Efficient Arrival Management Utilizing ATC and Aircraft Automation

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ABSTRACT
In this paper we present an airspace capacity research project at NASA's Ames and Langley Research Centers within the Terminal Area Productivity program, TAP. We describe an application area that deals with arrival traffic management and control in a 2010 time frame. We investigate utilizing and integrating air traffic control and aircraft automation. We address potential benefits and limitations and initial observations gathered from several controllers and pilots in the loop simulations.

Keywords
Automation, air-ground integration, simulation, air traffic control, flight management system, CTAS

INTRODUCTION

If current airspace operations remain unchanged, rapidly increasing traffic demands are expected to compromise both on-time performance and safety. Coping with these increasing airspace capacity requirements will require substantial modifications and improvements to current-day operations. One approach to addressing this problem is to give airlines more freedom in scheduling and selecting preferred traffic routes. Some free flight concepts go further, giving flight crews in highly developed aircraft the responsibility for separation, thus changing the role of air traffic controllers. ATC-oriented approaches focus on airspace restructuring and/or development of new tools for air traffic managers and controllers that enable them to manage air traffic more safely and efficiently. Finally, digital data link technology is being developed to improve communications between air and ground. The future air traffic system is likely to combine operational and technology changes in all of these areas. In this paper we describe an approach to integrating selected features of these new technologies to more efficiently and safely manage arriving air traffic.

PROBLEM

We focus on the problem of aircraft arrival rushes into major airports. The goal is to provide a safe, highly efficient flow of traffic from enroute into the TRACON airspace that reliably delivers aircraft to approach control.

APPROACH

We believe that efficiency enhancements over today's operations can be achieved by planning the most efficient arrival stream ahead of time and then executing the "arrival plan" as precisely as possible. Planning the arrival flow requires a thorough understanding of all flights, traffic management and spacing constraints. Coordination between controllers, flight crews, dispatchers and traffic management is necessary to harmonize needs and preferences. The planning task involves creating the most efficient schedule and sequence for all arriving aircraft and conflict-free flight paths that meet this schedule. These flight paths need to be communicated between flight crews and controllers [1]. Flight crews are responsible for precisely following the flight path. Sector controllers are responsible for maintaining separation and adjusting the arrival plan to changing circumstances. Automation and procedures are designed to help with all these tasks. Our goal is to construct a human-centered system in which controllers and pilots use procedures, flight management automation and decision support tools to assist them in actively managing arrival traffic. Our concept is more strategic than today's very tactical system but the controllers are actively involved in every step of the process of developing and executing a traffic flow plan for the arrival rush.

INTEGRATION OF DISTRIBUTED TECHNOLOGIES

Distributed technologies can be utilized to support planning, plan execution, coordination and communication, when integrated properly. In developing our integration concept we look at new technologies and procedures in the aircraft, on the ground and for communication between them. Our goal is to construct an operational environment where the most suitable technology is used to perform a given task. Because this project is part of NASA's Terminal Area Productivity (TAP) program, we have chosen technologies and procedures that could be operational by 2010, the TAP program's target time frame.

Aircraft

Flight Management Systems (FMS) and Cockpit Displays of Traffic Information (CDTI) provide substantial benefits. The main benefit of FMS aircraft is their capability of computing an efficient 3D/4D flight path and following it very precisely. FMS equipage is a requirement to participate in our operational arrival scenario. FMS automation provides the efficiency, predictability and precision to execute the flight paths that construct the arrival plan. Advanced CDTI technology allows flight crews to play an extended role in the planning process by creating and evaluating routes taking traffic constraints into account. CDTI may increase user benefits and safety, but is not required for our concept. Our 2010 time frame assumes a mix of jets and turboprops where all jets and most turboprops are equipped with FMS, some with CDTI.

Air Traffic Control

The main benefit of the ground automation lies in its ability to compute, integrate, evaluate and display flight path information for all aircraft, aiding sector controllers and traffic managers in visualizing and managing air traffic. Initial tool deployments in Europe (e.g. COMPAS[2]) and the U.S.A. (CTAS[3], URET[4]) demonstrate capacity and flow control benefits. Our 2010 scenario assumes a Center facility provided with several Center TRACON Automation System (CTAS) tools. The Traffic Management Advisor (TMA) helps optimize the arrival traffic flow and create the arrival plan. At the same time, the Descent Advisor (DA) provides air traffic visualization support and advisories to carry out the arrival plan. A conflict probe assists in detecting and resolving potential separation violations ahead of time. We assume a TRACON facility equipped with CTAS's Final Approach Spacing Tool (FAST) that assists approach controllers to assign aircraft to runways as well as sequence and schedule aircraft onto the final approach to the runway.

