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Human Factors Integration Challenges in the Traffic Flow Management (TFM) Environment

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13. ABSTRACT (Maximum 200 words)

This report discusses a high level examination that was conducted to identify human factors issues in the integration of future traffic flow management (TFM) tools. The focus of the examination is on the integration of future systems and was driven by the desire to benefit TFM Modernization (TFM-M). Although a high level examination does not address system requirements per se, some requirements are recommended in the text of this report. Information for this report was gathered from published sources, discussion with individuals who are developing new traffic management tools, and facility observations.

The issues that were found and discussed in this report are general, and only refer to current and proposed systems to illustrate human factors work that should precede integration decisions. The discussion includes issues related to decision support for weather constraints, demand estimation enhancements, decision support for traffic flow management initiatives, and communications and logging. The report addresses issues related to arrival management including time-based metering, the management of airport surface and departure traffic, and "what if" or trial-planning tools.

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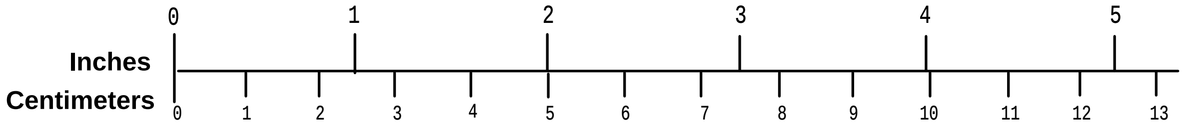

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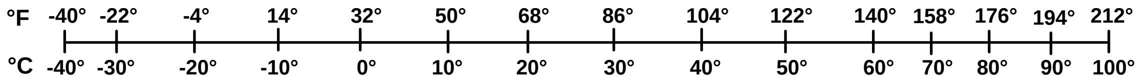

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PREFACE

The Federal Aviation Administration (FAA) Human Factors Research and Engineering Division sponsored this study. The author wishes to thank Alan Yost, colleague, pilot, and former air traffic controller for assisting with the collection and interpretation of the observational data, and to Dino Piccione of FAA ATO-P R&D and Dr. Kim Cardosi of the Volpe National Transportation Systems Center (Volpe Center) for reviewing an earlier draft. The author also wishes to express his appreciation to the many traffic managers who welcomed us to their facilities, permitted us to observe their work, and took the time to discuss the equipment that they use. Thanks are due to the traffic management professionals at Boston, New York, Indianapolis, Memphis, Oakland, and Los Angeles ARTCCs, Boston, Southern California, Northern California, and Atlanta TRACONs, Boston, Memphis, and Atlanta ATCTs, and at the ATC System Command Center. The author also wishes to express his gratitude to Mark Marchese of the TFM Product Development Team for coordinating these visits. Valuable suggestions about the human factors information that would benefit TFM Modernization were offered by Daniel Horton and Ahmad Usmani of the TFM Product Development Team and Dr. Tanya Yuditsky of the FAA Hughes Technical Center. The author is grateful to many researchers at the FAA Technical Center, NASA Ames Laboratory, and MITRE who provided documents and helpful discussions of their work. Marilyn Gross of the Volpe Center's Technical Reference Center provided expert guidance on referencing the wide range of materials cited in this report.

TABLE OF CONTENTS

Section **Page**

LIST OF TABLES

Table **Page**

EXECUTIVE SUMMARY

A high level examination was conducted to identify human factors issues in the integration of future traffic flow management (TFM) tools. Its focus on the integration of future systems was driven by the desire to benefit TFM Modernization (TFM-M). Although a high level examination does not address system requirements per se, some requirements are recommended in this report and the highlights of those recommendations are provided at the end of this executive summary. Information for this report was gathered from published sources, discussion with individuals who are developing new traffic management tools, and facility observations.

The issues that were found are general ones and only refer to current and proposed systems to illustrate human factors work that should precede integration decisions. The discussion includes issues related to decision support for weather constraints, demand estimation enhancements, decision support for traffic flow management initiatives, and communications and logging. It addresses issues related to arrival management including time-based metering, the management of airport surface and departure traffic, and "what if" or trial-planning tools.

In the area of decision support for weather constraints, the study re-emphasizes the Operational Evolution Plan guidance that states that improving the dissemination, display, interpretation, and application of forecasts is as important as improving the forecasts themselves. Forecast products should be unambiguous in their operational significance and located in the traffic manager workstation. Measures of likely route capacity in weather-impacted regions are thus preferred to the display of bounded areas such as convective polygons, which may be misinterpreted as "no fly zones." Interpretation errors are likely when the traffic manager must consider several pieces of information on a cluttered display while working under time pressure. Nonetheless, traffic managers are better able to determine the significance of forecasted weather than automation. The human factors objective is to present the traffic manager with the required information in an immediately usable format.

Displays intended for tactical air traffic control should remain available to traffic managers so that they can continue to use them to identify gaps for departures to enter the overhead traffic flow and to monitor sector workload. It may be beneficial to expand their range to include more airspace so that gaps can be identified farther away. The issues that once pertained to over-capacity alerting appear to have been resolved, although facilities vary somewhat in how they respond to these alerts. It is important to maintain the distinction between red and yellow alerts that are found in the Enhanced Traffic Management System (ETMS) Monitor Alert when integrating enhanced functionality because it indicates whether the over-capacity condition is very likely (red) or only somewhat likely (yellow) to occur, and whether the condition can be addressed by holding aircraft on the ground. Traffic information presented to the control room floor should not conflict with the information provided to the Traffic Management Unit (TMU) when it is intended to support the same functions (i.e., assessment of sector workload and the need for traffic management initiatives).

Several human factors issues were found with Traffic Management Advisor (TMA), an arrival management tool associated with time-based metering. Traffic managers indicated that there are

substantial limitations in the circumstances under which the tool provided usable metering sequences and times. When a traffic manager changes the airport arrival rate, the controllers' metering list "ripples" and can alter the previously assigned metering fix sequence and arrival times. As a result, traffic managers remove the metering list from controller workstations prior to the ripple. TMA thus has the potential to inhibit dynamic arrival rate adjustments resulting in a lower arrival rate than would occur without arrival management. Time based metering requires additional effort from Air Route Traffic Control Center (ARTCC) controllers who must adhere to a more constrained metering fix arrival schedule. However, the additional effort invested does not result in a positive return for the same facility. Instead, it benefits the traffic flow into an underlying Terminal Radar Control (TRACON), circumstances which the ARTCC controllers may perceive as unfair. A benefit claimed for TMA is that its aircraft timelines will permit facilities to take actions that improve the inter-facility traffic flow without explicit coordination. This claim is also made for Surface Management System (SMS), an airport and departure management tool that also provides timelines. Although workload reductions could occur as claimed, so could situations where the two facilities take incompatible or duplicative actions. The deployment of TMA and SMS should not result in eliminating current coordination procedures prior to an examination that would ensure that incompatible or duplicative actions do not occur.

Potential issues were identified for efforts aimed at enhancing airport and departure flow management. Two current systems (Departure Spacing Program or DSP and Airport Resource Management Tool or ARMT) require controllers to manually swipe bar coded flight strips to indicate when a flight receives its taxi clearance, after it begins to taxi (DSP), and after it joins the runway queue. Doing so briefly diverts the controller's eyes from scanning the airport surface, and the procedure is potentially subject to delay or omission, particularly when controller workload is high. Despite their limitations, these systems provide useful information and assist traffic managers with introducing traffic into some of the busiest and most complex airspace in the National Airspace System (NAS). SMS uses automated surveillance to provide a table of the earliest possible departure times for aircraft that are included in call-for-release programs. It requires more mental effort from traffic managers than a system like DSP that assigns departure windows to the flights. However, it reduces workload and head-down time while providing more continuous information compared to the manual procedure. SMS relies on historical averages in predictive modeling to support configuration change decisions. It is recognized that using averages introduces uncertainty that would be added to the uncertainty associated with pushback times, possibly reducing the effectiveness of the decision support. SMS offers trial planning for arrival/departure tradeoffs, relying on the traffic manager to manually adjust the airport arrival rate. However, adjustments to the arrival rate can reduce the use of TMA (and vice versa) setting up a potential conflict between these tools.

Trial planning tools offer traffic managers the option to see the modeled effects of initiatives before they are implemented. If, for example, an ARTCC and the Command Center prefer different initiatives, trial planning offers a comprehensive way to compare their likely results, facilitating collaboration. They also offer a way for an individual facility to compare alternatives. One issue is that trial planning requires time. It would be useful to know how much time traffic managers take to examine alternative parameters for ground delay programs in Flight Schedule Monitor (FSM) as this would roughly indicate the time available for other types of trial planning.

To minimize planning time, the tool may itself recommend one or more solutions. Trial planning tools have two particularly important sets of information requirements, especially those that automate complex cognitive functions such as planning a traffic management initiative. First, traffic managers need the information required to evaluate the recommended initiative. In general, this would include the display of pertinent information about the current unmodified situation and about the proposed solution(s). Second, they need the information required for task performance without automation (manual reversion). Thus, there are capabilities that must be preserved from the pre-automated functionality.

Traffic management initiatives often require considerable communication and coordination to plan, propose, implement, monitor, modify, and bring to a close. Human factors issues include disseminating initiative status to affected facilities in a timely manner and traffic manager workload. The National Traffic Management Log (NTML) has begun to address these issues, although additional connectivity and functionality are required for it to serve as the single point of data entry for NAS traffic management data. The NTML user interface requires functionality to format information for reporting and simplification to reduce the workload associated with frequent traffic manager entries. More needs to be known about the communication and coordination associated with particular types of initiative to guide its further development along the most beneficial path.

The human factors challenges to human-system integration for TFM Modernization are to continue to identify and resolve human factors issues, some of which are mentioned in this report, and to best utilize the available human factors capabilities and resources. Thus, the first challenge is to ensure that information requirements have been fully assessed and that the plan for Human System Interface (HSI) integration will fulfill the site-specific requirements for information and information flow. The second human factors challenge is to ensure that the workload and performance of traffic managers and controllers are assessed during human factors evaluations along with system performance and user acceptability. The third human factors challenge for TFM integration is to apply human factors principles and findings from empirical studies to decisions regarding the requirements for the integrated system.

In addition to the communication study mentioned above, another direction for human factors information development that would meet near term needs is a human-system interface standard for controls, color, symbols, and other graphic devices in traffic management workstations. The standard would permit developers to design future tools that are consistent with TFM-M, promote the best decisions, and incorporate limitations for individual preference sets that discourage errors.

