

# HUMAN FACTORS IN THE DESIGN AND DEVELOPMENT OF AN ADVANCED DECISION SUPPORT TOOL

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## Abstract

Human Factors concerns must be integrated in the design and development of automation to assist air traffic management efficiency and safety in future traffic systems. This paper describes the practices used in development of an advanced Decision Support Tool (DST) for addressing and resolving the human performance and information processing requirements. The En Route Descent Advisor (EDA) is an advanced DST that will assist controllers with metering of arrival aircraft in transition from Center to TRACON airspace. EDA generates comprehensive control advisories, allowing for efficient traffic control and compliance with metering and separation requirements. In today's environment controllers must rely entirely on their skill and judgment to provide instructions for conformance to flow rate restrictions and conflict avoidance. Automation that allows accurate, efficient ground-based control of the transition and descent phase of flight will result in a reduction in workload, flight deviations, and fuel consumption. A fundamental criterion for successful development of an advanced DST must be the acceptance and trust in the tool for use in an operational environment. The DST must provide a functional reduction in the controller's workload during periods of intense traffic demands, as well as during normal flow conditions. For use in traffic control, the DST must be accurate, stable, and efficient in all possible applications. Achieving these fundamental human factors design goals requires a dedicated focus on development of robust and versatile algorithms and the underlying processes that support the DST functions. Since EDA is still in the concept development phase, the project presents a unique opportunity for early and continuous Human Factors involvement throughout the development and evaluation cycle. To address these human factors concerns, simulation, testing and validation are performed as an integral part of the overall EDA development activity. The

incremental process for EDA development permits controller evaluations and recommendations to be included in the development of the mature DST capabilities. This paper discusses controller-in-the-loop trials for development of trajectory visualization and other information presentations.

## Introduction

Human Centered Automation is an important concept in air traffic management research and development initiatives. For human centered automation to be effectively incorporated in air traffic control systems, the cognitive and performance requirements of the system operators must be determined and included throughout the design and development process.

Advanced Decision Support tools (DST) are being developed to support the air traffic controller in efficient traffic management for the future airspace system [1]. DST development is intended to allow for increased traffic capacity and more economical air transport operations by improving controller workload and possibly offering improved control services.

The new DST's will require careful integration with the controllers' cognitive requirements to permit the full range of procedural enhancements envisioned for future airspace structures. The procedural enhancements and supportive automation will also change the performance requirements for the air traffic controller. An example of these changed performance requirements is provided by the movement towards time-based traffic control to alleviate flow-rate restrictions, (i.e. metering).

Traffic flow rate restrictions are applied when necessary to delay incoming flights to relieve capacity-constrained airspace. Even though flow restrictions only impact a small percentage of all flights, the resulting deviations are significant, with

adverse influences on flight efficiency and controller workload. In today's environment controllers must rely entirely on their skill and judgment to provide the instructions for conformance with the time based restrictions while simultaneously guarding against separation conflicts. This difficult four-dimensional traffic management problem is complicated by the convergent nature of arrival traffic and the high workload/traffic conditions that require the imposition of metering restrictions. Without additional automation, capacity is jeopardized by workload constraints that limit the controller's ability to fully comply with a metering plan for maximum throughput into the terminal area. Accurate and efficient ground-based control of the transition and descent phase of flight will enable controllers to strategically plan their flow-rate conformance actions resulting in a reduction in workload, flight deviations, and fuel consumption [2, 3].

The En Route Descent Advisor is an advanced DST being developed to assist Air Route Traffic Control Center (ARTCC) sector controllers with management of aircraft during the en route cruise and descent with specific arrival time requirements imposed for capacity throughput management. EDA allows controllers to precisely control aircraft in transitional airspace, safely and efficiently. EDA generates maneuver advisories to deliver aircraft very accurately to an arrival-metering fix located at the TRACON boundary. EDA works in conjunction with the Center-TRACON Automation System (CTAS) Traffic Management Advisor (TMA), which generates the precise schedules and sequences that EDA targets. EDA is capable of generating explicit "meet-time" maneuver advisories based on combinations of speed, altitude, and heading degrees of freedom. The maneuver advisories generated by EDA are designed to put aircraft on trajectories that: (a) deliver aircraft to the metering fix in conformance with the time based metering constraint; (b) ensure safe separation with other aircraft through to the metering fix; and (c) maximize fuel efficiency for the airspace user whenever possible.

