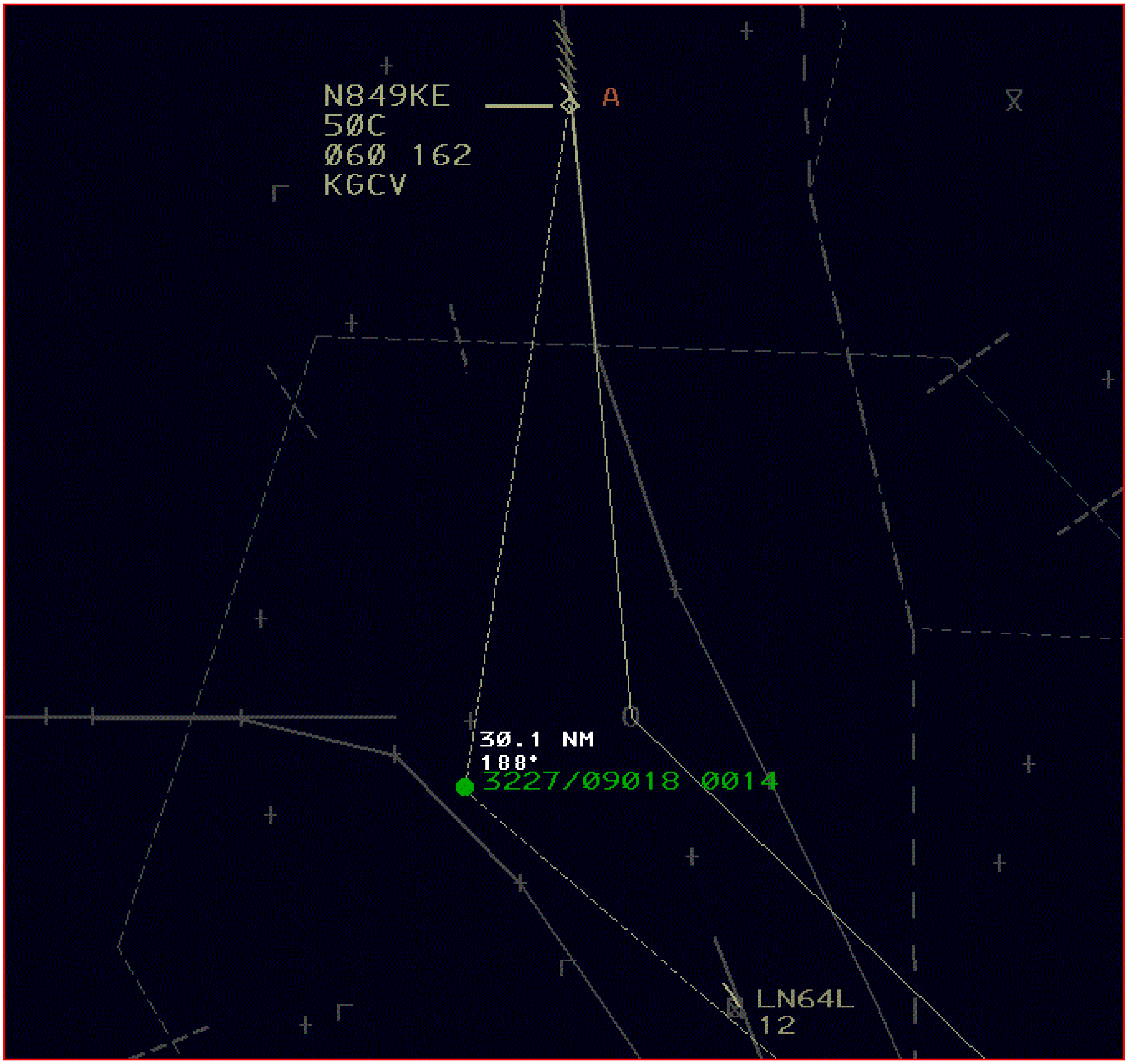

Figure 5. Graphic Route Tool.

2.3.5 On the primary display, introduce a GUI function that enables controllers to execute controller-pilot interactions via Data Comm for clearances such as altitude and frequency changes.

Data Comm (and related predecessor programs) has been under development by the FAA and industry for many years. Formal plans for Data Comm describe eventual implementation in en route and terminal environments, but the technical requirements and the deployment schedules for each phase have changed numerous times over the life of the Data Comm program. As of this writing, full implementation of Data Comm will likely not occur for many years, particularly in the terminal domain. However, because of the importance of Data Comm to many NextGen concepts and because Data Comm has the potential to fundamentally change how controllers interact with pilots and with automation, we included Data Comm in our analysis for both en route and terminal.

That said, the Data Comm and En Route Automation Modernization (ERAM) program offices actively made decisions and designed the Data Comm user interface for ERAM while we conducted this project. We attempted to simulate a version of Data Comm as up to date with those developments as possible (DCP S1P2), but were only able to accomplish this for two Data Comm functions: frequency changes and altitude clearances.

For the Data Comm. tool tested in this analysis, controllers were given icons, attached to aircraft data blocks, that indicated when aircraft were Data Comm equipped, when they were on frequency, and whether the controller had sent a message to the aircraft and was waiting for a response. The controllers could interact with the aircraft data blocks using a drop down menu (e. g., click an altitude for the Altitude drop down menu). Selecting an altitude from the menu not only selected a new altitude that was assigned to the flight using Data Comm, it also entered the newly-assigned information into the ERAM system for propagation throughout the NAS. Controllers were also given windows that could be used to create more complicated Data Comm clearances and show pilot responses and the history of Data Comm interactions. An example of the symbols associated with our representation of Data Comm is provided in Figure 5. An example of a Data Comm menu is provided in Figure 6.

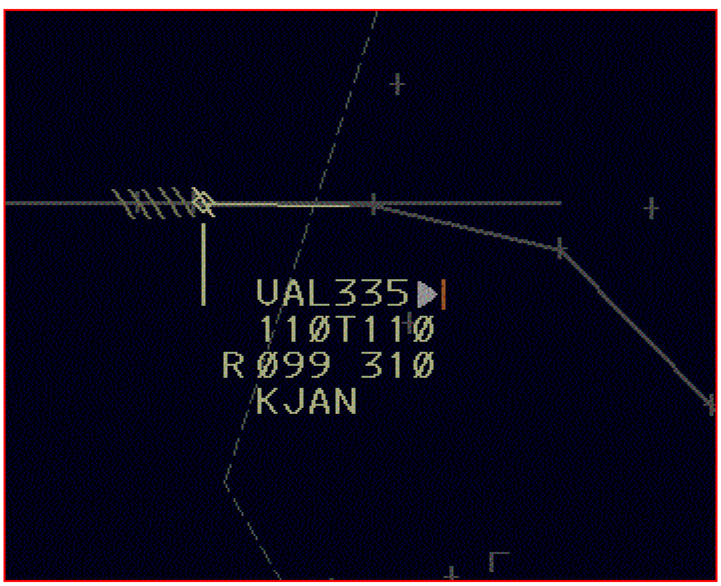

Figure 6. Symbol appended to data block indicating aircraft Data Comm capability.

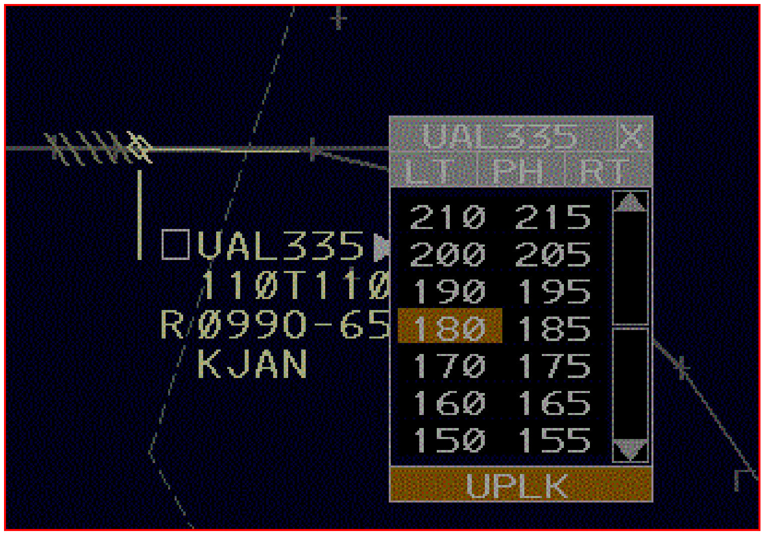

Figure 7. Data Comm fly-out menu.

2.3.6 Provide additional precipitation severity information in a format similar to that of STARS.

The CIR project team presented en route controllers with an example of how the occurrence of precipitation is indicated on the STARS display for terminal. The precipitation was simulated to include six levels of severity so that en route controllers could see how it differed from the three levels of severity presented on en route workstation displays.