Highlights of Recommended Requirements

Recommended Requirement	Business Case
Decision Support for Weather Constraints	
Make all weather information, including prototypes, available to TMC workstations	Safety and Capacity
Display capacity effects of weather if automation is accurate, otherwise assign to TMC	Capacity
If automation cannot clearly designate a route as open, it should designate the route as closed	Safety
Demand Estimation Enhancements	
Retain distinctive coding for Monitor Alert distinction between active and proposed flights	Capacity
Provide the same Monitor Alerts to area Operational Supervisors as are available in TMU	Capacity
Retain tactical traffic display capabilities including “See all” in TMU	Safety and Capacity
Decision Support for TFM Initiatives	
Evaluate controller and TMC workload and “implicit coordination” before TMA-MC, SMS integration into TMC workstations	Safety and Capacity
Evaluate effect of AAR adjustments (e.g., from ADTOT, SMS) on TMA list “rippling” and vice versa before TMA-MC, SMS integration into TMC workstations	Safety
Integrate automated SMS position data with DSP display of departure window, ARMT features	Capacity
Trial planning tools require large display to show current situation and proposed solutions at same time	Capacity
Provide for sharing of displays of graphical trial plan effects among facilities and between TMC and Operational Supervisors	Capacity
Retain all functionality required for manual formulation of initiatives and evaluation of trial plans generated by automation	Capacity
Communications and Logging	
Provide for simplified NTML data entry	Capacity
Add NTML capability to send TMC decisions to controllers in all types of facility and incorporate means for acknowledgement of receipt and understanding of routine messages	Capacity

1. INTRODUCTION AND SCOPE

The purpose of this study is to provide a forecast of human factors issues that may affect the integration of current and new traffic flow management (TFM) subsystems into air traffic control facilities. This is a high-level study intended to draw attention to human factors challenges for the Federal Aviation Administration (FAA) that may require further consideration or additional study. By identifying potential issues in a timely manner, this study may permit their resolution without adverse schedule consequences. As requested by FAA/TFM Development, the emphasis is placed on the future TFM system so the results may benefit the TFM Modernization (TFM-M) effort that is currently underway. For this reason, integration within systems that are under continual development such as Enhanced Traffic Management System (ETMS) is excluded from this examination. Information that may prove to be useful in the development of TFM-M contractual requirements and recommendations will be provided as part of this effort, but this high-level study cannot substitute for the thorough and detailed human factors analysis needed to establish requirements for the TFM-M contract. In this high-level study, current TFM tools are discussed to illustrate potential benefits that may be achieved through the integration of future tools. Recommendations to display or transmit information are made solely with respect to the usefulness of the information to the air traffic and traffic management personnel for whom the information is intended. Topics that this study does not address include information or airspace security and systems intended for non-FAA users.

The emphasis in this study is on tools that support real-time operational decision-making. The legacy TFM system is ETMS with the added capabilities of the Flight Schedule Monitor (FSM). Functionality present in the ETMS Traffic Situation Display (TSD) version 7.8 and FSM version 1.8.7 is considered the “current ETMS/FSM legacy system”. Human factors issues related to integration involving the Route Management Tool (identified in Federal Aviation Administration, 2003a as a platform for the integration of new functionality), National Traffic Management Log, tactical traffic control displays, and flight strip General Information messaging, are considered to be within scope. Existing tools of limited deployment and new functionality at any stage of technological readiness are also included. This study is not intended as an evaluation of any particular existing or future tool or enhancement, nor does it contain sufficient guidance on how they should be integrated. It is only intended to identify and describe human factors issues that require further attention for successful TFM system integration. Programmatic goals of enhanced safety and efficiency require satisfactory performance from human operators.

Descriptions of systems used in this report were derived from published reports and government documents. Operational experiences were obtained from published reports and discussion with traffic management experts at the following FAA facilities: the Air Traffic Control System Command Center (ATCSCC); the Boston, Indianapolis, Memphis, Oakland, Los Angeles, and Atlanta Air Route Traffic Control Centers (ARTCCs); the Boston, Northern California, Southern California, and Atlanta Consolidated Terminal Radar Approach Controls (TRACONs); and the Boston, Memphis, and Atlanta Air Traffic Control Towers (ATCTs).

2. SYSTEM INTEGRATION ISSUES

Traditionally, the human factors issues that need to be considered when planning for system integration involve the human-system interface (HSI) for the new tool within the legacy system and any modifications that need to be made to the legacy system HSI to accommodate the new tool. Human factors planning for system integration begins with analysis of information needs and information flow requirements. The information required for TFM varies with the type of facility and the characteristics of the airspace for which it is responsible. Information flow includes communications with operational supervisors (or directly with controllers in tower traffic management units or TMUs), meteorologists, TMUs located in other facilities, the ATCSCC and airspace users. While this distributed information network imposes additional human factors requirements for system integration, many requirements remain focused on the individual traffic management coordinator (TMC) workstation and tools shared among workstations. In addition, human factors issues with the integration of a new tool can arise from organizational functions such as staffing and training, from the differing TMU physical layouts found in various facilities, and from its effects on perceptions of fairness and equity.

The effectiveness with which a new tool or function is integrated into an individual workstation affects the usability of the tool (and thus its contribution to system performance), the amount of workload required to use it, job satisfaction for the TMC or traffic management specialist (TMS), and hence its acceptance. The key to its integration lies in its effect on the strategic and tactical information processed to perform TFM responsibilities. In particular, questions that need to be addressed in the integration of a new tool into individual workstations include:

- If integration results in removal of superceded equipment from the workstation, does the new tool provide all of the information capabilities (information manipulation, display, and communications) that were taken away?
- If a new tool provides information that duplicates or is similar to information already available in the workstation, does the new tool provide substantially better (e.g., more accurate or more timely) information?
- Does the new tool impose mental or physical workload or increase communication or logging requirements? If so, is there a positive return on the additional effort?
- Does the information provided by the new tool require a separate display for constant availability, or can traffic managers select the information from a menu when it is needed for temporary display?
- Does the new tool automate capabilities that humans perform better, or vice versa?
- Is the information that the new tool provides compatible with other information available in the TMU? If not, is comparison of potentially discrepant information useful or will it create confusion?
- Is the information that the new tool provides tailored to the specific type of facility and yet consistent with the information provided to controllers, airspace users, and other facilities?

Each of these questions will now be described in more detail as a prelude to the following section, which will consider human factors issues related to the integration of specific TFM tools and enhancements.

If integration results in the removal of superceded equipment from the workstation, does the new tool provide all of the information capabilities (information manipulation, display, and communications) that were taken away?

Removal of superceded equipment opens TMU space for better use, and the integration of the replacement capabilities can improve proximity, thereby improving accessibility and frequency of use. On the other hand, a prerequisite to the integration of the new capability is the identification of any components of the legacy system that the new tool will replace. This requires knowledge of how both the new and superceded tools are used, and TMCs may use the tools differently. Identifying the functionality of the legacy component is necessary because the new tool needs to provide the capabilities of the superceded equipment that TMCs found useful. This can include capabilities for the manipulation of information as well as the information itself. A second reason for understanding how the superceded tool was used is to compare workload. If the new tool imposes more workload to complete some of the same tasks, the workload must fall within limits set by the operational situation, and increased effectiveness or some other performance benefit should be present to justify the increase in workload.

If a new tool provides information that duplicates or is similar to information already available in the workstation, does the new tool provide substantially better (e.g., more accurate or more timely) information or impose less workload?

Acceptance and trust in new tools and related new procedures can increase or decrease as the tools are used in an increasingly wide variety of circumstances. For example, the Arrival Sequencing Program (ASP) introduced many to time-based metering (TBM) for arrival traffic. However, some controllers found it difficult to use, and this may have resulted in skepticism regarding TBM that transferred to the Traffic Management Advisor (TMA), an improved TBM program. Initial low levels of acceptance for TMA at some ARTCCs may have resulted in part from experience with the earlier program resulting in TMA needing to show that it is substantially better to gain acceptance. Finally, it should be noted that in some cases it is desirable to retain redundant functionality and equipment for back-up use in case the new tool fails or must be placed temporarily out of service.

Does the new tool increase mental or physical workload or increase communication or logging requirements? If so, is there a positive return on the additional effort?

Tools that are intended to increase capacity in the National Airspace System (NAS) can increase workload at some facilities while decreasing workload at others. For example, some tools may increase workload for ARTCCs and decrease workload for underlying TRACONs. Other systems may increase workload at towers and benefit centers. Despite evidence of increased system productivity, the increased effort of the controllers may not yield a perceptible positive return for their own facility. This violates a rule of fairness, that there should be a return on the effort invested. Even though ARTCCs and their underlying TRACONs and towers are interdependent systems, changes to procedures that yield benefits to other facilities are not always perceived as justifying increased effort at one’s own facility. Since controller acceptance of a tool is critical to its effective use, lack of acceptance of traffic management tools can become an issue for TMUs.

Does the information provided by the new tool require a separate display for continuous availability, or should traffic managers select the information from a menu when it is needed for temporary display?

Several issues can arise from the decision to either integrate additional information with that which is already on a legacy system display or present the information on a separate display. For example, the single display solution can create display clutter, causing information to become less available so important events are missed. On the other hand, comparison of multiple sets of complex information can impose unacceptable information processing requirements or memory load on the user, if they cannot be simultaneously displayed. The separate display solution requires additional space and attention to the sequence of information use so that information used in sequence is appropriately positioned on the display and in the workstation. These information display decisions need to be made in the context of the specific information to be displayed with consideration of how the information will be used.

Does the new tool automate capabilities that humans perform better?

Much of the new TFM functionality that has been proposed for integration would increase the extent to which traffic management coordinator (TMC) tasks are automated by aggregating complex data into meaningful displays that support TMC decision making. Automation is often applied in situations where human error is thought to contribute to inefficiency, risk, or where automation is able to reduce excessive human workload. While the automation may in fact perform “as advertised” (as is assumed in this study) unintended consequences arise due to failing to take into account all of the situations where a TMC will apply the tool. It is also important to understand how the automation will affect the roles and responsibilities of TMCs. For example, if TMCs no longer have access to information needed to evaluate decisions that the automation recommends, then they will be reluctant to assume responsibility for those decisions. It would be preferable to provide sufficient information to the TMC to check the automated solution and revert to manual operation when necessary.