EDA enables new capabilities and procedures that support the controller's precise management of en route traffic during cruise and the transition into

high-density terminal airspace. In order to derive the full potential benefit of the new procedures and capabilities offered by automation, the information processing requirements of the air traffic controller are included as an important feature for EDA's human-centered design.

To safely perform the difficult, precise control needed to manage timed descents, accurate trajectory predictions must be available. EDA does this by using the CTAS Trajectory Synthesizer (TS) to compute and update both an "active" and a "provisional" trajectory. The active trajectory is the best possible prediction of where an aircraft will be over the period of interest based on everything that is currently known regarding that flight. This active information includes the current radar track, wind field, aircraft dynamic model characteristics, and flight plan with modifications and amendments. The provisional trajectory is the prediction EDA generates and uses for verifying traffic conflict resolution and timed arrival accuracy when computing control advisories for potential aircraft maneuvers. Both the active and provisional trajectories, for all aircraft in the EDA system, must be cross compared for assurance of proper traffic separation. The computation and display of both the active and provisional trajectory is a key element in accommodating the information processing requirements of the controller.

EDA is an ATM development that has undergone several changes in scope and application since the preliminary work first presented almost two decades ago [4]. Previous prototypes went through an extensive series of conceptual revisions and eventual limited field testing [5]. The current EDA prototype incorporates selected functions and processes of the previous designs with additional functions.

The focus of the current project work is on providing a "Bottom Up" view to identify performance requirements and provide a practical design to realize development goals. The goal of this Bottom Up development project is to provide the en route controller with a robust DST for use in precise control of transitional traffic that will be fully functional with all procedures and equipment available in today's operational environment, and compatible with the increased capabilities projected for the future air traffic operations [6].

A fundamental criterion for successful development of an advanced DST must be the acceptance and trust in the tool for use in an operational environment. The DST must provide a functional reduction in the controller's workload during periods of intense traffic demands, as well as during normal flow conditions [7]. For use in traffic control, the DST must be accurate, stable, and efficient in all possible applications. To achieve this fundamental human factors design goal requires a dedicated focus on development of robust and versatile algorithms and the underlying processes that support the DST functions.

Since EDA is still in the concept development phase, the project presents a unique opportunity for early and continuous Human Factors involvement throughout the development and evaluation cycle. At this early phase, the major Human Factors concerns are;

- Proper identification of the Information Processing needs of the controller required to most efficiently perform the anticipated operations, and ensuring those information elements are fully offered in the DST.
- Structuring the content, format, and sequence of the DST advisories for best possible use by the controllers and aircrew.
- Attaining the optimum workload for the en route controller to improve efficiency in the current operational environment and allow for expected benefits available when processing an increased traffic load in projections of future needs.
- Ensuring the safety of operation of EDA; both to preserve the current level of safety with today's NAS and improve the potential for the controller to safely handle increased traffic flows in the future.

To address these human factors concerns, simulation, testing and validation are performed as an integral part of the overall EDA development activity. The incremental process for EDA development permits controller evaluations and recommendations to be included in the development of the mature DST capabilities. Controller participation in EDA development requires an appropriate Computer-Human Interface (CHI).

## **EDA CHI Development**

During the design and development phases of project development, CTAS uses a unique display system. The display uses an integrated plan-view graphic (PGUI) for track and text presentation, and a measured time-line (TGUI) for display of arrival time and sequences. This CTAS display system is separate from that used in operational air traffic control facilities. The EDA CHI described is currently part of this display system. At later stages of project maturity, this display will be modified for integration with the operational system in use.

The EDA user interface design is intended to minimize controller workload while providing for full range and flexibility of use of all processing functions and advisory services. Past studies of DST use by controllers have repeatedly demonstrated the importance of automating all processes involved in advisory formulation and display as much as possible in order to mitigate workload [8].

The EDA user interface provides a high degree of automated processing, but also allows the controller to retain full awareness and command of the decision making process. The controllers can tailor the presentation, timing, and content of all EDA functions through selectable options. The controller can also view the expected trajectory effects of advisory information as an automated "trial planning" display. And the controller can accept, reject, or modify any recommendation provided by EDA. A short description of some CHI characteristics follows.

### ***Center Options (F1) Panel***

The F1 panel (see Figure 1) allows the controller to pre-select and modify all aspects of the EDA displays and functions. The selection features of this panel enable the controller to tailor the EDA tool for individual preference and compatibility with specific sector requirements and dynamic traffic conditions.