Procedures

Procedures are used for coordination. In our concept FMS arrival procedures take aircraft from cruise flight along several altitude and speed restrictions to final approach intercept. Whenever traffic permits aircraft are cleared for an FMS procedure. Flight crews can request their most efficient flight path. Controllers can assign cruise and descent speeds to modify the flight path according to scheduling and spacing requirements. Flight crews are responsible to follow the resulting FMS trajectory. Controllers can monitor, evaluate and modify this trajectory using CTAS's accurate trajectory predictions at any time. Procedural coordination of FMS and CTAS trajectory computation functions enables operational use of the concept in a voice environment. If available, data link further supports the exchange of information to coordinate and synchronize the air and ground automation systems.

Data link

We believe that one of the most effective uses of data link is for communicating complex data sets between the FMS and ground-based automation. Our concept uses data link to communicate weather, route and speed information from the ground to the FMS and to send aircraft state, intent and preference information from the FMS to the ground [7].

For our 2010 environment we assume a mix of data link equipped and unequipped aircraft. If equipped, we assume that precise state information can be sent at one second (or better) update intervals and Controller Pilot Data Link Communication (CPDLC) is available.

PREVIOUS EXPERIMENTS AND EVALUATIONS

The CTAS tools, TMA and FAST, are already in operational use. The DA has been field-tested and its correct trajectory prediction and descent advisories have been demonstrated [3,5,11].

Data link functions are currently in use in the oceanic airspace, but these are still somewhat complicated and error-prone[6]. Furthermore, data link transmissions can suffer from significant delays.

Several experiments have been conducted at NASA's Ames and Langley Research Centers.

A full mission study on pilot interfaces and procedures was conducted at Ames in 1998 to investigate different data link interfaces and FMS usage in the terminal area. Use of data link for FMS-loadable clearances and FMS usage in the terminal area were both found to be acceptable and operationally feasible. Findings also suggested that a Vertical Situation Display can help pilots use highly automated vertical navigation functions [8,9].

A second flight deck study at Langley Research Center focused on trajectory prediction and execution differences between CTAS and the FMS. FMS aircraft where capable of flying CTAS computed trajectories very precisely. Arrival time errors were significantly reduced compared to today's vectoring environment [11].

ARRIVAL SCENARIO

The concept is applied to our arrival problem as follows: Aircraft arrive at the center's airspace on "free-flight" type random routes, direct routes or in-trail. The ground automation (CTAS) estimates feeder fix arrival times for these aircraft. During a rush, several aircraft may be predicted to reach the feeder fix at the same time. The TMA automatically creates an initial sequence for these aircraft, taking all airport flow control constraints into consideration. A "planning" controller evaluates this sequence and interacts with the TMA and the conflict probe to adjust the flow for spacing and scheduling purposes. This task is supported by the DA function, which assists the controller in creating flight paths (route and/or speed modifications) that meet the scheduled time at the feeder fix. If no significant delay has to be absorbed (~5 minutes or less), an early modification to the aircraft's cruise speed and perhaps its descent speed is usually sufficient. This flight path modification is relayed to the flight crew, who sets up their FMS accordingly. An arrival clearance is given to fly the FMS computed path, and the aircraft automation is then used to follow the plan precisely. Pilots and controllers know when the aircraft will start to descend and where it will be at any given time. If aircraft are data link equipped, the FMS flight path is transmitted to the ground system then compared to the ground-predicted trajectory, and the controller is alerted to any significant discrepancies between the two predictions.

HANDLING THE ARRIVAL RUSH

At least four controller positions manage one arrival flow: three in the center, and one in the TRACON. Center positions include an "area planner" (a new position created for this study) and high and low altitude sector controllers. For the runs that focused on center operations, one TRACON controller was responsible for the terminal area, and all aircraft landed on the same runway. All center positions are equipped with a TMA timeline, a conflict prediction list, access to the DA advisories and a trajectory preview tool that allows controllers to quickly "dial out" the predicted traffic situation to any given time in the future. A center controller display example is given in figure 1. The Final Approach Spacing Tool (FAST) is used to assist the TRACON controllers in feeding and controlling the subject aircraft to two different runways.