Is the information that the new tool provides compatible with other information available in the TMU? If not, is the comparison of potentially discrepant information useful or will it create confusion?

TMCs need to understand the accuracy of the information that they use. Thus, it should be clear whether different tools provide independent information. To illustrate this point, TMCs compare convective weather forecasts from different sources. Agreement among forecasts is regarded as indicating better reliability. However, this conclusion could be erroneous if the forecasts originate with interpretations of the same meteorological model’s output. For example, both the Weather and Radar Processor (WARP), and the vendor-supplied convective weather radar mosaic shown on the ETMS Traffic Situation Display (TSD) are derived from the same Base Reflectivity products (Robinson et al., 2002).

Is the information that the new tool provides integrated in a manner most appropriate for the particular type of facility and yet consistent with what is provided to other facilities, controllers, and airspace users?

Collaborative decision making (CDM) that makes use of a “common situational awareness” is stressed in recent plans for en route congestion management. For example, the FAA (2003b) suggests that the “common situational awareness of a predicted congestion area shared by the customer and service provider can reveal means to collaborate on mitigation of the constraint.” Similarly, participation of traffic management officers (TMOs) at ARTCCs and TMSs at the ATCSCC can benefit from a shared understanding of the predicted situation. However, each party requires additional information that differs from what the other party needs. The Command Center needs information to formulate a plan to optimize national airspace efficiency whereas an ARTCC needs information to best utilize its own airspace resources. Human factors issues can develop out of attempts to balance requirements for shared information and information specific to each party’s unique capabilities and responsibilities.

3. FUTURE TFM TOOLS AND INTEGRATION CHALLENGES

Many enhancements and additions to the traffic management tool set are under development and there are also proposals for integrating tools that currently exist. It is assumed that the following enhancements will either be integrated within ETMS or into TMU and Command Center workstations as standalone consoles.

- Weather forecast products that are more accurate or better suited for traffic management
- Enhanced estimation of traffic demand, including trajectory modeling
- Arrival management tools
- Airport and departure management tools
- Trial planning tools
- Communications and logging

TFM uses demand and constraint forecasts to decide on the imposition of traffic management initiatives. Improved weather constraint information and decision support tools (DSTs) for weather-related initiatives have been proposed. Enhanced demand prediction includes better trajectory modeling and departure time information. If monitoring of constraints and demand suggests that capacity will be exceeded, then a traffic management initiative may be planned. TBM, a more precise form of traffic management, is currently undergoing implementation supported by TMA, an arrival spacing tool. Other tools have been developed to expedite traffic movement through some of the busiest and most complex terminal areas, but have not been integrated with ETMS or implemented on a wide scale. Trial planning tools assist traffic managers in predicting the consequences of proposed initiatives. Human factors issues related to volume of communications that can be required for traffic management have been addressed in the National Traffic Management Log. These additions to the traffic management toolbox promise to assist TMCs in making better decisions about initiatives and traffic restrictions. Each project benefits based on its optimal use. However, these benefits can only be realized in actual operations if the enhancement is integrated into the TMU or Command Center workstation in a manner commensurate with human limitations and capabilities.

3.1 DECISION SUPPORT FOR WEATHER CONSTRAINTS

Weather forecasting is a critical function in traffic management. This is evident in the variety of weather products that are available in TMUs on separate displays and on the TSD. It is also clear from the regular briefings that National Weather Service meteorologists in Center Weather Service Units (CWSUs) provide to the ARTCC TMUs and from the meteorological support that is available to all traffic management units. The accessibility of meteorological advice to traffic managers varies, however. It is most easily accessible at the Command Center. Center Weather Service Units are separate from the TMU and the distance between CWSU and TMU can lead to decision making without a meteorologist’s advice even in emergent situations where the TMC would prefer to receive their input. This proximity issue in Centers, the time periods in which the CWSU is not staffed, and the lack of direct meteorological support in TRACON and tower TMUs increases the burden on displayed weather products for occasions when rapid decisions are required.

Considerable effort is being invested in better aviation weather forecast products for convection, icing, turbulence and other hazardous weather phenomena. However, as stated in the Operational Evolution Plan (FAA, 2002), “how these improved products are disseminated, displayed, interpreted and applied…is just as important as improving the forecast itself” (Federal Aviation Administration, OEP, EW-1). Forecasts should be displayed in a way that leads to correct interpretation and in a form that can be readily applied to support operational decision-making.

The positioning of a weather tool in the workstation can also affect its usability. The prototype Corridor Integrated Weather System (CIWS) provides convective weather depictions and forecasts for the growth and decay of storms over the Northeast Corridor. The CIWS is deployed as a stand-alone installation at ATCSCC, ARTCCs and at the larger TRACONs and towers in the region between Chicago and New York. Its use is credited with helping to keep routes open longer, with better support for reroutes, and with better handling of weather constraints at Center-TRACON borders, in comparison with established convective weather information and forecasts (MIT Lincoln Laboratory, October 2003). While the CIWS is installed with the bottom of the display approximately 3 meters high at Indianapolis Center, it is located within the TMU, and TMCs are able to view it without leaving their workstations. In contrast, it is located approximately 1 meter high in an aisle between workstation areas at the Command Center, and it is not usable from any workstation. A specialist at the Command Center commented that it would probably not receive much use until it becomes available on the TSD in the specialists’ workstations.

The assignment of accessible locations for separate tools requires different solutions for TMUs in towers, TRACONs, ARTCCs, and at the Command Center because of differences in how space is allocated to workstations and in how workstations are arranged. There are also differences in staffing and in the allocation of staff to positions among facilities of the same type (e.g., Center TMU positions can include coordinator or TMC-In-Charge, arrival, departure, metering, overflight, monitor/alert, reroute, en route spacing, weather coordinator, etc., but none include all of these positions). This variety of operational positions was developed to meet the particular requirements of each Center’s airspace, but it complicates the issue of proper locations for separate tools.

In addition to appropriate location in the workstation, other human factors issues should be considered to ensure an integrated system in which weather forecasts are displayed in a way that facilitates correct interpretation and decision-making. The decision of whether to code information using graphical attributes or text is a prominent issue because the large number of attributes that are relevant to TFM precludes coding all in a usable graphical format. For example, a survey was conducted on the use of the Collaborative Convective Forecast Product (CCFP). It found that “users were interpreting CCFP areas as no-fly zones, even when coverage was forecasted to be low (i.e., 25-49 percent of the area). This was attributed to the solid, opaque look of the CCFP convective areas. In fact, the survey identified occasions when air traffic was rerouted away from a CCFP polygon simply because it was there. The users did not realize that areas were low topped, low coverage, low confidence and would have had little impact on en route flights” (Sims et al., 2004). No information was provided on the survey items, results, or whether the misinterpretations actually reduced NAS capacity.

The survey findings resulted in consultation with human factors specialists who recommended changing the way that information was presented on the CCFP. They suggested modifying the convective coverage graphic presentation from different solid colors representing different coverage to different densities of fill in the convective areas, and changing the text box presentation of forecast confidence to a graphical presentation where levels of confidence are shown in different colors. These modifications are likely to facilitate better decision making because now both coverage and forecast confidence are displayed in the polygons representing convective forecasts instead of showing confidence in text boxes which are more subject to legibility issues on the TSD. In order to reduce TSD display clutter, the modified CCFP will also reduce the number of coded confidence levels from three to two (high confidence was rarely attributed to these multi-hour forecasts) and include a control to remove the text boxes. Future tools that will be integrated with TSD can similarly benefit from studies of how users incorporate the information they provide into their decisions, and how the human-system interface can facilitate the use of particular information attributes.

What conclusions can be drawn from the way in which users responded to the formerly solid yellow “low confidence” CCFP convective forecast polygons? Their responses may be typical of how humans react to operationally ambiguous information. The fact that convection was forecasted in a geographically bounded area appears to have outweighed the other, mitigating characteristics that were included in the forecast. Users may have assumed that if the weather would have little impact on aviation, then the meteorologists would not have included the area in their forecast. They may have interpreted low confidence to mean that worse weather with higher radar tops could develop. If a combination of confidence, coverage, growth, and tops would imply that the routes through the forecast area are passable (e.g., by flying above the tops), then the way in which the forecast is displayed should make that clear. If confidence is sufficiently low but the costs associated with a correct forecast are high, then perhaps the CCFP should suggest waiting until confidence increases before allowing flights to depart on routes through the forecast polygon (Masalonis et al., ND). When working under time pressure, users will often neglect to incorporate some of the available information into their decisions so the most important information should be conspicuous and presented in an operationally meaningful form.

In using a weather forecast product, a Center TMC must evaluate its implications for airspace and route capacity. One of the human factors challenges for future weather products is the display of what Boldi et al. (2002) call “‘regional’ penetrability: a measure of likely route capacity in a weather-impacted region.” Boldi et al. recognize that “time critical decisions [need] to be made in light of these forecasts with a minimum of meteorological interpretation.” The Route Availability Planning Tool (RAPT) uses an automated departure status prediction algorithm to determine whether a route will be passable when an aircraft reaches it. It classifies departure routes as clear, blocked, impacted, or unknown for each departure. Impacted routes are ones where the forecast storm boundaries only extend part of the way across a route. The TMC evaluates them using an animation loop showing the predicted movement of the aircraft and weather over time. However, impacted routes are operationally ambiguous: by declaring a route “impacted,” RAPT in effect tells the TMC that the automated support cannot determine whether or not to allow the departure to take off. As a result, “users often viewed the impacted status as either over-warning or under-warning, and had a difficult time interpreting the meaning of IMPACTED in the operational context" (DeLaura & Allan, 2003). This again illustrates the value of displaying information in a form that can be readily applied to support operational decision-making when the tool is integrated into a TMC workstation. If "regional penetrability" can be accurately determined, it should be presented, erring on the side of aviation safety.