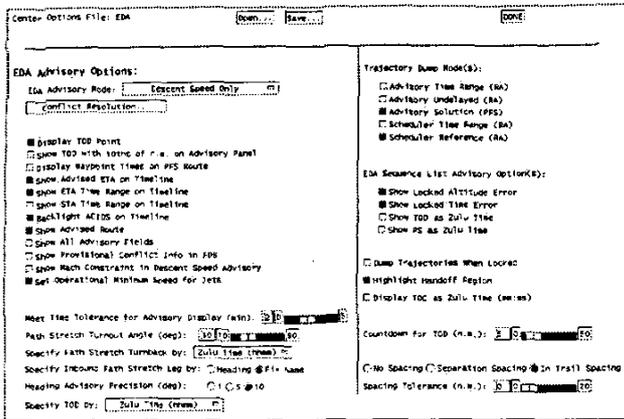


Figure 1. EDA Configuration Panel (F1)

**Time-Line**

EDA integrates the Plan-view Graphical User Interface with a time-line to show the aircraft's ETA and STA, as provided by an interface with the TMA scheduling tool. Provisional ETAs (prior to advisory acceptance) and the range of adjustment available and backlighting of selected aircraft call signs on the time-line are also displayed (see Figure 2).

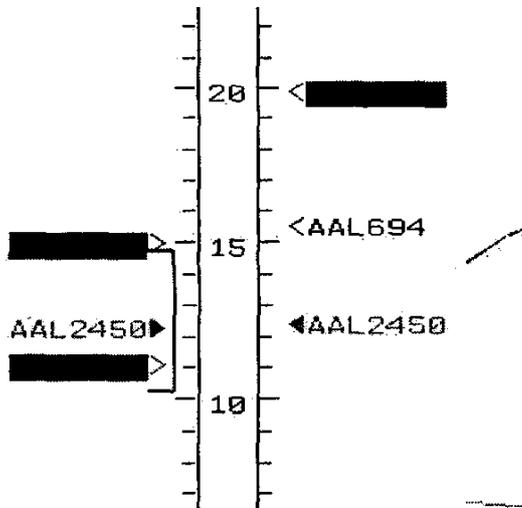


Figure 2. EDA Time Line Display

**EDA Portal**

An entry tag or portal is added to the fifth line of the PGUI data block. The EDA portal indicates that an EDA advisory is available for that aircraft.

The portal design hides advisory information until the controller is ready for it and helps to de-clutter the display. Clicking the portal calls up the display of explicit advisory information as shown in Figure 3.

**AAL 1083 DFW  
280C  
MD80 411  
EDA OK**

Figure 3. CTAS Flight Data Block with EDA Portal

**Flight Data Block**

The modified flight data block provides the controller with the ability to access EDA functions. Clicking of the portal replaces the EDA symbol with the advisory information suggested for aircraft control. Selecting the portal also invokes the display of provisional information on the time-line, together with relevant provisional plan-view graphics as shown in Figure 4.

Combined Speed and Path Stretch Advisory

**P/180 C/260 P/145/Karla D/260**

- P/180=** change heading to 180 magnetic.
- C/260=** maintain 260 knots calibrated airspeed
- P/145/Karla=** when at 145 nautical miles from Karla metering fix, turn back direct to Karla
- D/260=** when in the descent to Karla, maintain 260 knots.

**Note:** This advisory example is formatted for a FMS equipped aircraft using time based maneuver instructions. Advisory formats for non FMS equipped aircraft and distance based maneuver instructions are also available.

Figure 4. EDA Maneuver Advisory Example

**Advisory Window**

The Advisory Window (see Figure 5) allows the controller to accept, reject, or modify an EDA

advisory. This window is also displayed whenever the controller clicks on the EDA portal. The window disappears whenever the controller clicks "Accept" or "Cancel".