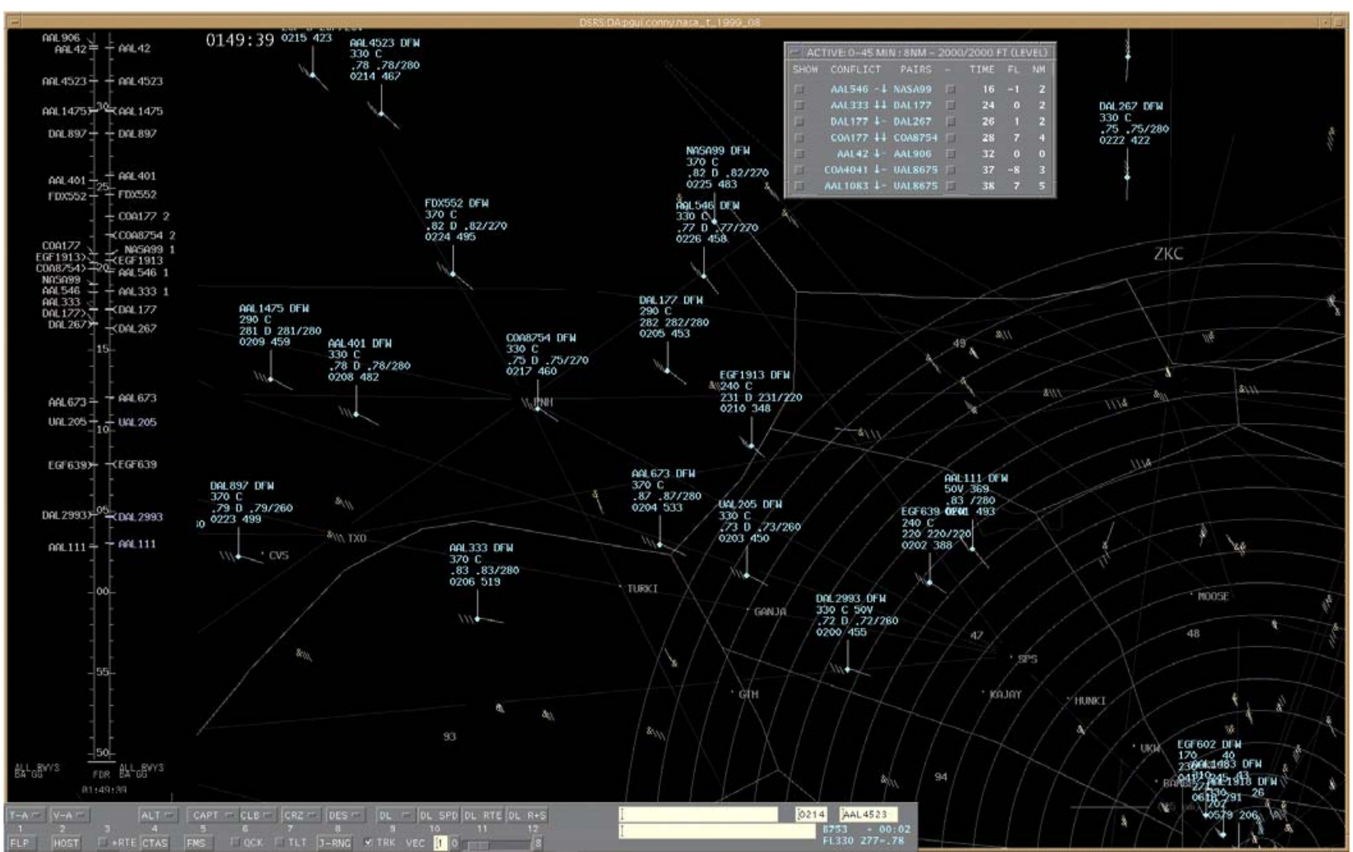
Scheduling and Planning

One of our Center controllers is an "area planner" who acts as a link between traffic management and the sector positions that control the arrival traffic. The planner is responsible for scheduling and conflict-free flight path planning, but is not responsible for separation.