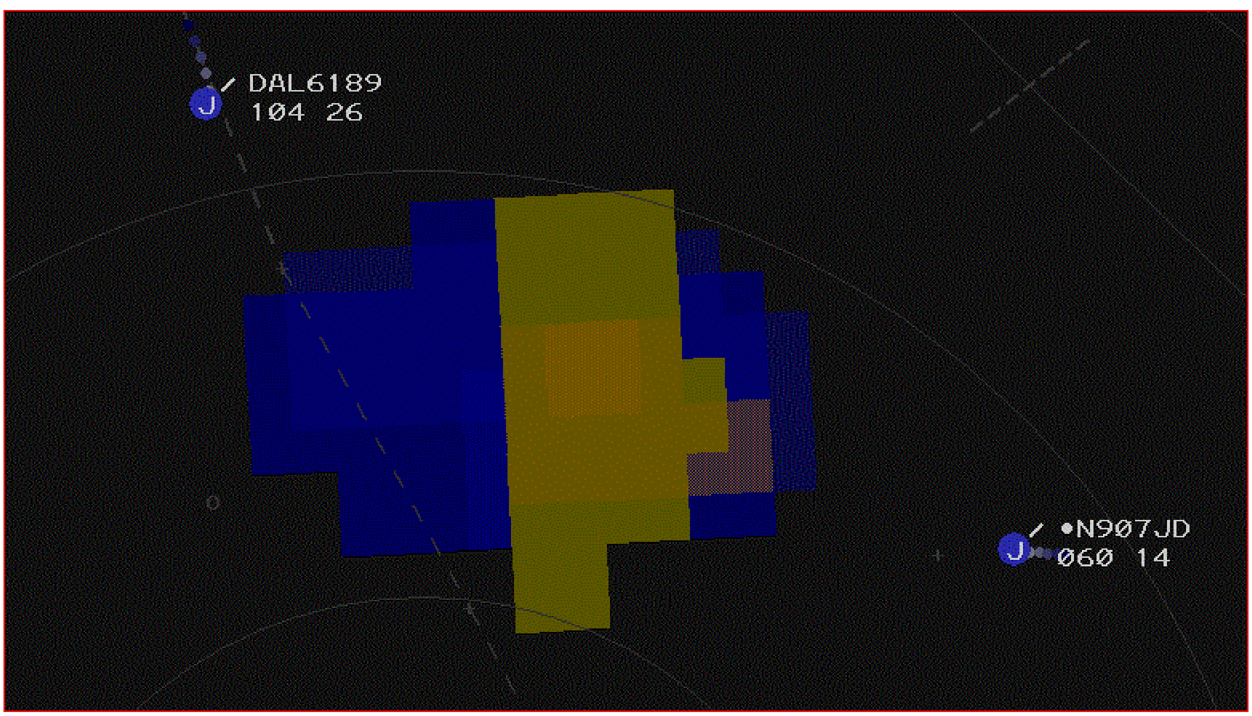

Figure 8. Six levels of precipitation severity in STARS

2.3.7 Provide persistent visual indication of aircraft to aircraft and aircraft to terrain conflict information in a readily detectable format similar to that used in terminal.

Conflict Alerts and Minimum Safe Altitude Warnings are presented differently in each domain. Both alerts and warnings are shown in line zero of the flight data block on the terminal domain workstation as shown in Figure 7.

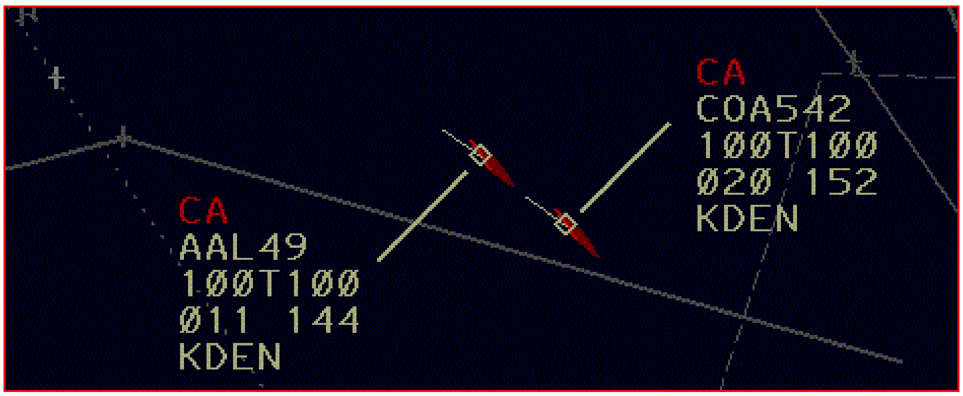

Figure 9. Example of conflict alert in red.

2.3.8 Indicate flight ownership status in readily detectable, non-textual format

The objective of this tool is to increase the reliability of ownership identification. En route workstations indicate non-ownership by the current sector using the letter "R" displayed in front of the CID in the third line of the FDB. The STARS terminal workstation indicates ownership status using colors, as shown in Figure 8. STARS uses the color white for text presented in the data block of aircraft owned by a radar position and the color green for aircraft not owned by the sector. The simulation tool used the same colors to distinguish owned from non-owned aircraft to en route controllers.

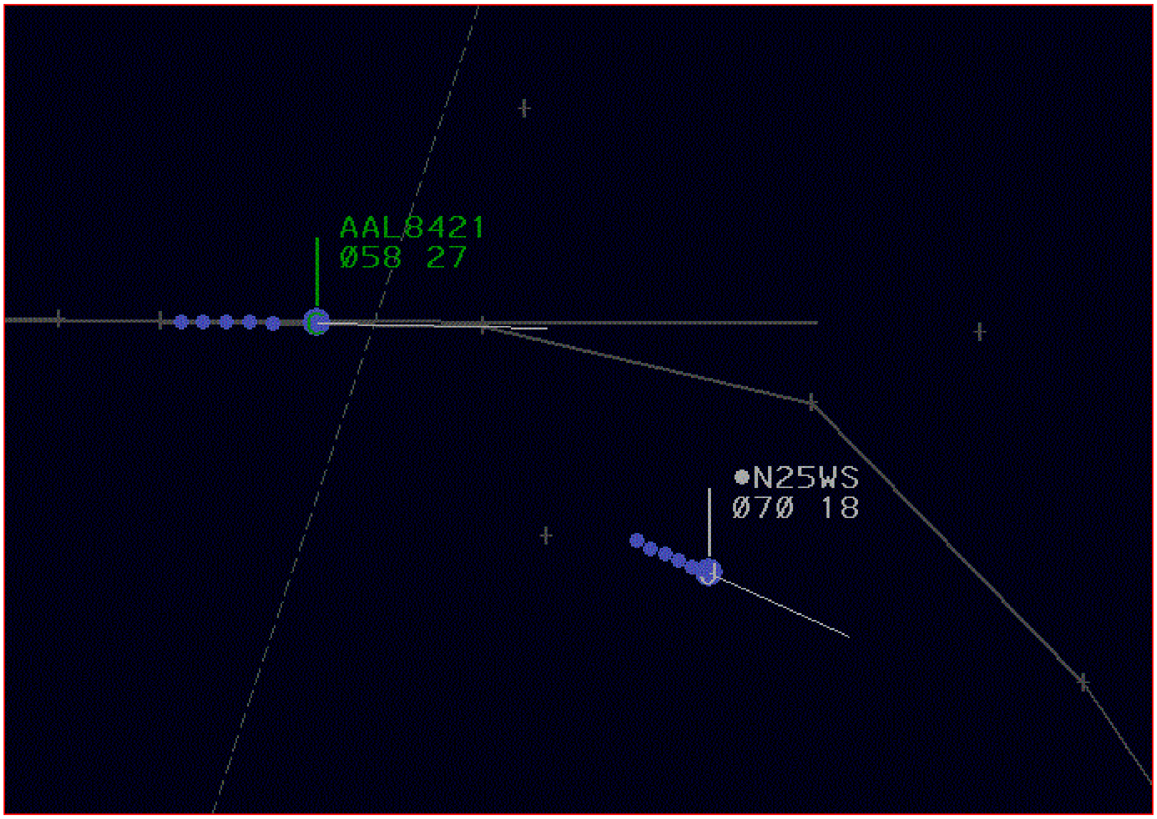

Figure 10. Colors used to indicate whether a sector has ownership of an aircraft.

2.3.9 Provide the user with information that calculates a safe and efficient sequence or spacing plan based on wake turbulence and given routes and display the information in a graphical format.

Two tools were simulated as examples of how the user could be provided with information about safe and efficient sequence or spacing plans calculated by an automated decision support tool. The first simulated tool was a representation of terminal's Automatic Terminal Proximity Alert. It displayed a triangle in front of trailing aircraft on a route, see Figure 11. The color of the triangle and a number in front of the triangle indicated whether proper spacing was being maintained.