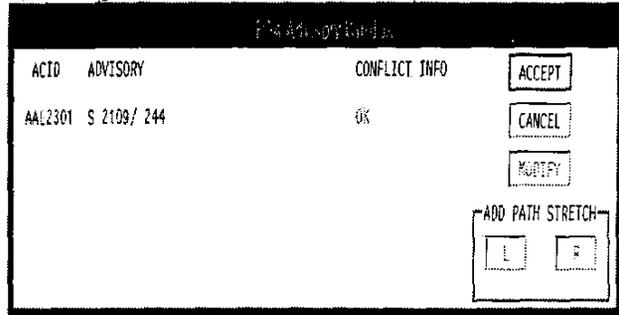


Figure 5. EDA Advisory Window

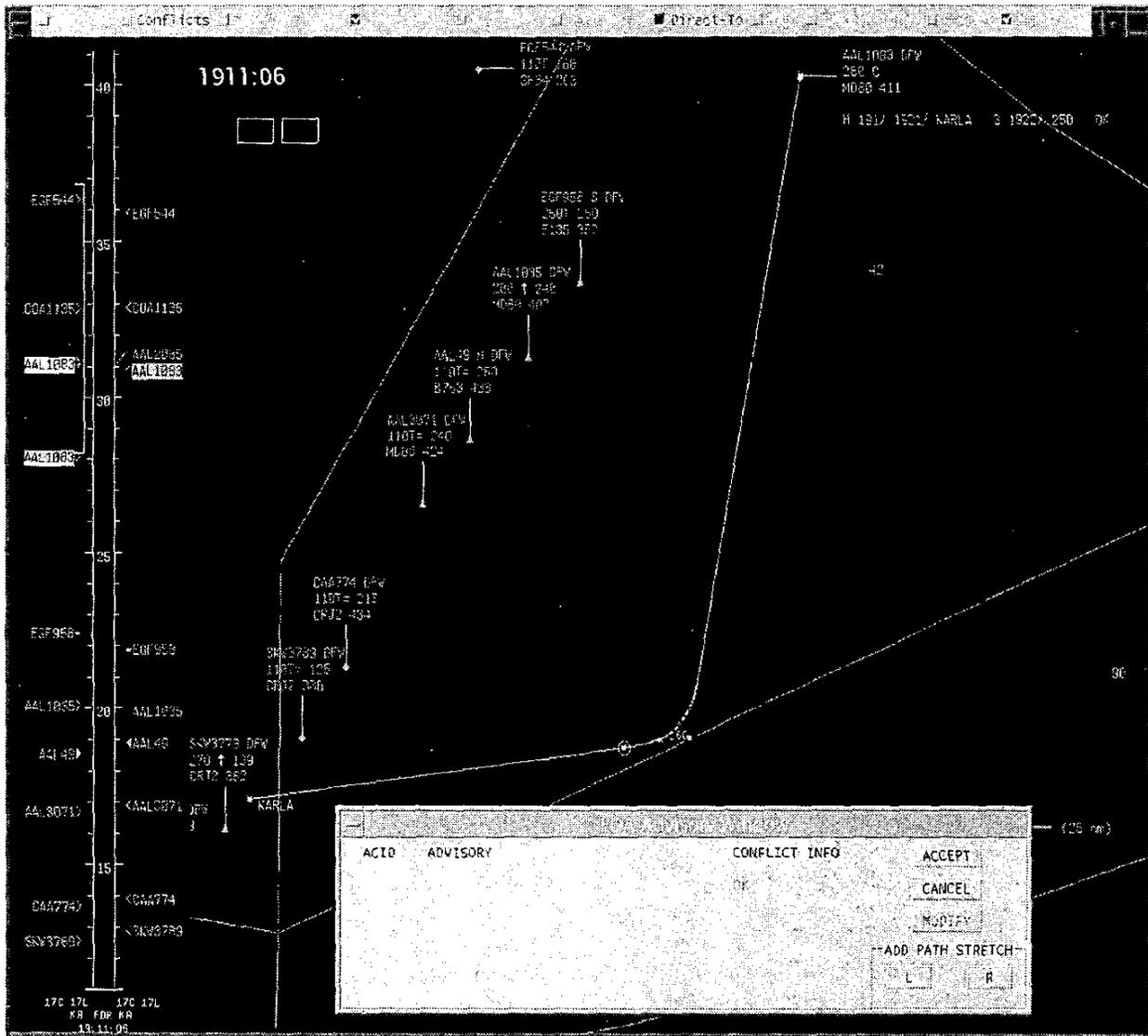


Figure 6. EDA CHI with a Provisional Trajectory Displayed

The Bottom-Up approach of EDA development has focused on refinement of the robust algorithms and functions needed to fully support the en-route controller when managing the complexities of high-density metered arrival traffic. The CHI described in Figure 6 is intended only as an interim development to permit full controller interaction during the incremental DST development process.