The preceding studies of the CCFP and RAPT point to the higher-level issue of finding a meaningful way to assess the effects of weather on the capacity of airports, arrival and departure fixes, routes, and airspace sectors. Adding to the difficulties that can occur during the interpretation of forecasts and their route impacts, the effect of the same weather on regional penetrability may differ in terminal and en route airspace. In an analysis of flights near Memphis ARTCC and Memphis International Airport, Rhoda et al. (2002) obtained results suggesting that, "pilots almost never penetrated level 2+ precipitation in the en route regime whereas they penetrated it hundreds of times in the terminal." Furthermore, in the present study, an Atlanta Center TMC said that he would seldom consider the routes leading to the Florida airports entirely impenetrable, regardless of what was shown on the CCFP, instead leaving the decisions about routing through forecast convection to airspace users. The reason given for this view was that there often are no good alternative routing options when convective weather affects large amounts of Atlanta Center airspace. In discussing how controller experience affects route capacity, an Indianapolis Center TMC suggested that a TMC who has worked in a particular sector might allow more flights through the sector than a TMC who has not. The reason is that experience provides a better understanding of techniques that can apply to that sector. Thus, the effective penetrability of a region depends not only on the weather, but also on factors influencing pilot behavior in different phases of flight (Rhoda et al., 2002), the availability of alternate routings, and local TMC experience with the route. Additional human factors and usability issues regarding the automation of TFM responses to convective weather are discussed in Ball et al. (2003) and Rhodes et al. (2003). They include defining Flow Constrained Areas (FCAs) for convective cells that join or divide from one forecast to the next and listing the flights in multiple Weather FCAs without duplication, and in the same Weather FCA when it is present in more than one forecast.

Under these circumstances, it is probably not appropriate to automate the determination of the significance of forecasted weather. Instead, operationally meaningful weather forecast information will allow TMCs to use their knowledge and experience to subjectively estimate any capacity effects, and respond accordingly. Aviation weather forecast formatting, route advisory automation for convective weather, and future automated estimation of how weather will affect capacity all should err on the side of safety to encourage both traffic managers and pilots to select safe routes. Formatting should unambiguously distinguish between airspace that is expected to present an unacceptable risk, and airspace that could develop dangerous weather (critical for contingency planning). Route advisory automation for convective weather avoidance should unambiguously distinguish safe routes from routes that the weather is expected to completely or partially block. Future automation that estimates route capacity in weather-impacted regions must avoid creating expectations that can only be met if TMCs accept too much risk when making rerouting decisions.

Before leaving decision support for weather constraints, it is worth noting the differences between the weather forecast needs of towers, TRACONs, and Centers. Towers and TRACONs require ceiling and gust-front forecasts and forecasts of visual and instrument meteorological conditions to predict airport configuration changes. Wind velocity can also affect the airport approach rates irrespective of the airport configuration. The terminal area is particularly susceptible to the effects of fog and small convective cells. However, this does not mean that terminal area TMCs require different information from what Center TMCs require. The same information should be available although it would not need to be as readily accessible. Providing the same information to Centers through automation will enable Center TMCs to monitor the operational conditions of underlying facilities more continuously and with less workload and interruption than through telephone communications.

Fog information will serve as an example of the similarity in terminal area weather information that is required by an ARTCC and an underlying TRACON. Information derived from sensors located on offshore buoys is used by TMCs at Northern California TRACON to forecast fog, wind, and other weather trends. The web page containing this information is available for display through a Systems Atlanta Information Dissemination and Display System (SAIDS). Oakland Center does not use this source of information, but until recently used a video feed of weather conditions on the approach path to the Bay Area airports to determine when the fog was about to clear. The Northern California TRACON and Oakland Center both display Geostationary Operational Environmental Satellite (GOES) information on current stratus conditions, but the wave height and water temperature information from the buoys and more exact visual information that the video feed provided are regarded as valuable supplements.

3.2 DEMAND ESTIMATION ENHANCEMENTS

The preceding section described human factors issues related to the integration of constraint information for TFM, specifically weather constraints. Constraints reduce the capacity of various elements of the NAS and can thereby cause demand to exceed capacity until traffic management initiatives reduce demand, scheduled demand lessens, or the weather constraint dissipates and capacity is restored. Predicting the demand on NAS resources is the complementary requirement for determining when to implement airspace restrictions and TFM initiatives.

ETMS provides alerts when the capacity of a NAS element (sector, airport, or arrival or departure fix), as indicated by its monitor alert parameter (MAP) value, is exceeded. If the MAP will be exceeded by counts of aircraft that are “active” (in flight), ETMS will display the sector in red instead of in its normal green. If the MAP is exceeded by counts of aircraft that are active plus those that are scheduled to depart but are not yet airborne (“proposed flights”), ETMS will show the NAS element in yellow. Sector MAP values are compared to demand counts that represent the maximum number of aircraft predicted to appear in the sector for any minute during 15-minute intervals. Operationally, at New York Center, TMCs consult the operational supervisor (OS) if a sector shows a red alert for two sequential 15-minute intervals. TMCs at other ARTCCs use their judgment to decide whether to respond to a red sector. It is a cause for action only if the count exceeds the MAP by more than several aircraft or if red alerts are predicted for an uninterrupted series of 15-minute intervals. Otherwise, the TMC assumes that the controllers can handle the small or temporary additional load.

The distinction between yellow and red counts is critical and must be maintained as future enhancements to demand estimation are integrated into ETMS. This distinction serves two purposes: It indicates whether the prediction is very likely (red) or only somewhat likely (yellow) to be correct, given that proposed departure times can be inaccurate. It also indicates whether the aircraft that comprise the excessive demand can be held on the ground. Holding on the ground through the imposition of a ground delay program is often preferable to airborne holding for various reasons including the additional airspace complexity and workload to monitor traffic in the holding pattern. Ground stops are also an important consideration, but are only available when sufficient demand is not yet airborne. This distinction will remain important even as improvements occur in departure time estimation.

Enhancements to demand estimation include the use of early flight path intent information (currently in progress), and other ongoing or proposed improvements to the ETMS trajectory model used to predict aircraft position. Three airport surface management tools, discussed below, could provide improved departure demand information. Air-to-ground data link has been suggested for more accurate or more frequently updated information on aircraft position, airspeed, aircraft weight (to improve climb and descent profile estimation) and winds (Wanke, 1997). However, there are other sources of inaccuracy in the trajectory model. They include the variability in the time that flight plans are submitted and activated in the HOST computer and differences between in the time that a taxi clearance is delivered and when the aircraft begins to taxi. They also include failures to enter revised route clearances into the HOST, error in top-of-descent placement, lack of runway queue, interim altitudes and an aircraft turn component in the trajectory model (Wanke, 1997; Mondoloni & Green, 2002). Variance in demand estimation is also due to the information that airspace users supply. These sources of inaccuracy include time-out delays, cancelled flights that operate without having been reinstated in ETMS, and flights that are not scheduled (e.g., pop-ups and air cargo fleets) or duplicated in the Official Airline Guide schedule. When different call signs for the same flight are found in the flight plan and ETMS the flight may be counted twice (Bonham, 2002).

Some improvements in demand estimation suggested by these sources of inaccuracy have been made or are in progress. In any case, during the facility observations conducted for this study, no TMCs pointed to a difficulty in interpreting Monitor Alerts as problematic and when asked TMCs described monitor alert accuracy as improved. A response from a supervisory TMC at New York Center was that the monitor alert worked well for the strategic decision making characteristic of TFM and that further enhancements might not benefit the strategic use of monitor alert. An objective comparison of monitor alert to enhanced models has led to mixed results (Lindsay, 2003). Enhancements such as including altitude restrictions in the trajectory model can be demonstrated to improve accuracy in some cases, but the improvement may only amount to fractions of an aircraft in sector counts.

The development of traffic management tools for controllers and OSs could potentially impinge on TMU integration at Centers. For example, the Enhanced Planning and Integrated Coordination (EPIC) tool is a set of capabilities intended to provide “better and more consolidated access to tactical and strategic traffic flow information” (Worden, 2005, p.1) for OSs and controllers-in-charge (CICs). These area supervisory personnel would use EPIC to plan staffing and sector configuration to better accommodate the expected traffic and thus reduce the need for traffic management initiatives. The operational concept (Newman and Worden, 2004) is predicated on the results of group discussions that found "supervisors universally dismissed the existing Monitor Alert as a warning devise as the data is often inaccurate, and there is only limited dynamic control of threshold [MAP] values" (Newman and Worden, p. 1-2). The findings of the present study fail to replicate those of Benson and Newman (2001) possibly because of enhancements to Monitor Alert that occurred during the three intervening years between the Benson and Newman and present studies.

EPIC provides a warning when volume and/or "complexity" exceed thresholds. Complexity is currently defined in EPIC as the number of conflict notifications provided by the User Request Evaluation Tool (URET) although "feedback from user evaluations of EPIC will be used to enhance the complexity algorithm by adding variables such as number of transitioning aircraft and/or letter of agreement requirements" (Worden, p. 3). The values corresponding to volume and complexity are displayed on an Area Loading Display that is similar to the ETMS Center Monitor display. If either one exceeds its threshold, the cell turns from green to yellow and if both exceed their thresholds, the cell turns red. The main human factors issue with EPIC is that this use of color-coding eliminates the distinction found in Monitor Alert between proposed and active aircraft in favor of providing a measure of complexity. This tradeoff requires examination both because of the utility of the active/proposed aircraft distinction for sector workload prediction and because complexity is a function of factors that URET conflict notifications may not entirely capture. For example, Kopardekar and Magyarits (2003) support a definition of complexity that includes 12 potential components including volume. On the other hand, if additional components are included in the EPIC complexity metric, it will become important to permit the user to break down the complexity value. As Callaham et al. (2003) observe, it is important to "provide some indication to the decision maker as to what factor(s) is/are predicted to cause the problem" in contrast to "an abstract number from which the solution is not altogether obvious" (p. 779).

Monitor Alert accounts for complexity indirectly through the MAP (i.e., a more complex sector would have a lower MAP threshold value). A TMC can change the MAP values for any specified time interval over the next 24 hours in a few seconds by using a command on the TSD. This way of handling complexity is appropriate if volume and complexity are highly correlated. The addition of a separate complexity metric requires justification through research indicating that volume and complexity are largely independent of one another. Otherwise, it should be possible to adjust for differences in complexity due to sector configuration and staffing through changes in the MAP value that the OS/CIC initiates and coordinates with the TMU for implementation. It is worth noting that, "most supervisors predict or assess the level of complexity by observing the physiological indications of the controller; for example, fidgeting, raising of the voice, coughing, or changes in posture relative to the radar scope. The supervisors feel that an automated tool cannot replace this form of measurement" (Benson and Newman, 2001, p. 2-8).