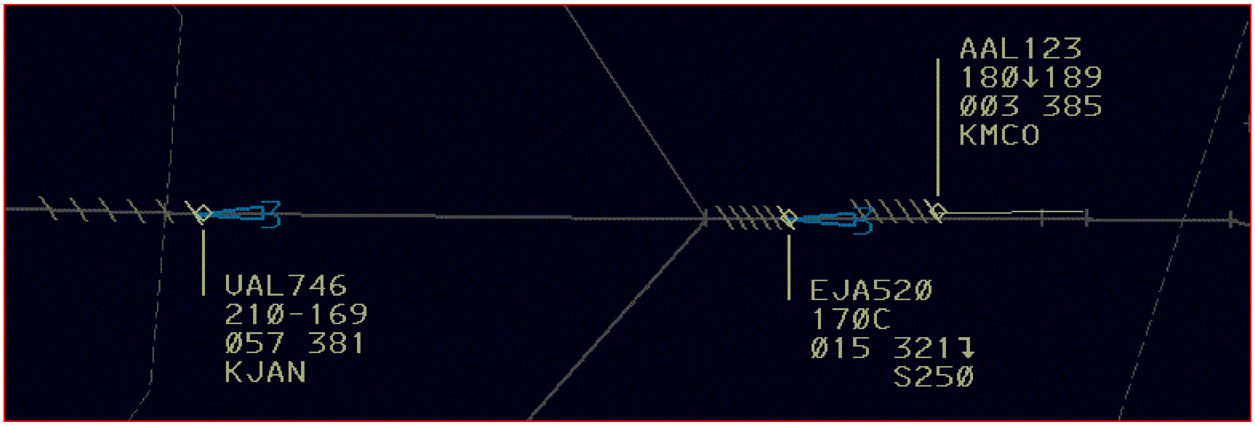

Figure 11. Automatic Terminal Proximity Alert in en route environment.

The second simulated tool was a representation of the Terminal Sequencing and Spacing tool. This tool was simulated in the en route environment and displays a circle on the route denoting where controllers are instructed to maneuver aircraft such that they will achieve the sequence plan and spacing calculated by the automated decision support tool.

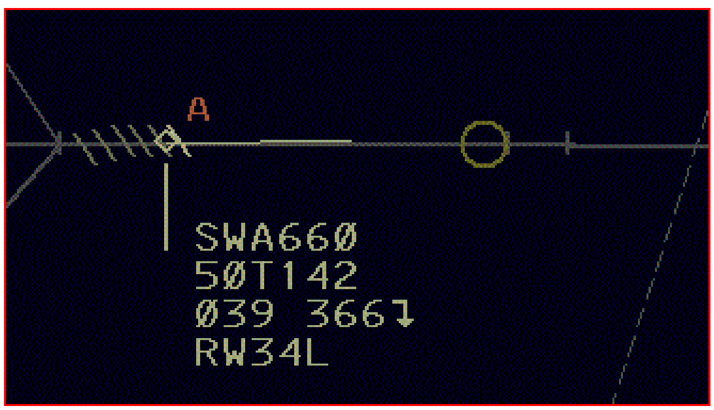

Figure 12. Terminal Sequencing and Spacing tool in en route environment.

2.3.10 Facilitate flight data entry on the primary display in a way that reduces workload and potential for entry errors

Access to tools for immediate updating of aircraft information in the NAS has been an improvement in the ERAM en route workstation system. We provided the same type of menu for the terminal controllers to use while controlling our simulated terminal sector. Flight data block menus are available in the ERAM's R-Side providing the controller with the information necessary to update each aircraft heading, speed, altitude (Figure 13). This feature, or a similar one, is not present in the terminal domain.

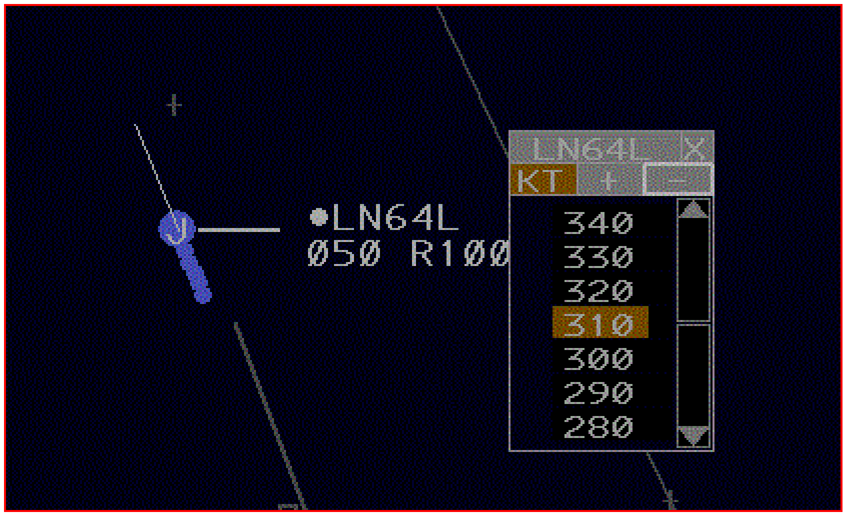

Figure 13. R-side interactive data blocks.

2.4 Implementation Plan

Two additional functions were dropped from the list of functions undergoing further analysis as they did not receive high enough usefulness ratings from the controllers in the previous cognitive walk through phase. The functions that were eliminated were providing en route controllers with automated, graphical sequencing and spacing aids and providing en route controllers with additional weather severity information in the format used for STARS.

The team then examined NextGen implementation plans to identify points within the ERAM and TAMR upgrade schedules at which the functions remaining on the list could be made available. In this phase of the project, the team examined the FAA's 2015 NAS Segment Implementation Plan (NSIP), which organizes many of the NextGen-related changes into Operational Improvements (OIs) and increments. OIs aim to capture proposed service-level changes and are grouped by their operational availability time frame, mid-term (present – 2020) and far-term (2021 and beyond). Increments aim to capture the individual changes necessary to deliver targeted service-level changes. Increments can be grouped by their parent OI relationship, NextGen portfolio, or NextGen implementation Segment (e.g. Alpha, Bravo, Charlie, etc.). The objective of this analysis is to identify where the candidate convergence opportunities could be considered as part of the NSIP increments implementation strategy.

The first step, identifying the increments, involved searching within the NextGen portfolios. The CIR project team reviewed the portfolio increment dependences timeline created by Sekhavat, Yaklich, and Sunshine in 2015 to determine which portfolios to choose for further examination. Five main portfolios were identified for this research: Collaborative Air Traffic Management (CATM), Time-Based Flow Management (TBFM), Performance-Based Navigation (PBN), On-Demand NAS Information (OD-NAS), and Separation Management (SepMan). These portfolios were chosen based on their technical relevance to the functions preferred by the controllers and the proposed improvements to the en route and terminal domains. The CIR project team examined each of the selected portfolios to associate increments to the identified functions and simulated tools through review of the NAS Implementation Plan. The rationale for establishing these associations was to develop human factors recommendations to support the achievement of CIR function implementation, by showing how it could be integrated into the NAS implementation plan timeline. This procedure provided a clearer structure for determining the best time to introduce proposed functions into the enterprise architecture (EA) so that they benefit the process without disturbing the chronological sequence already scheduled for the increments.

3. Recommendations and Information Requirements

The functions presented to the controller SMEs during the cognitive walk throughs are enumerated below. For each function, we provide a description of potential benefits related to the function, a discussion of how useful the controllers perceived the function to be, and the CIR project team's recommendation decision regarding the function and the NextGen implementation schedule.

Recommended decisions included:

Recommended – the results of this project suggest that the function represents an opportunity for convergence.

Inconclusive – the results of this project were not sufficient to recommend whether the function represents an opportunity for convergence or was not a useful candidate for convergence. Additional analysis regarding the usefulness of these functions is advised.

Not Recommended – the results of this project suggest that the function is not a useful candidate for convergence.

Recommended requirements are then provided in a table for each function that we judged to be either Recommended or Inconclusive.

The CIR project team derived Usability from an average ranking each controller who participated in the Cognitive Walk Through gave across several usability scales (see Appendix A). Values on the scales ranged from 1 to 10 where 1 was considered least usable and 10 was considered most usable. These averages were averaged across controllers from each domain.

Recommended information requirements were collected throughout the project. They came from observations made by project team members involved in the creation of the simulated tools or else from statements made by either the retired controller SMEs or current controller SMEs.

The sections in the recommended requirements tables are categorized as follows:

Functional Requirements: refers to what the workstation software should do.

Data Requirements: refers to the data required by the system to perform the function. The type of data, volatility, size/amount, persistence, accuracy, and value of the amounts of the required data are some of these attributes. Not all of these attributes are necessarily present for each function.

Environmental Requirements or context of use: refers to the circumstances in which the interactive tool or function will be expected to operate or be used and place emphasis in aspects such as:

a) Physical: center vs terminal
b) Social: information or data supposed to be used in collaboration and coordination
c) Technical environment: technologies required to run or being compatible with current or proposed systems

User Requirements: refers to the characteristics of the intended user group. User abilities and skills: en route vs terminal controllers, D-side vs R side.

Usability Requirements: captures the usability goals and associated measures of the tool or function. Extent to which function supports usability goals such as effectiveness, efficiency, safety, utility, learnability and memorability

3.1 Prevent occlusion of flight data blocks

Common Function Recommendation Decision: Recommended for both domains

New technologies and procedures associated with NextGen will likely lead to an increase in the amount of information displayed on the data block. In some cases, controllers will need to graphically interface with the data blocks to support new functions. To accommodate the new amount of information displayed, the size of the data blocks may increase, leading them to be more likely to overlap. At the same time, there will be a more frequent need to access text and icons on the data block. Managing data blocks has already been identified as the most frequent activity controllers perform (Willems & Heiney, 2002; Willems, Heiney, & Sollenberger, 2002). Therefore, the need to assist the controller in separating the data blocks becomes more important to avoid confusion and errors.