All aircraft enter the scenario filed for their most efficient routing to "UKW", a coordination VOR near the metering fixes that serve the northwest arrival flow in our simulation. Approximately one hour before touchdown the TMA automatically generates an estimated arrival time for each aircraft and creates an initial schedule for any given runway and meter fix. The area planner evaluates the schedule and coordinates with dispatch and traffic management for necessary modifications. The planner uses the timeline to compare between estimated and scheduled meter fix crossing times for the arrival traffic and to modify the TMA schedule. The planner also tries to create conflict free flight paths for these aircraft to the metering fix. This is done by using the CTAS descent advisor tools to adjust routing, cruise and descent speed such that the aircraft will meet its scheduled time without creating a conflict with another aircraft. Any adjustments to the assigned airspeeds or arrival routing are relayed to the aircraft by voice or data link and stored in CTAS, thus specifying the arrival flight path to both the flight crew and 'downstream' controllers.

Controlling the High Altitude Sector

The first and most important responsibility of the high altitude sector controller is to maintain separation. The second priority in our scenario is to maintain the schedule and execute the plan created by the planning controller. When the high altitude controller detects a discrepancy on the timeline between the estimated and the scheduled time of an aircraft, he or she can request a new descent advisory from CTAS to adjust the speeds accordingly. If the high altitude controller feels comfortable that the execution of a flight path for a certain aircraft will not create a separation violation, he or she issues the FMS descent clearance. The clearance is phrased "AC123 descend via the UKW FMS arrival at XXX knots" and clears the aircraft to start to descend at the FMS computed Top of Descend location with the given descent speed. This is not a pilot discretion



descent, which would be unacceptable in an arrival rush situation. The FMS descent clearance allows the controller to view the ground-computed and, for data link equipped aircraft, the FMS-computed Top of Descent location to maintain awareness of the descent profile.

Controlling the Low Altitude Sector

The controller's responsibilities in the low altitude arrival sector are very similar to today's operations: maintain separation and deliver the aircraft in a reasonable state to the TRACON. The low altitude controller uses the same tools as the high altitude controller to assess the arrival plan, and can also request speed advisories to fine-tune the meter fix arrival times. If the controller does not feel comfortable with the current situation and speed control seems insufficient, he or she can vector a problem aircraft off the FMS arrival at any time, then either continue to clear the aircraft using vectors, or instruct it to rejoin the FMS arrival.

TRACON Portion of the Arrival

In the ideal situation the Center controllers are able to create and maintain an efficient arrival plan that accounts for flow and runway restrictions. In this case the TRACON controllers receive a near optimal feed from the Center with all aircraft in the (same) expected state at the metering fix. Our FMS arrivals include a TRACON portion and the option to add an FMS transition to a certain runway that specifies routing, altitudes and speeds to final approach. The TRACON controller can clear aircraft for this transition and later for the (usually ILS) approach. More details on TRACON procedures can be found in [10].

Flight Crew Perspective

A flight crew flying an FMS and data link equipped aircraft arrives in our scenario at an airport on a preferred routing expecting an FMS descent. The flight crew uses FMS lateral and vertical navigation throughout the complete arrival until final approach. Approximately 45 to 60 minutes before touchdown the crew members receive a data link message including loadable descent forecast winds. They review and load those into their FMS. They also select the preferred descent speed, which is taken into account by the ground automation. Next the crew most likely receives a data link or voice message setting up the cruise and descent speed for the arrival portion of the flight. Having loaded these speeds into their FMS the crew members can see the estimated arrival time at the metering fix, which is unlikely to change any more. After switching the radio frequency to the high altitude sector the crew receives an FMS descent clearance by voice that restates the descent speed. This speed matches the previously uplinked speed, unless the controller needed to change it for spacing or re-adjusting the ETA. When transferred to the low altitude sector another speed adjustment may occur in certain cases by voice or data link. In the TRACON the crew receives a clearance to fly the FMS transition to the given runway. When the aircraft is near enough to the final approach, the approach clearance is received.

SIMULATION

A series of integrated air and ground simulations was conducted to demonstrate the feasibility of the approach, to identify open issues and to gather feedback and interaction data from controllers and pilots. Active center and TRACON controllers and airline flight crews participated in these simulations. The simulation layout is described below.

Two flight crew subjects participate in the research flight deck at Langley Research Center (LaRC), which represents a Boeing 757 aircraft with a commercial Honeywell Flight Management System that was slightly enhanced for the experiments. Up to 10 pilots at Ames Research Center control the aircraft of interest using the Pseudo Aircraft System (PAS), which also plays back prerecorded background traffic. The state data of all aircraft feed into the Aeronautical Data link and Radar Simulator (ADRS), which simulates today's noisy and alpha-beta tracked radar environment. The radar data are transmitted to the CTAS center and TRACON tools. Data link equipped aircraft downlink precise ADS-type information, which replace some of the noisy radar measurements on the controllers screens. Portions of the intended flight path are also downlinked and can be displayed. The controller can send FMS loadable data link messages to all equipped aircraft. The ADRS adds selected delay amounts to Controller-Pilot Data link Communication (CPDLC) and handles all format conversions as required.