The study that provided initial empirical support for EPIC found that "comments among the supervisors were universal regarding the consistency of information at the area and at the TMU for traffic flow events…. Having common displays and information would facilitate negotiations and situational awareness when developing and implementing flow strategies" (Benson and

Newman, 2001, p. 3-2). Traffic information presented to the control room floor should not conflict with the information provided to the TMU when it is intended to support the same functions (i.e., assessment of sector workload and the need for traffic management initiatives). In addition to the differences between the TMU Monitor Alert and EPIC in what causes these similar tools to alert, they also differ in time interval and range. Monitor alert signals peak volume in excess of the MAP during any minute of a *15-minute interval*, whereas EPIC signals when volume or complexity exceed their thresholds during any minute of a *10-minute interval*. Their lack of synchrony and color coding could produce different outcomes for the same traffic situation such as red alerts for two sequential time intervals in the TMU and only one yellow alert on the floor or vice versa. Monitor Alert also functions for all operational areas in all ARTCCs whereas EPIC is concerned with individual operational areas and is limited to the one ARTCC. Where EPIC is intended for a one-hour prediction of volume and conflicts, Monitor Alert warns of excessive volume over many hours. (EPIC's use of URET conflict notifications from predictions beyond the current 20-minute timeframe itself requires validation for accuracy). Whereas clicking on a sector in the ETMS Center Monitor display brings up the Time-in-Sector chart, clicking on a sector on the EPIC Area Loading Display brings up the Sector Loading Graph. These inconsistencies should be addressed in the ongoing development of EPIC to ensure that they do not produce discrepancies that require additional communications between traffic managers and OS/CICs to resolve.

Traffic management includes tactical as well as strategic decision making, and for this reason, Center and TRACON TMUs include the same surveillance systems (e.g., the Display System Replacement (DSR) or ARTS Color Display (ACD)) that controllers use. The DSR is often used in determining when to release aircraft into a gap in the overhead traffic stream as part of a call-for-release program. The primary reasons that the TSD cannot provide this information are that its traffic position information is comprised of both active and proposed flights and it is updated once per minute, whereas the DSR is updated every 12 seconds and the ACD is updated every 5 seconds. On the other hand, expanding the range of the tactical displays could help TMCs to identify gaps earlier, when they occur in an adjoining Center's airspace. A second example of tactical decision making in TFM is in decisions that require estimating controller workload. The DSR includes the capability to replicate the view on the screen of any controller at the facility. Since TMCs are former controllers at the same facility, they can interpret the current vector lines, routes, flight plan readouts, weather, display range and other settings in determining whether or not to send additional aircraft into a sector. URET conflict notifications are thus already available to the TMU.

Human factors issues may develop as trajectory modeling is enhanced and as demand estimation becomes more accurate. One proposal for improving the trajectory model is the Traffic Flow Automation System (TFAS) which would network the trajectory modeling used in the Center TRACON Automation System (CTAS) "to create a national CTAS functionality" (Titan, 2002) that can predict traffic positions within 45 minutes of the current time. It would not affect longer-range demand predictions so the integrated TFAS/ETMS would need to ensure that traffic managers in ARTCCs and at the Command Center do not make decisions that require the more accurate information unless that is what they are viewing. Thus, it may be necessary to create a visual distinction between the more accurate and less accurate demand information in the TFAS-enhanced ETMS. The increase in display complexity should be weighed against the benefits of the new applications that the increased accuracy would permit. It would also be necessary to ensure that the ETMS and TFAS models do not count the same aircraft twice or show its position twice.

The literature reviewed and observations conducted for this study did not reveal any issues related to inconsistencies between tactical controller displays and TSD. TMCs generally use the tactical and strategic displays for separate purposes. When they must use TSD to see whether gaps in the traffic flow are forthcoming because the tactical display does not show enough of the adjacent Center's airspace, they appear to understand the differences between the traffic shown on the tactical and strategic traffic displays. It would appear that the HSI for ETMS and the HSI for the tactical systems that are currently used in TMUs should remain separate.

3.3 DECISION SUPPORT FOR TFM INITIATIVES

In-trail, speed and altitude restrictions, rerouting, and airborne and ground holding are among the more frequently used traffic management initiatives (TMIs). Of the various types, possibly the most frequently employed is miles-in-trail (MIT). By increasing the minimum separation between aircraft, MIT spreads the traffic demand for a NAS resource over a longer time interval. MIT is provided in five-mile increments, an arbitrary and possibly inefficient limitation. It is sometimes used to reduce the volume on a route so that the remaining aircraft can use tactical reroutes to avoid forecasted weather or so they can compress into a narrow altitude band to fly over the top of a convective weather system. When MIT restrictions are applied to a route that is already subject to heavy volume, slowing traffic can result in a "pass back" of the restriction to an upstream facility.

Air traffic control services, as a rule, are provided on a first-come-first-served basis. As a result, traffic that is already en route will usually not be slowed or vectored to accommodate aircraft waiting to depart and enter the overhead flow. TMCs must pay close attention and act quickly to identify gaps in the traffic flow to accommodate these departures. Often, only those aircraft destined for specified arrival fixes are subject to MIT and specified types and originating airports can be excluded from the restriction. Thus, the task of determining the appropriate MIT value and monitoring its effectiveness can be difficult. ETMS includes some helpful capabilities such as assigning a particular color to aircraft that may be excluded (or included) in the restriction. Altitude restrictions are often combined with MIT and the TMC must then monitor both restrictions to assess their effectiveness so that they can determine when the restrictions will need to be modified, extended, or canceled. They also must monitor the situation to determine whether to impose a call-for-release program on internal airport departures or request a pass back MIT restriction from an upstream facility.

Kopardekar et al. (2003) observe that "generally, internal options are considered first before restrictions are passed back on adjacent upstream facilities." However, at times the call-for-release or Approval Request (APREQ) program results in lengthy delays while transcontinental flights receive priority over departures from the middle of the country and overseas arrivals receive priority over departures from coastal airports. The sense of unfairness that MIT can create in this way is one of the factors that can produce "an environment of 'protectionism' in most facilities that is not conducive to productive collaboration" (Farley et al. (2001, p.6). This attitude may at least in part account for the preference to use call-for-release over passing back MIT restrictions. TMC workload is another possible factor as less effort is required to coordinate internal than external TMIs. MIT requires time to take effect. When an immediate reduction in airport demand is required due to an insufficiently conservative MIT restriction, for example, TMCs may need to require airborne holding at arrival fixes.

3.3.1 Arrival Management

Controllers currently use Traffic Management Advisor (TMA) and its prototype enhancement TMA Multi-Center (TMA-MC) to provide time-based metering (TBM). TMA and TMA-MC utilize the CTAS trajectory model. Like MIT, TBM regulates the density of air traffic flows. However, in contrast to specifying a minimum distance like MIT, TBM requires controllers to advance or delay flights so that they arrive over a metering fix within a highly constrained time interval (i.e., each within one minute of an automation-provided target time). Unlike MIT, any positive integer value is acceptable for the TBM target time-in-trail. The additional effort required for controllers to adhere to the metering schedule is expected to reduce the need for airborne holding and maintain the traffic flow into TRACON airspace at the maximum rate.

TMA-SC (Single Center) is currently used at individual Centers and TRACONs. TMA-MC coordinates arrivals from multiple ARTCCs to a common TRACON and airport. Both forms of TMA provide facilities with a common view of one another’s operations. According to a TMC at Los Angeles Center, the mutual awareness of each facility’s aircraft acceptance rate encourages the Southern California TRACON (SCT) to accept more aircraft. It is possible that the increased acceptance rate occurs because TMA enables SCT to see the demand that Los Angeles Center needs to handle so that they could understand the rationale for accepting more aircraft. Alternatively, SCT may have accepted more aircraft because they knew that TMA permitted Los Angeles Center to see their task load. Additional human factors information is needed on this point because it is important to understand whether tools such as TMA can enhance inter-facility cooperation. Greater cooperation would presumably decrease protective attitudes and would thus facilitate productive collaboration. The examination should also include its effect on TMC awareness of other neighboring and under/overlying facilities’ traffic situations, whether it encourages cooperative decisions, and its effects on other aspects of CDM such as the time taken to reach agreement on initiatives. A cooperative attitude may be a prerequisite for “implicit coordination,” which Farley et al. (2001) expect to reduce the need for explicitly coordinated TMIs. Implicit coordination should be studied to ensure that it does not lead to situations where the two parties take incompatible or duplicate actions.

If it extends TBM to second tier facilities, TMA-MC might increase the acceptability of TMA by spreading the additional effort that TBM requires among more Centers and increasing the airspace available to absorb delays necessary to adhere to the metering schedule. Los Angeles ARTCC would then receive a “return on investment” for their additional effort. Centers that send traffic to them would not benefit, but they may not perceive the additional workload required from each of them as excessive because it would have been divided among the other Centers. Parameters that TMA requires include the airport acceptance rate (AAR) associated with the runway configuration and whether visual or instrument approaches are conducted. Among the factors that affect the AAR are winds and traffic mix (because of wake turbulence). TMCs at

Atlanta TRACON may change the AAR almost hourly to maintain the maximum throughput. When the AAR or airport configuration is changed, the TMA arrival list "ripples" potentially changing the aircraft sequence and meter fix arrival times. It may become necessary to insert departures from nearby airports and other "pop-ups" (aircraft that had not previously appeared in the arrival list), also resulting in rippling. In TMA-MC, the effects of rippling and of aircraft that miss their meter times in outer Centers do not affect the meter times for the inner Center because the list freezes first for the outer Centers. However, there is a potential issue with dynamic changes to the airport configuration to maximize throughput if it leads to disruptive effects of rippling.

Human factors issues associated with ARTCC controller use of TMA-SC (the single-Center version of TMA) are discussed in Cardosi (2004), but lack of acceptance by controllers can constitute an issue for TMCs. Accordingly, TMCs at Los Angeles Center questioned its usability with heavy traffic and identified situations where its aircraft and environmental models did not provide usable aircraft sequences and meter times. They found that its use was limited to situations without propeller-driven aircraft, and to conditions without substantial headwinds, tailwinds, or turbulence. If these concerns are validated, some adjustments to the TMA (CTAS) trajectory model may be needed. They mentioned some other potential limitations as well. They thought that it could work well where traffic arrives at an airport from four corner posts, but encounters problems with complicated airspace (e.g., with military operations areas (MOAs)) and terrain constraints. They mentioned that it would not work when a controller needs to reroute traffic around thunderstorms. They thought that its use with too few aircraft would introduce unnecessary delays. Similar to MIT, it could be difficult to decide manually when to begin and terminate the use of TBM. The TMA load graph is useful for this, however, and a STMC indicated that a glance at the load graph shows when a restriction is needed. Estimating the start and end times for TBM could prove difficult with more complex traffic flows such as those containing aircraft only some of which require metering. The TMC must also estimate the appropriate number of minutes in trail. Its computational requirements, especially the advantageous capability to drag and drop aircraft between timelines, cause lagging that precludes the use of both traffic position and timeline displays on the same monitor.