Usefulness

Two simulated tools were presented to the controller SMEs, Automatic Data Block Offset (ADBO) and drag and drop data blocks. Usefulness was collected for both even though the simulated tools represent two ways of achieving the same function.

Half of the controllers who participated in the Cognitive Walk Through (n=4, terminal=2 and en route=2), out of all controllers interviewed (N=8), agreed that an ADBO function in their current environment would be helpful, however the ability to toggle the offset for each individual data block could increase the number of controllers who considered the function beneficial. Both en route and terminal controllers felt that the ADBO would be useful in NextGen. Terminal controllers (n=4) described smaller non-busy sectors, such as satellite positions, as the most useful areas for automatic data block offset. According to these controllers, most terminal TRACON operations employ an “assembly line” type pattern where tags and direction of aircraft are similar all day so de-confliction of information is not often necessary. One en route controller thought that ADBO would be more useful for busier sectors and one thought it would be more useful for sectors with light traffic. The other two thought ABDO would have about the same usefulness for sectors with either light or heavy traffic. Two of the four en route controllers also felt that ADBO would not be as useful in arrival sectors where controllers sometimes use data block positioning to determine spacing. .

Of the controllers (N=8) interviewed, all agreed that the ability to drag and drop data blocks would also be beneficial to their current environment. In particular, it would allow them to perform operations single handed and provide high position flexibility while limiting time spent looking at the keyboard (heads down time). En route controllers felt that drag and drop is useful in all sectors and conditions, but they were unsure as to whether they would want the radar associate controller (also called D-side) to have the ability to move data blocks via drag and drop as well. Terminal controllers saw the use of drag and drop being useful primarily in smaller non busy airspace or satellite sectors. They felt that the function allowed them to manage their data blocks more easily but wanted to use a keystroke instead of a trackball pick to select them. All controllers agreed that drag and drop would be useful in the NextGen timeframe.

Usability

ADBO

Terminal controllers gave this tool an overall usability score of 6.45 out of 10 while en route controllers gave it an overall usability score of 8.05.

Controllers noted that there was a need to identify on the display which data blocks were under ADBO control. In the simulation design there was no such indication. One en route and one terminal controller found it necessary that orientation after de-confliction should also preserve data block positions used as reminders of which flights are arrivals or departures. ADBO would de-conflict a data block and then snap it back to the manual orientation position after de-confliction so that controllers still had their intended reminder. Alternately, ADBO could have the ability to build in rules to automatically give tags orientation according to the controllers' intended reminder and then de-conflict them accordingly. In en route, this is something that many controllers already do with ERAM macros.

Recommended Requirements (ADBO)

Functional Requirements	This function will enable the automated positioning of FDBs to prevent them from overlapping on primary en route and terminal ATC radar displays.
Data Requirement	The function needs to have access to targets and FDB positions (pixel coordinates) to identify immediate and future overlapping FDBs.
Environmental requirement or context:	The function will be most useful in sectors with airspace definitions where FDBs are prone to overlapping. These include small sectors with high traffic (e.g. in the northeast US), and feeders and low altitude sectors where climbing and descending traffic results in constant appearance of FDBs.
User requirement:	Users that exercise constant offsetting of FDBs due to traffic density and/or sector size.
Usability Requirement:	1. The user should be able to toggle the automatic positioning function On and Off. 2. An FDB that has been manually repositioned (via keypad) should be able to go back to the automated mode per user command. 3. The function should allow an FDB that has been manually repositioned to stay in its assigned orientation until the user chooses to reactivates the automatic positioning function on it.

	4. The function should move only a "manually repositioned" FDB to prevent overlapping and then it should snap it back to its original orientation after the overlapping event is over. 5. The user should be able to identify if an FDB is in manual or automatic positioning mode. A graphical cue to indicate the mode type would help controller discernment of the mode status. 6. The function should reposition FDBs in a manner that is smooth and limit sudden movements to reduce the potential for unnecessary distractions. 7. The function should permit the controller to customize the orientation of the FDB according to traffic flow characteristics and user preferences.

Drag and Drop Data Blocks
Terminal controllers gave this capability an overall 6.97 usability score out of 10 while en route controllers gave it an overall score of 8.50.

Recommended Requirements (drag and drop data blocks)

Functional Requirements	The drag and drop function will enable users to manually position FDBs via trackball buttons and cursor movements to any desired location on the primary en route and terminal ATC displays.
Data Requirement	The function will need access to the full range of x and y coordinates on the ATC display.
Environmental requirement or context:	Both en route and terminal environments are candidates for this function to reduce the overlapping of FDB. However, in the en route environment, the control of the function seems to be more appropriate to reside on the R-Side workstation. It is especially useful on sectors that manage targets with a wide range of attributes (speeds, headings, altitudes).
User requirement:	En route and terminal sector controllers. Users that exercise constant offsetting of FDBs due to traffic density and/or sector size.
Usability Requirement:	1. The function should allow the user to toggle the drag and drop positioning function On and OFF. 2. The function should allow an FDB that has been moved to stay in that orientation until the user chooses to reposition it to one of the 8 default orientations (keypad) via keyboard entry. 3. The function should allow positioning of FDBs via drag and drop (using the track ball) to an infinite number of positions according to

	controller's needs and display resolution while extending the leader line. 4. The user should be able to easily differentiate between a FDB that has been repositioned via drag and drop function vs. those that were not (e.g., using a dotted leader line).

Common Function Implementation Timeline Analysis

This function could be implemented and benefits gained at the earliest possible planned release date (2017-2019).

3.2 Provide visual indication of current flight non-conformance with route (RNAV, OPD) restrictions in a readily detectable format compatible with the manner used to display conflict alerts in STARS.

Common Function Recommendation Decision: Recommended for both domains.

The implementation of RNAV routes and OPD procedures introduces a need for more precise aircraft conformance monitoring. This common function could assist controllers in the timely identification of aircraft that do not adhere to published lateral and vertical route restrictions

Usefulness

Two out of 4 terminal controllers and 3 out of 4 en route controllers who participated in the Cognitive Walk Through thought this tool would be useful to have. In general, those with experience using RNAV routes noted that nonconformance was so rare that it would be helpful to draw their attention to it when it did occur. One controller mentioned that if he could see an aircraft out of altitude conformance before it reached its next fix, it would give him a chance to get the aircraft back to the altitude it needs to be when it crosses the fix. Controllers thought conformance alerts would be most useful for altitude violations and OPDs. Controllers who did not think this function would be useful cited issues with how RNP/RNAV routings were currently being implemented in general, such as there being too many reasons to take an aircraft off the routing in sectors with which they were familiar.

Weather can play a significant role in keeping aircraft on RNP/OPDs routes. Sometimes a weather event requires controllers to divert aircraft from these preset routes for short instances before returning them to the route. Due to these circumstances controllers felt that the tolerance level for the conformance alerts would need adjustment so that controllers would not ignore the alerts due to the frequency in which an alert occurs when not necessary.

Controllers were also asked to rank the priority of each type of conformance alert with Altitude nonconformance being ranked highest overall.

Four controllers mentioned that they thought the priority of conformance alerts was not sufficiently high enough for this type of alert to merit a red colored font on the screen.

Usability

Terminal controllers rated the usability of this tool at 7.5 overall out of 10 while en route controllers rated it at 8.02 out of 10.

Recommended Requirements

Functional Requirements	The system will display an alert in line 0 of the FDB if the aircraft is out of lateral or vertical conformance .
Data Requirement	The function needs to have access and compare aircraft lateral and vertical conformance to published lateral and vertical RNAV route restrictions.
Environmental requirement or context:	The Conformance Alert Information function could support en route and terminal controllers who manage traffic in sectors that contain RNAV / RNP routes. RNAV / RNP routes are inclusive of OPAs, OPDs, Q routes, T routes, and other performance-based routes that have specific aircraft equipage requirements to meet lateral and vertical route restrictions.
User requirement:	En route and terminal sector controllers. The function will be most beneficial to users interacting with routes and sequencing where aircraft are left to operate under vertical and/or lateral restrictions. Controllers who work feeder sectors and at terminals with intense sequencing operations.
Usability Requirement:	1. The conformance alert should be displayed on line 0 of the FDB 2. The conformance alert should be displayed using a distinctively different color from conflict alerts or any other safety alert, but still provide contrast with the rest of the FDB. 4. Altitude and heading are the most important variables to monitor, in that order 5. The user should be able to toggle the alerts Off and On

Common Function Implementation Timeline Analysis

Based on the results of this study, conformance status indication implementation should occur at the earliest possible planned release date as it would complement RNP as long as tolerance levels filter for false and extraneous alerts.

3.3 Provide visual indication of aircraft ADS-B capability on the primary display in readily detectable, non-textual format

Common Function Recommendation Decision: Recommended for both domains.

Implementation of NextGen technologies and procedures requires new methods to convey target information and position. Each domain displays targets in different manner even though some embedded information points to the same aircraft/tracking attributes. Due to the use of different separation criteria and other new procedures enabled by Automatic Dependent Surveillance Broadcast (ADS-B) capabilities, controllers will need to be able to distinguish between ADS-B equipped and non-ADS-B equipped aircraft at a glance. Using a new symbol to replace the target symbol for ADS-B aircraft in both the terminal and en route domains will allow controllers to quickly distinguish ADS-B capability and will foster similarity between the terminal and en route workstations. As the en route environment will be transitioning to a new symbol that represents location via a target fusion technique, a potential opportunity exists to implement this change.