## Simulation Objectives and Methods

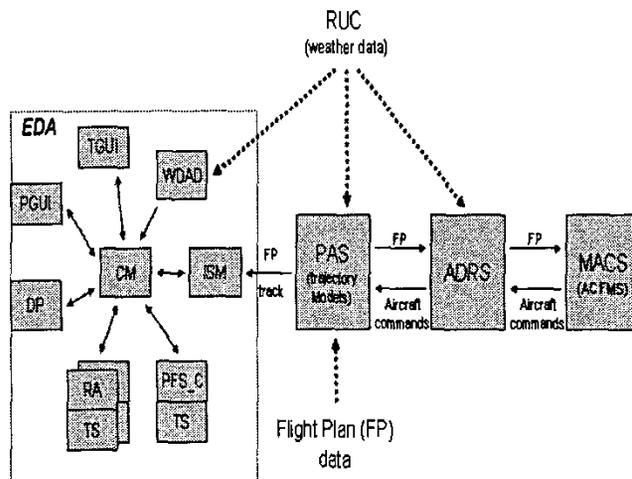
A series of closed loop system simulations have been conducted to ensure controller participation in design and evaluation. The simulations have often been informal, with emphasis on attaining productive design recommendations rather than measured evaluations of performance. The primary goals of the simulation series are:

- (a) Test the accuracy, continuity, and stability of the system processing functions.
- (b) Evaluate the content, format, and utility of the advisories provided.
- (c) Provide the opportunity for the engineering staff to receive and incorporate preliminary opinions and recommendations on the operational feasibility and desirability of EDA use in an operational environment.

## Method and Participants

The EDA simulations are conducted using a closed loop system developed at NASA Ames. The closed loop simulation allows for capture and manipulation of real air traffic flows and the ability to control the aircraft tracks in response to participant instructions (see Figure 7). There are two major functional components to the EDA Simulation: the EDA system and the pseudo pilot system. The EDA system consists of the various CTAS processes that make up EDA (see [www.ctas.arc.nasa.gov/](http://www.ctas.arc.nasa.gov/)). The pseudo pilot system consists of a combination of the Multi Aircraft Control System (MACS), Aeronautical Data-link and Radar Simulator (ADRS), and Pseudo Aircraft System (PAS). MACS provided control inputs to the pseudo aircraft, derived through MACS user interface (emulations of actual aircraft automation

inputs FMS & MCP commands). PAS contains the aircraft models and generates the aircraft trajectories as commanded by MACS. MACS and PAS are interconnected via the ADRS interface and PAS connects directly to EDA to provide aircraft data.



**Figure 7. Closed Loop Simulation Components**

The participants for the simulation are operational controllers with experience using other CTAS systems to perform metering operations.

## Test Scenarios and Configuration

Test scenarios are created using recently archived air traffic, usually centered on arrivals to the Dallas-Fort Worth Airport. The scenarios are developed to allow the controller to issue EDA commands and have aircraft respond to those commands under a variety of traffic conditions. The simulation scenarios usually recreate a North East arrival flow with metering conditions imposed. Variations of the arrival scenarios are created to permit full evaluation of all design options with progressive levels of traffic complexity. In addition to the prepared scenarios, EDA processing and advisories are evaluated using a live feed of current traffic situations.

## Results

The initial system simulations have consisted of a series of informal trials that allow for a

complete evaluation of all EDA processes and provide objective data and observations to incorporate as improvements of the EDA design. A brief summary of the results for each of the three major objectives, are as follows:

***(a) Accuracy, Continuity, and Stability***

The utility and ultimate acceptance of the DST depends on the accuracy, continuity, and stability of the underlying trajectory predictions and the resulting control advisories. EDA processing is robust and consistent with design goals. The accuracy and continuity of EDA is dependent on the successful integration from several dynamic sources. To evaluate the system processes, performance data is captured and recorded for each trial. The data available includes information files of; aircraft state and track, original flight plan (host) messages, all EDA advisories generated, flight plan amendments, and controller actions. Preliminary analysis of the accuracy of the trajectory advisories is encouraging. EDA is able to provide an acceptable trajectory for all metered aircraft, for an arrival at the metering fix within 30 seconds of the TMA specified time. EDA performance was also shown to be consistent, with the demonstrated ability to constantly process and compute trajectory projections for the arrival aircraft with changing conditions throughout their track.