Whereas Center TMCs emphasized the limitations of TMA-SC, a TMC at Southern California TRACON (SCT) said that it produced an even, steady traffic flow and that it was overall "a plus." He would prefer that its current limited use were extended to 24 hours. The differing ARTCC and TRACON views emphasize the need to advise TMCs about the limitations of TMA during training on the system. They also reiterate the importance of understanding how it affects CDM.

TMA-SC reportedly reduces workload (Swenson, et al., 1997), but few details of the methods and results were published. Some workload implications of TMA-MC are discussed in Farley et al. (2001). Issues related to controller workload that Farley, et al. identified include a presumably temporary workload increase as controllers adjust to TBM, and some more permanent workload benefits. Among the latter are controller workload reductions that would result from more regular arrival flows and less airborne holding, less TMC coordination workload because of "implicit coordination" and less need to revise metering programs. On the other hand, additional workload could occur from the application of TBM to high traffic loads and the telecon(s) to decide on and possibly revise the day's metering plan. Increased workload could also occur through the manual introduction of internal departures, to coordinate arrivals with departures, and from airport configuration changes that would ripple the metering list. Implicit coordination requires study to ensure that incompatible actions do not occur.

The placement of the metering horizon that freezes the aircraft sequence and metering fix times needs to allow enough airspace for controllers to delay or advance aircraft to meet the assigned metering times at the TRACON boundary. Farley et al. (2001) found in a simulation study that setting the metering horizon arc farther away from the TRACON boundary "more equitably distributed the workload across more sectors" and helped to meet metering times. However, in doing so "the system becomes more prone to error in the sequences it generates, and sequence errors cause controllers to quickly lose faith in the system" (p.8). Workload issues that can arise from the placement of the arcs that define the metering horizon must be carefully considered during the adaptation of TMA. Operational evaluations of TMA-MC have been conducted, but they have not yet incorporated workload measures. One evaluation (Farley et al. 2001) identified the potential need for controllers to ensure separation for complex traffic flows containing both metered and unmetered aircraft as an issue. Future evaluations should employ scenarios representing the concerns that TMCs have voiced after using TMA-SC and opportunities to evaluate implicit coordination. These evaluations should employ measures of controller and TMC workload that assess workload dimensions such as cognitive, communications, time pressure, performance, frustration, and effort.

Some TMA functions have proven useful apart from TBM. TMA provides functionality to help TMCs coordinate departure times to merge aircraft smoothly into the traffic flow. Even though Oakland Center does not use TBM, a TMC there said that he was unable to set up traffic for Los Angeles Center as precisely without this capability (i.e., the timeline charts for the various Oakland Center airports and airspace). A Los Angeles Center TMC uses the separate timelines for scheduled and unscheduled departures from Los Vegas to identify aircraft that are about to call for release.

3.3.2 Airport and Departure Management

Three systems in addition to TMA include functionality that can provide support for APREQ programs, the Departure Spacing Program (DSP), the Airport Resource Management Tool (ARMT) and the Surface Management System (SMS). DSP and ARMT are currently in use. The use of DSP at New York Center, New York and Philadelphia TRACONs and at airports near New York City, and the use of ARMT at Atlanta Center, Atlanta TRACON, and at Atlanta International Airport indicate their usability with the high traffic volumes that these facilities handle. Our observations revealed a high level of acceptability for DSP at New York Center and for ARMT at the three Atlanta facilities. Observations were not conducted at other New York area facilities that use DSP.

DSP automates the determination of departure sequencing times, departure sequencing across coordination fixes, common runway departure coordination, and delay recording, according to its manufacturer (Computer Sciences Corporation, 2000). For tower controllers, DSP provides departing aircraft with departure window times to prevent excessive demand at departure fixes.

For TRACON departure controllers, DSP provides flight and runway lineup status for each flight at each airport. For ARTCC controllers, including the departure complex and TRACON TMU coordinators, DSP provides a complete flight plan for each flight. A TMC can set the DSP departure rate to achieve a required MIT restriction although this involves a simple conversion between the desired MIT and departure rate (e.g., 20 MIT equals ten aircraft per hour). The automatic determination and communication of departure release times greatly reduces the volume of communications that would otherwise occur during APREQ programs. Without DSP, calls-for-release could reach a volume that would prevent TMCs from answering calls to the Center, thus delaying departures.

DSP requires a review of the proposed routing for all departures. This is necessary to prevent rerouting after the aircraft are airborne. In each ATCT, controllers need to swipe a bar code located on the flight progress strip as they complete their handling of departures. Three swipes are required: after the aircraft receives its taxi clearance, after it begins to taxi, and after it is in line for takeoff. These actions could be delayed, and are subject to omission and duplication, particularly when the controller is busy. They also briefly divert attention from visually scanning the airport. The acceptability of DSP that was found at New York Center may not extend to towers and TRACONs. Its effects on controller and TMC workload should be examined at these facilities because they provide much of the additional effort DSP requires. DSP may show the reverse of the effect of TMA where additional effort is expended without a return for the facility. It may thus be possible to resolve this issue by deploying both arrival and departure management tools simultaneously or integrating the tools so that the facilities that put forth the additional effort also see benefits on their operations.

ARMT displays information about both arrivals and departures. It tracks individual aircraft delays, shows the departure demand and how it is balanced over the departure fixes, and provides an aural warning when a delayed arrival is approaching. TMCs in Atlanta Tower announce the arrival's call sign to the local controller. ARMT tabulates and displays the mix of wake vortex and other aircraft and how they are balanced across the arrival fixes. It provides feedback to TRACON TMCs on how the actual combined landing rate compares to the target airport acceptance rate (AAR) for the current airport configuration and calculates inter-arrival times and ground delay program (GDP) performance. While some Atlanta TRACON TMCs do not use the departure and departure split lists, others do. All use the taxi list. ARMT gives the ramp destination of each arrival so that, in the event of a taxiway closure, the TRACON TMC can change the runway for aircraft headed for affected gates. Atlanta Tower TMCs pay attention to the color-coded display of departure delays. Center TMCs enter ground stops, departure restrictions, Estimated Departure Clearance Times (EDCTs), departure release times, changes in meteorological conditions, and AAR. Tower controllers scan a flight strip bar code after providing taxi instructions, after the taxi has cleared the gate area, and when the aircraft is ready for take-off.

While it is beneficial for Center TMCs working with a call-for-release program to know whether an aircraft is ready to depart, ARMT does not indicate an aircraft's exact place in the runway queue or the number of aircraft in queue. Unlike DSP, ARMT does not provide departure window times. The drawbacks of flight strip bar code scanning are similar to those of DSP, except that the bar code is not scanned when an aircraft begins to taxi. Aircraft may not begin to taxi immediately following the delivery of their taxi clearance so estimates of when an aircraft will arrive at the departure runway could be inaccurate.

SMS receives position information from ASDE-X and other radar and non-radar surveillance capable of providing aircraft identity. It displays current aircraft position on an airport map display, predicts the departure demand at an airport including departure sequences, times, queues, delays, and aggregate departure demand. A prototype at Memphis International Airport that is not used operationally shows arrival gate information on data tags associated with the arrival traffic on the airport map display. SMS will also predict the demand for gates.

As an example of how implicit coordination could reduce TMC workload, TRACON TMCs could stop sending arrivals to a runway upon seeing an SMS display of a queue at that runway. "Similarly, if the TRACON TMU had information about queues trying to cross an arrival runway, the TRACON could adjust the gaps between arrivals to facilitate crossing without the ATCT needing to call to ask the TRACON to slow the arrival rate" (Surface Management System Operational Concept, Feb. 4, 2003, p.19). As suggested earlier, implicit coordination would reduce workload relative to explicit coordination, but it could introduce a risk of incompatible or duplicate actions.

SMS support for APREQ consists of providing "a table of the earliest possible departure times for each APREQ flight, accounting for surface traffic, directly to the ARTCC TMC. When convenient, rather than when the ATCT calls, the ARTCC TMC can plan a release time, enter it into SMS, and SMS will relay the release time to the ATCT without the ATCT having to call" (Surface Management System Operational Concept, Feb. 4, 2003, p.30). Unlike DSP, which provides APREQ departure window times, only the minimum release time is given. Using SMS, the TMC is required to identify a gap where the departure can enter the en route traffic flow. A Memphis Center TMC commented that SMS should account for APREQ departures from other Memphis area airports. This would provide a broader solution to the timing of calls for release. In comparison, DSP coordinates departure release times from six airports. The same TMC also said that using SMS for APREQ takes no less time than the current telephone procedure. This may in part be due to the need to manually coordinate departures from the other airports that feed the Center airspace. It may also be partly due to the serial selection of aircraft to release, where each selection can influence the earliest departure times for the other APREQ aircraft. DSTs should "give the user information in an immediately usable form requiring no mental transformation" (Cardosi, 2004, p.10). The current table of earliest possible release times requires more mental effort than would, for example, automation that recommends a sequence of aircraft and release times that would minimize runway queues and delay for all departures that are ready to taxi.

Like TMA, SMS receives data from automated surveillance. As a result, obtaining position information requires no effort from controllers and it is not subject to human error and variability in performance. It also provides relatively continuous position information, which could improve the accuracy of its departure time calculations, compared to DSP and ARMT.

SMS tracks aircraft as they follow their assigned taxi route and "if SMS recognizes, based on surface surveillance, that the aircraft is being taxied to a different runway, SMS will change the predicted departure runway for the flight" (Surface Management System Operational Concept, Feb. 4, 2003, p.34). This should not occur automatically. Instead, this capability could be better used to alert the ground controller that the flight is not conforming to its taxi route. SMS should first obtain an acknowledgement that the new runway is intended and not an instance of a pilot taking the taxi instructions provided for another aircraft (e.g., one with a similar call sign).