Usefulness

All 8 controllers, 4 terminal and 4 en route, thought this indication was useful in general and 6 of the 8 specifically mentioned the additional directionality feature as being particularly useful as well.

Usability

Terminal controllers rated the usability of the new symbol for ADS-B at 7.53 out of 10 while the en route controllers rated it as 9.02 overall.

We replaced the target symbol on both domain displays with a chevron shape that indicates the aircraft's direction of flight. By using a target symbol that denotes current direction of flight of an aircraft to replace the target symbol for ADS-B aircraft in both the terminal and en route environment allows controllers to quickly distinguish ADS-B capability, fosters similarity between the terminal and en route displays, and provides controllers with an additional capability – the capability to know at a glance the direction an aircraft is heading. ADS-B enables those who receive it to know the direction the aircraft is traveling with greater fidelity. Neither en route nor terminal target symbols in use today currently show directionality at a glance without the use of additional indicators (Friedman-Berg, Allendoerfer & Deshmukh, 2010).

Recommended Requirements

Functional Requirements	The system will display a different target symbol for ADS-B equipped aircraft. This function has 3 primary purposes: 1) Assist controllers in distinguishing ADS-B equipped aircraft from non-ADS-B equipped aircraft, 2) For aircraft that are ADS-B equipped, the tool can then further assist in distinguishing which aircraft have ADS-B -In/Out capabilities, and 3) The tool has trajectory indication capabilities which present the direction of flight to controllers via the chevrons.
Data Requirement	The system needs to be able to identify which aircraft are using ADS-B equipage and display a unique target for those aircraft.
Environmental requirement or context:	This functipn would be most useful in sectors where different separation rules (reduced separation, aircraft-to-aircraft interval management) will be implemented or where radar coverage is

	either not available or is intermittent (e.g., low altitude sectors with surrounding mountainous terrain, non-radar environments).
User requirement:	En route and terminal sector controllers. Users interacting with a wide range of aircraft equipage, where separation varies or where operational constraints increase dependency on ADS-B returns.
Usability Requirement:	1. The new target symbol for ADS-B equipage should eliminate the use of the "A" character (next to target symbol) to indicate a non-ADSB equipped aircraft in en route. 2. The new target symbol should eliminate the use of the "solid circle" (next to the FDB) to display a non-ADSB equipped aircraft in terminal. 3. The new target symbol (e.g., chevron) should provide the immediate direction of flight of the aircraft. 4. A new set of shapes should be used for the target to convey ADS-B modes (e.g., In: chevron with circle, Out: chevron, loss of ADS-B). 5. The history trail for ADS-B equipage should be related in shape and color to the new target so as to indicate the direction of flight at recent position updates.

Common Function Implementation Timeline Analyis

The en route target symbol will be updated around 2019 to represent radar fusion capabilities. It would make sense to give the fusion target symbol design the ability to show flight direction and ADS-B equipage status at the same time. Changing the design to incorporate these functions during this time period would avoid having to make minor changes in the future and allow the controllers more time to acclimate to the design change.

3.4 Provide the ability to manipulate flight routes using a graphical user interface on the primary display to reduce controller workload and potential for error

Common Function Recommendation Decision: Recommended for both domains.

On the primary ERAM display, en route controllers can access a data block drop down menu to input minor aircraft route changes. More complex changes require en route controllers to use the ERAM Decision Support Tool (EDST), which is located on a secondary display. Without the assistance of a D-side, R-side controllers must divide their attention between both the primary and secondary displays to input complex route changes such as airborne reroutes.

Controllers working at terminal workstations do not have even the tools that the en route controllers currently have when it comes to performing airborne reroutes. Terminal controllers who use STARS make data entries to the National Airspace System (NAS) using a keyboard with an alphabetical key layout (as opposed to the QWERTY keyboard used by en route controllers). Currently terminal controller tasks do not require them to make as many data entries as en route controllers. For example, unlike en route controllers, terminal controllers do not make a data entry each time they instruct an aircraft to change altitude. TRACON sector controllers can ask a controller at a Flight Data position to enter the reroute information or else they can pass the rerouting task on to an en route controller to complete, when traffic load does not permit them the time necessary to enter the reroute information on the tools they have available at the sector today.

This function would reduce the workload and potential for errors associated with performing airborne reroutes for both en route and terminal controllers. For terminal controllers it would allow them to perform more reroutes themselves than is possible today. This would particularly be helpful to terminal controllers handling satellite or departure separation operations. This, in turn, would improve coordination between terminal and en route controllers and pilots and improve the predictability of flights in the system needed to maximize the potential benefits of NextGen planning tools.

Usefulness

Results showed that 6 out of the 8 controllers interviewed during the Cognitive Walk Through (3 en route, 3 terminal) approved of a graphic route display and manipulation (GRDM) function. GRDM allows controllers to see and change a route graphically on their radar display. This gives them the ability to reroute aircraft by selecting points and dragging them to create new routes. GRDM gives controllers the ability to plan routes around weather and other problem areas.

Three controllers from each domain (n=6) stated that Data Comm is necessary to make any GRDM function work effectively. En route controllers were annoyed that they still had to transmit all clearances created using the routing tool via radio because Data Comm is not standard yet. For this reason they found use of the function in its current state to be far too long a process. This was especially true for the terminal controllers. However, if Data Comm were to absorb this function, then all eight controllers agreed it would benefit the NAS in NextGen. In en route, the increase in use of OPDs makes it necessary to have a function like this to make changes and add restrictions to the routes without voicing them. The terminal controllers felt that generally, OPD and terminal traffic pop up too quickly to allow enough time for route editing via a track ball pick method. They did support the idea of using GRDM to create routes for sequencing and aircraft in an OPD. Terminal controllers do not have routes displayed on their scopes, so they felt the ability to amend or re-route without having to contact the Flight Data position would be a "game changer." However, like with Data Comm, the controllers requested a macro capability that would allow them to make their most common flight data entries with a minimum number of keystrokes and cursor movements.

Usability

Both terminal and en route controllers rated the usefulness of this potential new tool similarly. Terminal controllers gave it a 6.95 of 10 overall and en route controllers gave it a 7.55 of 10 overall.

The ability to use keyboard macros to control settings for the tool would help decrease the time needed to use it in a busy TRACON operation. Having the capacity for a controller to edit information in a route string (graphically or otherwise) and snap to a known fix instead of dragging the route manually each time was also important to controllers. Like with Data Comm, this function could be helpful in high altitude sectors in en route and primarily airspace surrounding satellite or small facilities in the terminal environment.

Recommended Requirements

Functional Requirements	The system will provide an interactive graphical display of the aircraft route allow entering route changes in a manner that reduces controller workload and the opportunity for error.
Data Requirement	The system needs to access an aircraf's current flight plan, navigation performance, and airspace fixes and restrictions to provide instantaneous metering information for the new fix or route.
Environmental requirement or context:	Any sector, terminal (satellite and departure operations) and en route (large sectors), preferably under a Data Comm. environment and/or systems with FDB menus (e.g., ERAM).
User requirement:	En route and terminal radar controllers. Users required to vector aircraft for rerouting (e.g., planning due to weather) or conduct intra facility coordination.
Usability Requirement:	1. The graphical interface should display the proposed rerouting option using an easily differentiated line type and color (e.g., white segmented line). 2. The user should be able to add and remove waypoints to the new route during the rerouting process. 3. The graphical interface should only display the route (and waypoints) that are contained in the controlled sector. 4. The tool should have access to proximal reroute waypoints and fixes when selecting the new waypoint for rerouting. 5. The user should be able to access and interact with the tool via both trackball (e.g., selecting waypoints and moving them along a route) and keyboard 6. The tool should provide an error check feature before sending/uploading the new route (read/review window could be used for this functionality). 7. The tool should display waypoint restrictions (altitude, speed and time) via menus for planning (OPDs) and metering purposes.

	8. Menus used to display waypoint restriction options (altitude, speed and time) should include high contrast colors to differentiate between available options and restrictions selected.

Common Function Implementation Timeline Analysis

This function could be implemented and benefits gained in en route at the earliest possible planned release date. For terminal, however, flight data manipulation must be in place first.

3.5 On the primary display, introduce a GUI function that enables controllers to execute controller-pilot interactions via Data Comm for clearances such as altitude and frequency changes

Common Function Recommendation Decision: Inconclusive for the terminal domain

Data Comm can reduce voice communications on radio frequencies, reduce workload associated with handoffs, and reduce the potential for certain types of communication errors. Data Comm. is related to technologies that might reduce workload as well for such tasks as uploading lengthy route clearances or broadcasting the same information to more than one aircraft. In this project terminal controllers were only shown the handoff and altitude clearance functions. All controllers believed a communications latency of 30 seconds would be too long for tactical clearances.