Scenario Airspace and Traffic

Our simulation scenarios were based on the northwest arrival stream into Dallas Ft. Worth, which currently experiences at least two major arrival rushes every day.

The main scenario was derived from recorded traffic and weather data from a day with IFR conditions in spring 1999. All aircraft that arrived at the northwest gate during the main rush period were removed from the scenario, with the other aircraft converted into background traffic that could be played back using the Pseudo Aircraft System (PAS). New aircraft were inserted into the scenario to represent the north west arrival stream. These aircraft arrived on 'free-flight' direct or random routes. Traffic loads in different scenarios ranged from moderate to more than current day peak rush demand. In the first set of simulations no significant restrictions were imposed on the TRACON in terms of runway or meter fix acceptance rates. Figure 1 shows a typical arrival scenario. All arriving aircraft have been cleared direct to the gate (UKW) and to follow an FMS arrival procedure into the TRACON. This results in numerous overlaps of estimated arrival times at the metering fix and conflicting routings on their way.

Test Sessions

Each session took three days for the controllers and one day for the flight crew. The center controllers were trained for one and a half days on the CTAS tools and FMS arrival procedures. After the initial training they were capable of handling a moderate arrival rush that can be compared to most rushes today. However, at this point the controllers were still learning how to effectively use the interface and the tools, and continued improvements in controller performance were observed throughout all simulation runs. Four data collection scenarios were run during the last two days of each session.

OBSERVATIONS AND OPINIONS

This section describes our preliminary observations and opinions regarding the success and effectiveness of the concept as observed in our simulation runs. A subsequent paper is planned to provide objective performance data and subjective workload and questionnaire results.

All subjects stated that the overall concept is very promising and bears a great potential for improving traffic flow into, out of, and across congested areas.

When it Works, it Works Well

After three days of training and simulation runs, participant controllers were capable of handling complex arrival rushes that included approximately 150% of the prerecorded arrival traffic rush from which the scenarios were modeled. In these scenarios typically 40 aircraft landed on one runway within 45 minutes.

In several runs, the three center controller participants (Planning, High, and Low sectors) successfully handled the arrival traffic flow. During these runs, the majority of aircraft received FMS descent clearances and benefited from almost undisturbed descents into the TRACON. The planning controller was able to create a feasible, conflict free schedule and arrival plan. This set up the high and low altitude sector controllers to execute this plan by issuing the FMS descent procedure and appropriate descent speed to each aircraft. Center controllers then made fine adjustments to maintain the arrival plan and ensure aircraft compliance during the descent. Most aircraft arrived at the metering fix within 15 seconds of their scheduled time and a near optimal TRACON feed was provided without imposing extensive workload on the controllers.

…But the Strategic Plan May Fall Apart

In some runs controllers reverted to tactical control of the traffic. The strategic FMS arrival plan was disturbed or even fell apart. Successful implementation of the arrival plan is very sensitive to good planning and aircraft compliance with the planned flight path.

Arrival planning

The role of the arrival planner became increasingly important with the complexity of the arrival rush. The planning job required very good skills in traffic management and control, and proficiency with the tools. Arrival plans that set up aircraft well within their performance limits and used similar descent speeds among aircraft were generally easier to handle for downstream controllers. Also, passing situations during altitude changes tended to make sector controllers uncomfortable. If the plan did not provide sufficient comfort for the sector controllers, they were likely to change it or not execute it.

Aircraft non compliance

Aircraft that did not comply with their clearance or did not receive the descent clearance on time often caused significant problems for the controllers in implementing the arrival plan. Because of the use of high-energy FMS descents, non-compliance or late descents typically required controllers to vector the problem aircraft to meet the TRACON restrictions. In some runs the controllers tried to maintain the sequence of aircraft over the metering fix and vectored all aircraft trailing the problem aircraft. This takes all aircraft off their FMS arrivals and requires complete reversion to current day vectoring procedures, collapsing the arrival plan. Other controllers vectored the problem aircraft out of the arrival stream and did not vector the trailing aircraft. They then created a new slot and re-inserted the problem aircraft into the arrival stream. This technique maintained the integrity of the overall arrival plan and only affected the problem aircraft.