SMS is currently a developmental system and still subject to automation errors. This was evident during a visit to Memphis International Airport, where SMS is set up for demonstration. In one case, when an aircraft departed and its tracking switched from surface to airborne radar, two targets were displayed. The surface radar target was not removed and remained stationary on the display while the airborne radar target showed the aircraft continuing along its departure route. Since SMS accepts data from a variety of radar and other surveillance sources that track position on the airport surface, it could improve ETMS demand predictions and alerts. Aside from human factors concerns about display clutter and mistaking the bogus target for an actual one, the failure to remove targets promptly could adversely impact these demand estimation benefits. Further limiting the improvements to ETMS that data from SMS could provide is the low rate at which SMS obtains gate pushback times perhaps because many flights do not turn on their transponders in the gate area or because of surveillance limitations in the gate area (Clow et al., 2004). Similarly, a test of SMS found that "FedEx Tower results were inconclusive because the displays missed several flights" (Nene et al., January 22, 2004, p.30). Clow et al. found, however, that SMS generated wheels-up and wheels-down times that were both accurate and timely, and would benefit ETMS.

SMS utilizes predictive modeling to provide configuration change decision support. Shadow-mode testing at Memphis International Airport in 2003 suggested potential usefulness for this purpose (Walton et al., July 16, 2003). However, its use of historical averages in modeling taxi time "introduces substantial uncertainty" (Surface Management System Operational Concept, Feb. 4, 2003, p.33). Combined with uncertain pushback times and potential automation errors, the SMS modeling capabilities and the "what-if" planning that may be built upon them may not provide sufficiently usable information. Assuming these issues are resolved, SMS could support configuration change decisions by providing timelines with predicted arrivals and departures for a runway over the next hour, predicted departure runway queue lengths, and the predicted runway average delay by time (Mayo et al., January 22, 2004).

SMS trial planning that would generate predictions for alternative departure splits (Mayo et al., January 22, 2004) and arrival/departure tradeoffs is under consideration. "In addition to providing raw information, SMS will advise a schedule of coordinated arrival and departure capabilities that match the time-varying demands for the two types of operations…. To achieve the planned arrival-departure mixture, the Center TMU can manually adjust the airport acceptance rate (AAR) to which TMA schedules arrivals…" (Surface Management System Operational Concept, February 4, 2003, pp. 24-25). As pointed out earlier, adjusting the AAR would cause TMA metering list to "ripple," changing the metering times, possibly changing the traffic sequence and thus reducing its usability. (It is less usable because the TMU removes the metering lists from controller displays prior to the ripple). Another potential issue with SMS (and other) trial planning capabilities is that "SMS users may not have the necessary information or time to plan beyond immediate airport movements, especially during busy periods" (Surface

Management System Operational Concept, February 4, 2003, p. 21).

A proposed DST, the Arrival/Departure Tradeoff Optimization Tool (ADTOT), would also optimize arrival-departure capacity tradeoffs. TMCs can weight arrivals and departures differently for different airport configurations. An evaluation found that ADTOT led to better performance than arrival-departure tradeoffs that TMCs suggested (Gilbo, 2003). Under certain circumstances, ADTOT may offer multiple optimal tradeoff recommendations, and a TMC would choose one for implementation based on constraints that are external to the tool's algorithm. Multiple solutions are more likely to result when the sum of arrival and departure capacities in all possible tradeoff combinations is the same and arrivals are weighted equally with departures. Human factors expertise should be provided during the integration of this and other trial planning tools to ensure that they remain usable under high workload conditions. Like SMS, the usability of ADTOT for determining arrival-departure tradeoffs requires the availability of sufficient time for the TMC to evaluate one or more "optimal" solutions and to then implement the selected solution.

3.3.3 Trial Planning

An analysis of information requirements should precede the integration of any traffic management tool and this is especially true of tools that automate cognitive functions such as complex planning tasks. Trial planning capabilities such as those that have been proposed for arrival-departure tradeoffs have two particularly important sets of information requirements. First, TMCs need the information required to evaluate the automated guidance. In general, this would include the display of pertinent information about the current, unmodified situation and about the proposed solution(s). For example, the TMC will need the information necessary to determine whether increasing the arrival/departure tradeoff in favor of the airport departure rate will lead to airborne holding at an arrival fix. Alternatively the TMC would require the information needed to determine if tilting the tradeoff in favor of the arrival rate will lead to a "gridlock" situation in which airport resources are not available so that ramps or key taxiways become blocked.

A second area of information requirements for trial planning is the information needed for manual reversion. Automation is often "brittle" providing inadequate solutions because all of the possible scenarios in which the automation will be used and the full range of data quality are not adequately considered in its design (Smith et al., 1997). Given training on the limitations of the automation and information needed to evaluate the automated guidance, TMCs can decide whether or not to implement the automated system solution or to perform the task manually. All of the information, system functionality, and TMC skills required for manual reversion must be preserved from the pre-automated functionality. A potentially important factor in deciding whether or not to accept an automated solution is how the facility assigns responsibility for non-optimal or erroneous decisions. For example, in TRACONs TMCs report the party responsible for failures to meet APREQ times as either an airspace user or ATC. It will be critical to ensure that TMCs have the time and information that they need to evaluate automated solutions especially if they will be held responsible for delays or other problems that result from implementing the automated solution.

Trial planning capabilities for one type of TMI, the ground delay program, already exist in FSM and work has proceeded on modeling proposed rerouting plans. Because different TMIs are sometimes applied at the same time or sequentially to reduce or halt the traffic flow through an identified constraint, trial planning for multiple TMIs has also been studied.

TMSs collaborating with Center TMCs may use a tool, the Integrated Impact Assessment (IIA) in conjunction with ETMS to design and implement multiple initiatives. In an example from the IIA Concept of Use (Ball et al., 2003), (1) a "familiar reroute strategy" to reroute traffic around forecasted convective weather is agreed upon at 1600Z. The plan involves two routes. IIA is used to see the predicted effects on sector demand. At 1700Z (2), the Command Center and affected TMUs take another look at the reroute results after airspace users have had an opportunity to alter their plans in light of the rerouting decision. They now decide on MIT in addition to the rerouting plan. Using IIA, the TMS experiments with different MIT values for the two routes and decides to propose a third reroute. TMCs then use IIA to determine that delaying the start of MIT on one of the routes would keep the demand within threshold. After the plan is published, TMCs in the affected Centers use IIA to evaluate the possible need to pass back MIT to upstream Centers. At 1715Z, (3) the TMCs prepare flight lists for affected airspace users and send them out. The plan is implemented at 1730Z (4), but at 1830Z, (5) a TMC finds that demand needs to be further reduced. Since the weather is forecasted to start in one-half hour, the TMC uses IIA to identify flights that can be held on the ground. Following further discussion between TMU and Command Center (6), a TMS contacts the airspace users to delay those flights.

This example from the IIA Concept of Use illustrates the iterative, collaborative development and management of a plan that incorporates the use of IIA. Although it involves roughly six steps, note that it employs a familiar reroute strategy and that the weather was assumed to develop as forecasted. Considerably more effort from the Command Center and TMUs could be required if an unusual rerouting strategy was employed or the weather forecast was inaccurate. Several human factors issues could appear during the integration of a trial planning tool that enables traffic managers to "experiment" with alternative TMIs and parameters.

A fundamental issue is whether specialists and TMCs will have time to use a tool that could increase decision time by including deliberation about additional alternatives. It would be useful to know how much time traffic managers take to examine alternative parameters for ground delay programs in FSM as this would indicate roughly the time available for other types of trial planning. Trial planning would replace "best guess" decisions, but multiple solutions may require evaluation before an acceptable one is found. Specialists and TMCs under time pressure are unlikely to use IIA to its full capability unless the required amount of human-system interaction is minimized. Its usability would also increase if the IIA demand estimates accounted for other TMIs that are active during the same time period as the operational concept stipulates (Chambliss & Yee, 1999) and as traffic managers participating in a human-in-the-loop exercise suggested (Wanke et al., 2003).

In Wanke et al., (2003), Center TMCs use IIA to display the impact of a MIT-reroute strategy on a 16 x 42 time-by-sector matrix consisting of 672 cells that represent the projected demand in each sector for each 15-minute interval during the 4-hour initiative. Cells are color-coded similar to the ETMS Center Monitor, except that they are outlined in light blue if the demand is predicted to decrease due to the strategy or in dark blue if the demand is predicted to increase. Color-coding cells that show an increased or decreased demand would help users to make trial comparisons, but the amount of increase or decrease is not depicted, nor are downstream effects and importantly, whether the increase or decrease changes the airspace element's alert status (i.e., crosses the Monitor Alert parameter value). It would be better to permit the trial of multiple strategies simultaneously and to simplify the demand presentation. For example, for each strategy, only the original situation and sectors that show a change in Monitor Alert status might be shown. While this may require a large enough display to show the original situation plus several strategies, a TMS could compare multiple strategies against the original on the same screen. Accommodating the trial results of multiple plans may encourage a user under time pressure to employ a strategy that finds the best of the alternatives instead of using a serial strategy that may encourage stopping after confirming that one plan is marginally workable (e.g., with passbacks or holding). This way, users would not need to "'toggle' between strategies" (Masalonis, et al., 2002, p. 3-12) to compensate for the memory load associated with the comparison of large and potentially complex matrices (Estes & Masalonis, 2003). It is likely that simultaneous comparison would reduce the time required for interaction with IIA, reduce errors from human memory limitations, lead to the consideration of more alternatives, and thus produce better strategies.

Masalonis et al., (2002) provides additional support for a TMI planning display. These investigators used two monitors to display functions similar to those envisioned for IIA. Although they expected to need to simplify the functions for integration with the single monitor ETMS, "the two-monitor configuration was used for this evaluation in order to use the functions more efficiently, without the added time and frustration of the window overlap that occurs in the one-monitor configuration" (p.2-7). In Masalonis et al., (2002) one monitor presented traffic and the second was used to define a rerouting plan and model its effects.

Observations conducted for the present study suggest that Center TMCs generally evaluate demand by using the TSD rather than the Center Monitor although they do use the Center Monitor to view the impact of proposed TMIs. Command Center specialists who may be less familiar with Center airspace rated the assessment information as more useful when shown on a traffic display (Wanke, 2003) and they may more rapidly evaluate the demand if it is shown in that manner. Consideration should thus be given to multiple impact assessments on displays that present their effects on the future traffic situation as well as on a Center Monitor display.