Usefulness

All but one terminal controller (n=3) and all en route controllers (n=4) felt that the frequency changes and altitude clearance functions of Data Comm would be useful for their current environment and for future NextGen. All controllers agreed that using Data Comm would be useful in NextGen to issue Optomized Profile Descents (OPDs), Airborne Reroutes (ABRR), ride reports, and repetitive messages. However, all controllers also agreed that the current average latency of ~30 seconds is too long for trajectory or tactical clearances. The results of our interviews support that the best use of Data Comm, at this point, is for transmission of frequencies, check-ins, SIGMETS, AIRMETs, ATIS codes, and other repetitive information. According to the en route controllers, the latency issues inherent to Data Comm make it primarily useful for clearances only in large departure and high altitude sectors over wide spaces such as the Midwest/West NAS, where controllers have time to process information and plan. The terminal controllers echoed this sentiment, and said that terminal operations occur too quickly to use Data Comm for trajectory information but it would be great for aircraft check-ins and assigning runways. Even with this agreement, there was the fear that you could lose the human aspect associated with check-ins by not doing them through voice.

The controller SMEs identified three necessary features that a Data Comm function must have to be successful: keystrokes to control Data Comm features, control boundaries for Data Comm messages between sector team positions, and the ability to send ride reports and ABRR. Some of our controllers liked Data Comm functionality but they felt tethered to using a trackball and pick to send and receive messages. They suggest having the ability to access Data Comm functions via key commands instead. En route controllers want to make sure that if Data Comm function is determined to be necessary for both the R and D side that there would be sufficient controls or locks in place so that the D-side can only operate Data Comm with R side permission. These boundaries would help to avoid confusion and eliminate duplicate messages to aircraft. Since terminal does not have a D-side, they had no comment on this issue.

Usability

Terminal controllers gave this a usability rating of 6.52 on average while en route controllers rated it at 8.85.

Recommended Requirements

Functional Requirements	The system will provide interactive data communication symbols to issue and display frequency changes (hand off) and altitude clearances.
Data Requirement	The system needs to use aircraft position and tracking control to display appropriate data for frequency changes and altitude updates
Environmental requirement or context:	En route or terminal sectors supporting Data Comm and especially useful with ADS-B equipped aircraft where return rates are faster.
User requirement:	En route and terminal sector controllers. Users in en route domains where radio frequency is highly congested. Users interacting with foreign air carriers.
Usability Requirement:	1. The function needs to provide feedback that accounts for uploading and downloading latencies 2. The number of symbols used to send commands and display feedback should be constrained to the minimum to avoid FDB cluttering 3. FDB menus should be provided to display frequencies and select appropriate option 4. The function should not preclude the user from executing the task via radio communication when a time-critical response is required 5. The function should be accessed by both R and D side

Common Function Implementation Timeline Analysis

Our analysis did not suggest that en route implementation of this function follow anything other than the existing plans for Data Comm. In order for Data Comm. implementation in the terminal radar environment, with an interface similar to the one implemented for en route, terminal controllers will first need to have a capability to enter flight data at the radar controller position using fly-out menus similar to those used with ERAM.

The following increments are all areas that would support the release of Data Comm. According to results of the interviews, the controllers found Data Comm. To be the most useful for delivering recurring messages to aircraft and transmitting reroutes. This could be especially helpful for set routes such as PBNs, OPDs, and UAS profiles where controllers need to send out repetitive messages to anyone who uses that route. The first three increments, 101202-21, 22, & 23, added new information for flight planning into the NAS. As information increases, it will be necessary to do flight planning in a way that the system as well as the controller both know where aircraft are located.

- 101202-21 Flight Information Service
  - Provides the ability to have current synchronized real time flight data for planning.
- 101202-22 Unique Attributes for UAS Flight Planning
  - Provides controllers the ability to know if there are any unique flight characteristics for a UAS flight plan which may effect air traffic integration.
- 101202-23 Extended Flight Planning Horizon
  - Provides ability to know capacities so that TMU can inform controllers and Air Service National Providers for planning routes for aircraft far in advance.
- 103306- 02 Tailored NAS Status via Digital NOTAMS for ANSP
  - Provides the ability for controllers to issue digital NOTAMS to aircraft. The controllers can filter what information to send and to whom it should be sent based on an aircraft's specific flight/trajectory.
- 103306- 03 Automatic Terminal Information Service Via Data Comm
  - Provides Data Comm messaging capability to terminal operations.

3.6 Provide additional precipitation severity information in a format similar to that of STARS

Common Function Recommendation Decision: Not Recommended for en route domain.

The controller SMEs did not judge this tool to be useful.

3.7 Provide persistent visual indication of aircraft to aircraft and aircraft to terrain conflict information in a readily detectable format similar to that used in terminal

Common Function Recommendation Decision: Inconclusive for en route domain.

Losses of separation have been attributed to circumstances whereby the conflict alert in en route is no longer displayed while a conflict still exists. Besides providing a persistent visual indication of conflict, the conflict alert presentation in STARS has other features that human factors principles would describe as improvements over the way conflict alerts are presented currently on en route workstations. Considering the potential benefits for training, implementation costs, and shared situation awareness, we presented en route controllers with a conflict alert display that looks similar to the display of conflict alerts in STARS but was designed for the ERAM environment. The controller SMEs did not give this simulation tool a high usefulness rating. However, some new method of displaying conflict information is still needed.

Usefulness

The effectiveness of safety alerts is a point of some contention in the ATC community. For example, the NTSB has recommended that perceptual salience of safety alerts be increased to prevent controllers from failing to perceive or attend to an alert. On the other hand, the current safety alerts, especially conflict alert, suffer from a high false or nuisance alert rate, which discourages controllers from trusting and utilizing the automation. Major improvements to the usefulness of safety alerts will require algorithmic and functional improvements rather than presentation changes. However, we do not see any advantage to the current discrepancy in safety alert presentation between the domains. We also believe that the presentation used by STARS has better human factors attributes than the equivalent presentation in ERAM. We believe that any concerns or misgivings that en route controllers may have about using the STARS safety alert presentation will diminish over time.

Usability

En route controllers rated the usability of this type of alert display at 6.07 out of 10.

Recommended Requirements

Functional Requirements	The system will display a visual conflict alert or aircraft to terrain warning in the FDB whenever two aircraft are in conflicting trajectories that may result in loss of separation or when an aircraft nears a minimum safe altitude threshold.
Data Requirement	The system needs to use information about aircraft performance (e.g., speed, heading, altitude, distance between aircraft, minimum safe altitude) to calculate conflict trajectories and display the alert label in the FDB.
Environmental requirement or context:	To be implemented on all en route sectors because the terminal environment already has this feature
User requirement:	En route sector controllers. Users controlling air traffic in en route radar sectors (R-Side) using ERAM.

Usability Requirement:	NA

Common Function Implementation Timeline Analysis

This function could be implemented and benefits gained at the earliest possible planned release date (2017-2019).

These increments are proposed to create visual indication of aircraft to aircraft and aircraft to terrain conflict information.

- 102117-22 Active Surveillance Collision Avoidance
  - Provides better tracking algorithms to detect possible collisions and reduce false alerts that could come from reduced separation standards.
  - 102144-21 Wake Turbulence Mitigation for Arrivals- Rear GateProvides ability to predict wake turbulences.

The active surveillance collision avoidance shows conflict alerts along routes while reducing false alerts that can occur in terminal environments. Wake turbulence mitigation will show wake turbulence alerts, which are necessary for controllers to provide safe separation of smaller aircraft from larger aircraft that may generate wake turbulence dangerous to the smaller aircraft in their sectors.

3.8 Indicate flight ownership status in readily detectable, non-textual format

Common Function Recommendation Decision: Inconclusive for en route domain.

Indication of ownership needs to be unambiguous and easily determined. Incidence of errors in the en route domain suggests that making small text changes in a screen full of moving text boxes isn't always sufficient. Although the controller SMEs did not favor the simulation tool we used to fulfill this function, another improved means of displaying ownership is still needed.

Usefulness

Three out of four en route controllers thought the function is needed.

Usability

En route controllers rated the usability of this particular simulated tool as 6.92.

Recommended Requirements

Functional Requirements	The system will be able to display the FDBs in a readily detectable form using two distinctive colors to indicate sector ownership.
Data Requirement	The system needs to be able to identify aircraft position in relation to the sector boundary and identify hand off event to assign corresponding color according to ownership.

Environmental requirement or context:	It would be useful in en route sectors since the terminal environment already has this feature (STARS).
User requirement:	En route sector controllers exposed to high density traffic where aircraft are handed off to several distinctive surrounding sectors.
Usability Requirement:	NA

Common Function Implementation Timeline Analysis

More research is necessary before it is determined if this convergence would be beneficial. The year 2022 was chosen as an implementation date to not impact current 5 year plans while providing the time needed to conduct further analysis of this function.

The following increments show ways of presenting information about an aircraft's position and movement through a controller's airspace. To track the status of these increment functions, a controller needs to be able to determine, at a glance, which aircraft belong to their sector.

- 102144-23 ATPA for Closely Spaced Parallel Runway (CSPR)
  - Provides visual proximity alerts for aircraft separation and spacing.
- 105208-21 Airborne Re-routing
  - Provides the capability to amend routes inflight
- 105208-23 Arrival Route Availability Planning
  - Allows TMU to provide controllers with instructions to reroute traffic for better efficiency based on demand predictions.
- 105208-24 Aircraft Equipage Eligibility During TMI's
  - Allows the ability for aircraft to receive Traffic Management Initiatives from controllers.