Compression

One problem of FMS arrivals is the increased compression effect created by high-energy FMS descents. In today's environment controllers adjust speeds and altitudes step by step to maintain consistent states between aircraft. However, aircraft performance on idle FMS descent profiles varies significantly by aircraft type, weight and descent speed. Hence, two aircraft that appear to follow each other with sufficient separation at the same indicated airspeed may soon lose separation, if the leading aircraft is not as efficient as the trailing one (like a B757 following a B737). This adds 4 dimensional complexity to the task non-existent in today's environment where all arriving aircraft in the same region fly at the same altitudes and speeds.

Frequency Congestion

One of the main advantages of the concept is the significant reduction in frequency congestion. Less radio communication was observed and will likely hold true in any actual data collection experiments. The strategic FMS clearances eliminated the need for most tactical clearances, like headings and altitudes. These observations and controller and pilot opinions indicate that this helps resolve frequency congestion problems in today's ATC environment. Use of data link can further decrease frequency congestion.

Data Link

Data link in this concept needs to be viewed from several angles. Even though the concept does not require the availability of data link per se, the passive data exchange aspects seem to be very helpful. The availability of CPDLC seems to be a nice feature to have rather than a requirement.

ADS-type Downlink of State and Intent Information

Controllers indicated and observations confirm that having reliable ADS-type downlink of precise state and intent information constitutes a significant help and has many positive effects. Controllers were willing to run aircraft closer to their separation minimum knowing that the displayed information about position and velocities was precise and reliable. They could also verify that the FMS computed Top of Descent point and routing matches what was computed by the ground automation. The ground automation could more precisely predict an aircraft flight path having the data link information available.

Uplink of Weather Information

The uplink of descent forecast winds, temperature, and pressure into the aircraft does not require any controller action and imposes only few additional actions on the flight crew. It harmonizes the CTAS and FMS models of the current atmosphere and thus enhances the flight path predictions on both sides. This step is very important and no negative side effects were observed or reported.

CPDLC Communication of Routing and Speeds

In general, controllers and pilots felt comfortable using CPDLC for FMS-loadable clearances. The available message set consisted of a new routing, new cruise and descent speeds and a combined message for routing and speeds. It was considered very helpful to be able to uplink a new routing to the aircraft instead of issuing several vectors. However, the trial plan function on the ground side invoked for creating a new routing was considered clumsy and difficult to use, so that controllers preferred to use vectoring in time-critical situations. Controllers stated different opinions and showed different behavior for issuing cruise and descent speeds via data link. Some liked it because it cut down on verbal communication and was easy to use. It was in fact so easy to use that controllers sent more speed updates to the aircraft than they would have issued by voice, causing some confusion in the aircraft. Other controllers did not like to have to wait for the data link response, which is delayed compared to the immediate readback they get in the voice environment. They stated that having to continuously monitor the data link status indication in the data block was an additional task, whereas by using voice they did not have to closely monitor the aircraft for a while after giving the instruction.

AUTOMATION SHIFT FOR CONTROLLERS

The shift between manual flight control and automated flight management in modern aircraft has been discussed and researched in depth. Flight crews already use a very high level of automation in their aircraft while controllers still manually control airplanes. Our 2010 scenario requires controllers to use and trust the automation in the aircraft and on the ground. Similar automation issues arise for controllers as for flight crews. These include the potential for mode confusion, clumsy entry procedures, and problems with shifting between tactical and strategic control. Controllers were asked to move from controlling the traffic in their own sector exclusively, to planning flight paths for downstream sectors and executing plans from upstream sectors. The controllers were comfortable using the automation, procedures, and phraseology presented in the simulation. However, we observed that reverting from use of automation to manual control caused problems and is an issue that needs to be addressed.

The controllers were enthusiastic to see new technologies supporting new tasks and challenges. For example having the timeline with scheduled and estimated times available on the controllers' screen was consistently ranked extremely useful. The concept and the tools were said to encourage teamwork and looking beyond an individual controller's immediate traffic situation. This is underlined by our observations that when teams coordinated more than usual between sectors, they planned and handled the traffic more smoothly and precisely.

CONCLUDING REMARKS

The overall concept of utilizing air and ground automation in an integrated arrival environment appears very promising and worth pursuing. The integrated simulation of air and ground side technologies revealed several open issues that need to be addressed in future studies. We will conduct controlled experiments in summer 2000 to evaluate the benefits and problems of the concept more thoroughly.

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