***(b) Content, Format and Utility of the Advisories.***

The main product of EDA is the advisory presented to the controller, which contains the information needed to precisely manage the metered flow of arrival aircraft. The trajectory information provided by EDA can be complex, especially when changes in course, speed and descent points are combined. This need for accurate and timely voice transmission of complex control instructions has been a real concern for DST design feasibility. The simulations have shown that the controllers are easily able to issue all control instructions provided by the EDA advisories, and comply with the required procedures for issuing clearance amendments [9]. The controllers have developed the phraseology for delivering the complex EDA instructions to the aircraft in a

manner that is compatible with current procedures and regulations.

Based on the controllers' recommendations, the format and content of the EDA advisories was modified to allow for controller selection of either time based or position based instructions. The EDA trajectory instructions can be issued based on a specified time of action (i.e., a speed, course, or altitude changes are directed to be initiated at the specified future time). This time based system of flight direction was fully adaptable and acceptable to the controllers during the simulation. Trajectory instructions can also be presented based on geographic referents (i.e. speed course, or altitude changes are directed to be initiated at a specified future position). This position based instruction is more consistent with current control procedures and may be preferable in most circumstances.

Another important aspect developed and validated through simulation was providing the controllers with the ability to visualize the effects of the control instructions prior to issuing the command, and monitoring the aircraft track for compliance. The graphic aids for course revisions and top of descent points worked well for these purposes. The ability to easily tailor and select the graphics through the F1 panel was endorsed by the controllers as a key feature of EDA usability.

***(c) Preliminary Opinions and Recommendations***

The simulation series provided the opportunity for the participating controllers to contribute preliminary opinions and recommendations to help guide the future development of EDA. They provided suggestions for the broad issues that influence the core philosophy of EDA, as well as specific items for improvement of the processing functions. Two key recommendations were derived by the simulation series and have been incorporated in the DST development.

The first key recommendation was the importance of providing a single, conflict-free control advisory as soon as possible to the controller. This was identified by the participants as a "simple but flexible" key characteristic for DST acceptance and usability in the operational environment. Another key recommendation was the development of a combined degree of freedom

processing and advisory mode, to be used as the expected primary mode for the DST in the operational environment. This combined degree of freedom mode has now been incorporated and is being evaluated during subsequent simulations. Other items for suggested improvement included selectable turn-out angles for path stretch advisories, selectable priorities for meet time mode priorities, and separate tolerances for keying EDA advisories depending on controller preferences and traffic based demands.

## Discussion

EDA is an advanced DST that is in the concept development phase of development. At this early phase, the primary human factors concerns for successful design and development are centered on the fundamentals of operator trust in an automated control system, information processing needs, and unique safety requirements for DST use in air traffic management. These human factors concerns are best addressed at this phase of development by a dedicated focus on refinement of the robust and stable algorithms and processing functions that will comprise the DST.

Published guidance for human factors concerns in air traffic management projects is available [10]. These guidelines have been compiled from lessons learned in previous development and evaluation projects. When dealing with an entirely new potential technology, as is the case with advanced DST development, published guidelines must be adapted or augmented to fit the new roles required for controller performance. For this purpose, the following overarching human factors requirements are suggested as prime considerations for the system requirements of Advanced Decision Support Tool design and development.

- The Information Processing Requirements of the controller to perform the expected revised tasks expected with the additional capabilities offered by the DST must be fully assessed and integrated in defining the initial system requirements.
- Integration and interoperability of the DST with all aspects of the expected operational environment must be considered. The operational environment includes other

technological developments, possible or required revisions to control procedures, airspace requirements, and workplace and workforce demands.

- Procedural and Safety considerations. Development of air traffic management systems must be particularly concerned with all possible influences on the safety of operations. The safeguards presently ingrained in the procedural requirements for air traffic control must be preserved in the revised controller tasks proposed for the DST use.

Since EDA is still in the early phases of completion, the project presents a unique opportunity for early and continuous human factors involvement throughout the development and evaluation cycle. The initial simulations have provided encouraging results. All system functions were fully evaluated using realistic scenarios. The system functions and processes were shown to be robust and adaptable to operational requirements and procedures. More importantly, the controllers endorsed the basic design concepts for EDA and provided beneficial suggestions for design improvement. Overall, the EDA concept and design was shown to be practical and beneficial in management of transition arrival traffic. EDA development will continue with additional simulations and controller participation planned in the near future. The goal of this Bottom Up development project is to provide the en route controller with a robust DST for use in precise control of transitional traffic that will be fully functional with all procedures and equipment available in today's operational environment. Further development of EDA is anticipated with the ultimate goal of field implementation of a DST that will assist the en route controller and be fully compatible with the increased capabilities projected for the future air traffic control environment.

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