3.9 Provide the user with information that calculates a safe and efficient sequence or spacing plan based on wake turbulence and given routes and display the information in a graphical format

Common Function Recommendation Decision: Not Recommended for en route domain.

Many of the benefits associated with NextGen rely on the predictability of flights within the system. Decision aids such as these create the potential for greater predictability throughout the system. The controller SMEs we interviewed did not judge this function to be useful.

3.10 Facilitate flight data entry on the primary display in a way that reduces workload and potential for entry errors

Common Function Recommendation Decision: Recommended for terminal domain.

Terminal controllers who use STARS make data entries to the NAS using a keyboard with an alphabetical key layout (as opposed to the QWERTY keyboard used by en route controllers). Currently terminal controller tasks do not require terminal controllers to make as many data entries as en route controllers are required to make. This is likely to change as NextGen will require both terminal and en route controllers to make more data entries so as to offer more flexibility and predictability for flights.

This function would reduce the workload and potential for errors associated with performing data entry for terminal controllers. It would allow terminal controllers to enter data more efficiently and more frequently than is possible today. This, in turn, would improve coordination between terminal and en route controllers and pilots and increase the predictability of flights in the system.

Usefulness

The discussion of the usefulness of this function was conducted along with the discussion for the "provide the ability to manipulate flight routes using a graphical user interface on the primary display to reduce controller workload and potential for error" function. Three out of four terminal controllers believed this function would be useful to have.

Usability

The simulated data block menu tool was demonstrated along with the Graphical Route Tool. No usability measures were taken for this simulate tool separate from the Grahic Route Tool.

Recommended Requirements

Functional Requirements	The system will provide interaction with the FDB via menus with options for heading, speed and altitude input to update the NAS.
Data Requirement	The system needs access to current aircraft trajectory, speed, flight plan and necessary attributes to update the NAS.
Environmental requirement or context:	Terminal sector using STARS. Especially useful for intra-facility flights and instrumental for Data Comm in NextGen environment.
User requirement:	Terminal sector controllers updating flight information in the NAS.
Usability Requirement:	1. The FDB menus should be fully activated via interaction using cursor and trackball buttons. 2. FDB menus should have a fixed width and height to standardize range of options in the list boxes and reduce clutter.

	3. FDB menus should differentiate selected option in the list box from the rest of the options available using a high contrast combination of colors. 4. FDB menus should be landscape scrollable (up/down arrows) to provide access to all options while still constrained to the standard height and width.

Common Function Implementation Timeline Analysis

This function should be implemented and benefits gained at the earliest possible planned release date (2017-2019).

4. Results of Implementation Plan Analysis

Results of the implementation plan analysis are summarized in Table 2, by each of the recommended common functions and their relationship to increments. The two originally identified functions that were not shown to the controller SMEs in the final validation phase and the two functions that were not recommended after the final validation phase are not included in this table. The Common Function Implementation Timeline Analysis column identifies the recommended timeline for introduction of a common function. Rationale for time periods chosen were provided for each function in section 3 of this paper.

Table 2. Common Function Implementation Recommendations

Common Function	Domains for which this would be a New Function	Common Function Implementation Timeline Analysis(estimated year)	Increments that the Function could benefit	Increment Operational Availability Dates
Prevent occlusion of flight data blocks.	Both	At the earliest possible planned release date (2017-2019)	Cross-cutting	2015-2030
Provide visual indication of current flight non-conformance with route (RNAV, OPD) restrictions in a readily detectable format compatible with the manner used to display conflict alerts in STARS.	Both	At the earliest possible planned release date	104124-11 Initial Tailored Arrivals (ITA'S)	2010-2011
			104124-12 OPD's Using RNAV STARS	2010-2011
Provide visual indication of aircraft ADS-B capability on the primary display in readily detectable, non-textual format.	Both	When En Route target symbols will be updated to represent radar fusion capabilities (2019)	102137- 15 Automated Proximity Alert (ATPA) for In Trail Separation	2010-2014
			102137- 28 Vertical Conformance Verification	2022
			102137- 34 En Route Conformance Monitor for PBN Routes	2022
Provide the ability to manipulate flight routes using a graphical user interface on the primary display.	Both	Implementation for En Route at the earliest possible planned release date	102146-21 Increase Capacity and Efficiency Using Flight Management Computer (FMC) Route Offset	2024-2026
			102146-22 4D Trajectory	2024-2025

Common Function	Domains for which this would be a New Function	Common Function Implementation Timeline Analysis(estimated year)	Increments that the Function could benefit	Increment Operational Availability Dates
		Implementation for terminal after flight data manipulation capability		
On the primary display, introduce a GUI function that enables controllers to execute controller-pilot interactions via Data Comm for clearances such as altitude and frequency changes.	Both	En Route implementation should follow the existing Data Communications plan. Terminal implementation should occur after the flight data manipulation capability.	101202-21 Flight Information Service	2020-2022
			101202-22 Unique Attributes for UAS Flight Planning	2017-2020
			101202-23 Extended Flight Planning Horizon	2022
			103306- 2 Tailored NAS Status via Digital NOTAMS for ANSP	2020
			103306- 3 Automatic Terminal Information Service Via Data Comm	2021-TBD
Provide persistent visual indication of aircraft to aircraft and aircraft to terrain conflict information in a readily detectable format similar to that used in terminal.	En Route	At the earliest possible planned release date	102117-22 Active Surveillance Collision Avoidance	2020-2025
			102144-21 Wake Turbulence Mitigation for Arrivals- Rear Gate	2022
	En Route		102117-21 Wake Turbulence Mitigation for En Route controllers	2019-2025

Common Function	Domains for which this would be a New Function	Common Function Implementation Timeline Analysis(estimated year)	Increments that the Function could benefit	Increment Operational Availability Dates
Indicate flight ownership status in readily detectable, non-textual format.		After the end of current 5 year plans (2022)	102117-22 Active Surveillance Collision Avoidance	2020-2025
			102137- 15 Automated Proximity Alert (ATPA) for In Trail Separation	2010-2014
			102137- 28 Vertical Conformance Verification	2022
			102137- 34 En Route Conformance Monitor for PBN Routes	2022
			102144-21 Wake Turbulence Mitigation for Arrivals- Rear Gate	2022
			102144-23 ATPA for Closely Spaced Parallel Runway (CSPR)	2016
			102146-21 Increase Capacity and Efficiency Using Flight Management Computer (FMC) Route Offset	2024-2026
			105208-11 Execution of Flow Strategies	2012
			105208-21 Airborne Re-routing	2016
			105208-23 Arrival Route Availability Planning	2015-2020
			105208-24 Aircraft Equipage Eligibility During TMI's	2016-2021

Common Function	Domains for which this would be a New Function	Common Function Implementation Timeline Analysis(estimated year)	Increments that the Function could benefit	Increment Operational Availability Dates
Facilitate flight data entry on the primary display in a way that reduces workload and potential for entry errors.	Terminal	At the earliest possible planned release date	Cross-cutting	2015-2030

* Years referenced in this column are estimates based on the authors' knowledge of current upgrade plans and schedule

5. Summary

Terminal and en route workstation software, while similar in many ways, has evolved over the last 50 years to enable different ATC functions. Greater similarity in the software used by the two workstations would reduce the cost associated with development and implementation of new controller tools, help to simplify the controller training process, and potentially improve shared situation awareness among? the different types of controllers. Given that the two workstations evolved to meet the unique needs of the two controller domains, standardizing the two domain workstations for the sake of standardization alone has the potential to negatively impact the ability of controllers to perform their jobs. There is reason to suspect, however, that some functions currently found in one controller domain may provide benefits if also made available to the other controller domain as well. For example, displaying conflict alerts similar to the way the terminal workstation presents them might be beneficial to en route controllers and providing en route flight re-routing tools might be beneficial to terminal controllers. Moving towards commonality of proposed NextGen tools, such as Data Comm., may also make sense.

The CIR project team compared ATC task analyses, reviewed ATC workstation software manuals, visited sites where new ATC tools are being developed, and met with several retired controllers to identify current and NextGen en route and terminal functions that are potential candidates for convergence. In particular, the team identified the following:

- Functions that currently exist in both domains, but where the implementations of tools to accomplish the functions are substantially different (such as indication of aircraft ADS-B equipage) and where planned NextGen changes may provide the opportunity to reduce the differences.
- Functions that currently exist solely in one domain or are planned as part of NextGen to be implemented in one domain but not the other, and where the second domain might benefit if the functions from the first were added (such as a adding a data block drop down menu for changing flight data on the primary display to the terminal NextGen workstation).
- Functions that do not currently exist in either domain, but where proposed NextGen improvements could be developed to minimize differences in the interfaces used by both domains (such as Data Comm.).

The CIR project team conducted cognitive walk throughs with eight current controllers (four from the en route domain and four from the terminal domain) to validate the initial assessments of the candidate functions and flesh out the requirements and design recommendations. The team also examined NextGen implementation plans to determine the optimal points in the upgrade schedules for en route and terminal when steps toward convergence could be taken.

The CIR team identified twelve functions for initial consideration. Ten functions were presented to the eight current controller SMEs during the cognitive walkthroughs for validation. Of those ten, five functions were recommended as convergence opportunities across the terminal and en route domains and three were suggested for further analysis. Two were not recommended as convergence opportunities, based on controller judgments regarding how useful they would be in the controller domain in question.

Providing terminal workstations with data block drop down menus, and providing en route workstations with both an ownership indication color convention and an alert presentation similar to STARS, and giving both terminal and en route workstations the same target symbol would go a long way toward making the two displays look and behave in a similar fashion. Both types of controllers, terminal and en route, seem to like the example symbol used to indicate ADS-B equipage. Terminal controllers thought that tools such as FDB menus and graphic reroute tools would be a useful and welcome addition to their primary displays. En route controllers however, although not actually objecting to them, were not enthusiastic about using terminal style ownership indications or conflict alerts.

The method used to conduct this project identified five functions that, if converged across controller domains, are expected to provide benefits based on Human Factors and ATC SME opinion. Two more functions may also be of value after more review. Additional analyses will be necessary to determine the extent that the potential benefits can be realized. Two functions were not recommended for further consideration.

We believe that the methodology developed here could be useful for exploring other new concepts to determine whether it makes sense to invest additional resources in their development.

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7. Acronyms

ACL	Aircraft List
ADBO	Automatic Data Block Offset
ADS-B	Automatic Dependent Surveillance – Broadcast
ATC	Air Traffic Control
ATM	Air Traffic Manager
ATPA	Automated Terminal Proximity Alert
CA	Conflict Alert
CAMI	Civil Aerospace Medical Institute
CRR	Continuous Range Readout
CJI	Controller Jurisdiction Indicator
Data Comm	Data Communications
D-side	Data-side or Data Controller Position
ERAM	En Route Automation Modernization
FAA	Federal Aviation Administration
FDB	Full Data Block
FDIO	Flight Data Input Output
FEWS	Future En Route Workstation System
FMA	Final Monitoring Aid
FTWS	Future TRACON Workstation
GRT	Graphic Route Tool
LA	Low Altitude
LDB	Limited Data Block
MSAW	Minimum Safe Altitude Warning
NAS	National Airspace System
NextGen	Next Generation Air Transportation System
RBL	Range Bearing Line
RNAV	Area Route Navigation
RPI	Relative Position Indicator
R-side	Radar-side or Radar Controller Position
SME	Subject Matter Expert
STARS	Standard Terminal Automation Replacement System

TMU	Traffic Management Unit
TOC	Transfer of Control
TRACON	Terminal Radar Approach Control
VFR	Visual Flight Rules

Appendix A: Satisfaction and Usability Questionnaire

Automatic Data Block Offset and Drag and Drop Ranking

1. Were the Flight Data Blocks difficult to read? (1 Not at all; 10 A great deal)______
2. Did you feel that you spent time moving FDBs around instead of scanning for traffic? (1 Not at all; 10 A great deal)______
3. Did the automation help to prevent overlapping data and clutter on the display? (1 Not at all; 10 A great deal)______
4. Were you distracted with the automatic data blocks movement? (1 Not at all; 10 A great deal)______
5. Will the drag and drop repositioning feature be most useful under busy traffic, medium traffic, or low traffic conditions?
6. Were you able to identify dragable FDB from FDBs that were on automatic repositioning mode? (1 Not at all; 10 A great deal)______
7. Were you able to reengage the FDB in automatic repositioning mode? (Circle One)
   A) Always B) Most of the time C) Half the time D) Sometimes E)Never

Ownership Ranking

1. Would change in data block color be helpful in determining ownership? (1 Not at all; 10 A great deal)______
2. Was this indication helpful for point outs as well as handoffs? (1 Not at all; 10 A great deal)______
3. Were you able to rapidly identify point outs? (1 Not at all; 10 A great deal)______

Target Position Ranking

1. Did the fused targets provide sufficient information? (1 Not at all; 10 A great deal)______
2. Did the fused targets occlude the radar tracks? (1 Not at all; 10 A great deal)______
3. Were you able to determine whether the aircraft were under reduced separation? (1 Not at all; 10 A great deal)______
4. Would a color change of the data block help with recognitions of these states? (1 Not at all; 10 A great deal)______

Automated Terminal Proximity Alert Ranking

1. Did you find the colored cones distracting? (1 Not at all; 10 A great deal)______
2. Did you find the colored cones cluttering? (1 Not at all; 10 A great deal)______
3. Were you able to understand the meaning of each ATPA alert graphic? (1 Not at all; 10 A great deal)______

4. Was ATPA helpful in maintaining sequencing? (1 Not at all; 10 A great deal)______

5. Was ATPA helpful in maintaining separation? (1 Not at all; 10 A great deal)______

6. Would a halo around the target be more helpful during turns? (1 Not at all; 10 A great deal)______

Conformance Ranking

1. Could you easily tell which aircraft were in conformance with their route during the scenario? (1 Not at all; 10 Always)______

2. Was the flashing and color change helpful in determining conformance? (1 Not at all; 10 A great deal)______

3. Was the frequency of these alerts too distracting to be helpful in your environment? (1 Not at all; 10 A great deal)______

4. What indication would you find most distracting for your environment? Rank from 1 to 4
   - Altitude ______
   - Speed ______
   - Heading ______
   - Weather ______
5. Based on importance, rank the different types of conformance indication (1 most important to 4 less important)
   - Altitude ______
   - Speed ______
   - Heading ______

Colored Alert Ranking

1. Were you aware of possible conflicts before the CA alert went off? (1 Not at all; 10 A great deal)______

2. Was the flashing and color change helpful in indicating conflicts? (1 Not at all; 10 A great deal)______

3. Could you easily tell which aircraft were in conflict? (1 Not at all; 10 A great deal)______

4. Was the flashing and color change helpful in determining MSAWs violations? (1 Not at all; 10 A great deal)______

5. Was the frequency of these alerts too distracting to be helpful in your environment? (1 Not at all; 10 A great deal)______

6. Could you easily tell which aircraft were violating MSAW? (1 Not at all; 10 A great deal)______

Ghost Target Ranking

1. Was the relative position of ghost target easy to read for projections into the merging patterns? (1 Not at all; 10 A great deal)______

2. Was this tool helpful in merging traffic during the scenario? (1 Not at all; 10 A great deal)______

3. Did you find the ghost targets distracting? (1 Not at all; 10 A great deal)______

4. Did you find the ghost targets cluttering? (1 Not at all; 10 A great deal)______

Reroute Ranking

1. Compared to the simply vectoring, how much did this tool help you re-route aircraft? (1 Not at all; 10 A great deal)______

2. Did you find it an effective planning tool? (1 Not at all; 10 A great deal)______

DataComm Ranking

1. Was it difficult to enter information into Data comm instead of voicing it? (1 Not at all; 10 A great deal)______

2. Was the delay in response from the aircraft due to the nature of Data comm distracting and difficult to work around? (1 Not at all; 10 A great deal)______

Slot markers Ranking

1. Were the slot markers useful in providing metering, and sequencing capabilities in the scenario? (1 Not at all; 10 A great deal)______
2. Did you find it difficult to determine which slot marker belongs to each aircraft? (1 Not at all; 10 A great deal)______
3. (Enroute Only) Did you prefer this method to the ERAM delay countdown timer? (1 Not at all; 10 A great deal)_____

General Usability Questions

1. The automation tool/function was easy to use	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal
2. The display was uncluttered	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal
3. I could find the information I needed quickly	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal
4. I was able to prioritize information easily	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal
5. Information was updated or changed on the display in a predictable manner	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal
6. The information was presented in an easy-to-understand format	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal
7. It took only a few simple steps to get the information I needed when it was not available directly on the display	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal
8. The coding of the information (e.g. colors) helped me locate what I needed quickly	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal
9. The text was easy to read	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal
10. The graphics were easy to interpret	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal
11. Was your situational awareness on traffic management increased?	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal
12. Do you feel that the tool will reduce your workload?	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal
13. Will the tool prevent errors?	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal
14. Will the tool increase your efficiency?	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal

15. Will the tool reduce the amount of key entries?	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal
16. Will the tool be most useful in a busy traffic environment?	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal
17. Will the tool be most useful in a moderate traffic environment?	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal
18. Will the tool be most useful in a light traffic environment?	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal
19. Will the tool be most useful in a full data communication environment?	Not at all	1	2	3	4	5	6	7	8	9	10	A great deal

Appendix B. Open Interview Discussion Prompts

Open Interview

1. Will this tool be useful in your current operational environment?

2. What part is the most useful? And Why?

3. What part is the less useful? And Why?

4. Under what conditions (e.g. small vs large sector, busy vs light traffic, high vs low altitude sector) will be more useful?

5. If not possible with this tool, what type of additional information/functionality would you like to see in your workstation to accomplish the same objective?

6. Will this tool be useful in a NextGen operational environment?

7. Will the tool be useful in traffics environments with ADS-B?

8. Will the tool be useful in operations with optimized descend profiles?

9. In what type of TRACON operation (Feeder, Final Departure, Transition, Satellite, Final Monitor) do you see this tool more useful?