As the IIA example amply demonstrates, considerable collaboration and coordination occur during the development and implementation of a rerouting-MIT strategy (steps 1, 2, 5 and 6). Communications are required between TMUs in ARTCCs and the Command Center, between the Command Center and airspace users, and between ARTCC TMU, TRACON TMU and OSs for the affected sectors. Through a process of collaborative decision making, differing perspectives and priorities are brought to bear on the emerging TFM strategy. A possible benefit of IIA and other trial planning capabilities is that the resulting graphical strategies can be electronically shared to expedite the process of reaching agreement on a strategy. In the example from the IIA operational concept, this occurs when “the TMCs use the corresponding sector estimates to convince controllers’ supervisors that a manageable volume of traffic can be achieved…” (Ball et al., 2003, p. 5-12). During a site visit conducted for this study, a TMC at Indianapolis Center similarly suggested that reroute modeling results could be used to show the Command Center what would happen if traffic were rerouted in a certain way.

3.4 COMMUNICATIONS AND LOGGING

Davison and Hansman (2001) raised several human factors issues related to inter-facility communication. They determined that the status of traffic management actions is not immediately distributed to all affected facilities: “Often, the current status of a restriction fails to arrive at the towers” (pp. 62-63). An operations supervisor said “the airline pilots departing knew of the end of a GDP before the controllers knew” (p. 68). Second, they provided evidence suggesting that the workload associated with coordinating initiatives through telephone calls is excessive, because for example, less efficient routes are assigned to aircraft “to avoid spending time coordinating with other facilities to achieve a more direct route” (p. 68). During a visit to BOS ATCT for the present study, a TMC commented that APREQ programs are sometimes undermined when the Boston Center TMU does not have the staffing to answer the phone to find out that a departure is (or is not) ready for takeoff. Third, a Traffic Management Officer (TMO) stated that, “TMCs spend too much time transferring information into multiple information systems. This reduces the TMC’s time for their major task, which is monitoring the tactical controllers and managing flows” (p. 51). Observations conducted for the present study confirmed the TMO’s statement.

The National Traffic Management Log (NTML) was developed to provide a “single point of data entry for NAS TM [Traffic Management] data… reduce unneeded phone calls…[and] make status information available to system users in real time” (Grovac, November 2003). Accordingly, NTML responds to the three communications issues from Davison and Hansman, although the amount of communication and coordination required for specific types of traffic management initiative needs to be better understood to guide the further development of NTML along the most beneficial path. Plans for NTML integration include information from ETMS (runway visual range (RVR) and Monitor Alerts), combined sectors, notices to airmen (NOTAMs), scheduled equipment outages, special use airspace, and airport delays. The intended use of NTML is consistent with its integration with future DSTs such as the planned Reroute Data and Execution DST (“Go Button”). The “Go Button” will provide “timely dissemination and implementation of flight-specific reroutes generated by TFM Decision Support Systems” (Traffic Flow Management Research and Development Plan, July 2003, p. I-26).

The plan to consolidate all logging into NTML should also include simplifying data entry to reduce TMC workload. In September 2003, the total number of monthly entries reached 50,000 (Grovac, November 2003), and ten or more entries can be required hourly under busy conditions. End-of-shift summaries are sent to the Command Center. Continued human factors support for NTML integration will ultimately allow TMCs to spend more time monitoring air traffic flows and the initiatives and restrictions that are required to manage them. There currently is a procedural way to contend with NTML data entry workload: At Oakland Center rather than requiring each TMC to enter information into NTML, the TMCs provide it to the supervisory TMC (STMC) who then enters it into NTML. This procedure reduces the NTML data entry workload for TMCs while keeping the STMC informed, but it adds a step that would not be necessary if NTML data entry workload were low. The STMC could stay informed by monitoring NTML and observing the TMCs and traffic situation.

Plans exist to present NTML information on ESIS displays at ARTCCs and TRACONs. The large wall-mounted ESIS displays are positioned high in the TMU and tactical controller areas. The information that they present varies with the facility. For example, the Operational Information System (OIS) web page is displayed on ESIS in the New York Center TMU. OIS is a Command Center web page that displays current GDPs, ground stops, delays, airport closures, de-icing, and runway/equipment status information. There are plans to connect NTML and OIS. Somewhat different information is shown on ESIS at Oakland Center, adding airport configurations and MIT restrictions. Southern California TRACON displays TSD and some facilities display weather information on ESIS.

There is currently a widespread practice of duplicate data entry. TMCs electronically receive information on one system and then manually re-enter it into other systems. Integrating these systems should eliminate redundant data entry. Entries are made in NTML to log an action and into TMC Tools or SAIDS to send it to controller workstations. At Indianapolis and Oakland Centers, TMCs enter rerouting information into NTML, but also into Flight Data Input Output-General Information (FDIO-GI) messaging systems to send the information to the floor. The integrated system should retain the capability of only sending the information to the specific area(s) concerned with the initiative. A way for the area supervisor to acknowledge that the information was received may be required: At Southern California TRACON, the TMU message flashes at the area supervisor workstation until acknowledged. OSs currently retype the information to display it on ESIS for controllers. When the AAR changes at Atlanta International Airport, a TMC in Atlanta TRACON enters the new information into four systems: ARMT, SAIDS, OIS (to send the revision to the Command Center), and NTML.

While some of the same inefficiencies are found in towers, oral communications between TMCs and controllers facilitate traffic management and tower control operations at both BOS and ATL. Boston ATCT controllers currently need to retype restrictions and initiatives received in FDIO/GI messages from Center TMCs into their Traffic Management Log and SAIDS. While NTML could replace their Traffic Management Log as their official record of traffic management activities, the requirement for tower controllers to view the airport out the window and the close proximity of TMU and controller workstations suggest different needs and opportunities for integrating logging and communication systems in towers.

NTML will need to satisfy some additional user requirements to achieve its full potential as “a single point of data entry.” Table 1 shows examples of the logging that currently occurs in the NAS in addition to NTML. Some of the remaining logs consist of information needed for facility briefings. Other logs are currently needed to send information to the controllers or to the Command Center. Some logging is amenable to automation. For example, Memphis Center requires the logging of Monitor/Alerts. The planned connectivity between ETMS and NTML could enable the required Monitor Alert records to be generated automatically. To eliminate duplicate logging, NTML reports should contain options that provide the necessary information formatted for facility briefings and for the Command Center.

Human factors research is needed to determine the categories of information that can be transmitted “electronically” through NTML, and those that will continue to require telephone communication. Observations at BOS ATCT and Memphis Center indicated that telephone calls are used to acknowledge electronic messages (i.e., the only purpose of the call is to say that the restriction was received electronically). At least some types of acknowledgement could occur electronically. If specific routes, MIT values, or aircraft identifications need to be repeated to ensure mutual understanding, the electronic acknowledgement could include a checklist with these specifics. A Memphis Center TMC suggested that TMCs should only have to make a phone call if they disagreed with the restriction. NTML should incorporate an appropriate means to acknowledge the receipt and understanding of common, routine messages, and then the current requirement for telephone acknowledgement of those messages could be eliminated. Electronic messages are less distracting than telephone calls, but may not be received as rapidly. When traffic managers are working under time pressure to resolve an imminent situation, telephone calls should be reserved for urgent and time-sensitive communication, such as calls to release APREQ departures in the immediate future. Inter-facility discussion of developing NAS constraints will probably continue to require telephone communications.

Table 1. Examples of TMC Logging in the National Airspace System

Facility	Log	Entries (Examples)
BOS ATCT	Daily Facility Log	Runway closures
BOS ATCT	TMC Log	Runway closures
BOS ATCT	Ops Net	Delays
ZNY	TMC Tools Log	Send restriction information to floor
ZME	Restrictions Log	Restrictions, sent to sectors
ZME	Monitor/Alert Log	Over-threshold demand alerts
NCT	Briefing Sheet	Delays, quiet periods, yesterday’s counts, flight restrictions
NCT	TM Log	Facility outages, emergencies
NCT	SAIDS	Restrictions, emergencies, VIP movement
ZOA	Ops Net	Delays, NTML used to verify
SCT	SAIDS	Time-based metering schedule, arrival flow, outages
SCT	Briefing Sheet	Flight restrictions
SCT	Facility Log	Outages, emergencies
SCT	Ops Net	Traffic counts
SCT	Sign-On Monitor	On-duty time for Quality Assurance, sick leave
ZTL	Daily Log	Current restrictions, notes during convective weather season
ATL	SAIDS	APREQ
A80	Ops Net	GDP summary, traffic counts

4. FUTURE CHALLENGES OF HUMAN-SYSTEM INTEGRATION

The human factors goal of user acceptance is frequently but mistakenly, identified as the singular performance criterion of the program. Placing too much emphasis on this necessary goal can lead to failures to determine what information the traffic manager requires and how the information will be used. Task analyses and concepts of use often lack sufficient detail to support HSI design and evaluation. Without them, it is difficult to know how to write requirements to integrate systems in a way that would minimize the potential for human error.

For example, questions of what information is needed and how it will be used could be better addressed in the design of the Route Management Tool (RMT). At two of the facilities visited during the present study, TMCs said that they only use RMT to find airport identifiers. RMT contains a very large number of route alternatives, and the database is well designed, but few of the routes are actually used. It appears that the designer did not sufficiently consider the benefits of controller familiarity with the route and the amount of coordination required to reroute traffic along an unfamiliar route (Davison and Hansman, 2001). The first human factors challenge to human-system integration for TFM is to ensure that information requirements have been fully assessed and that the plan for HSI integration will fulfill the requirements for information and information flow.

The goals of acceptability and performance are sometimes misunderstood to represent the same thing. As a result, human factors evaluation can end when a group of user representatives considers a design acceptable, even though the evaluation has not determined how different display alternatives will affect performance. Instead, human factors evaluation needs to also test how design alternatives would affect both operator and system performance. The second human factors challenge is to ensure that performance is assessed during human factors evaluations.

Another consequence of assuming (incorrectly) that the proper role of human factors is to gain user acceptance for a design is that human factors expertise is only needed when users disagree. Human factors specialists then may not be in a position to provide the services that they have traditionally, including allocating functions to human operators that are better performed by humans than by automation and ensuring that the HSI supports effective operator performance. Instead of rigorously testing specific alternatives, human factors evaluation may merely demonstrate alternative ways to integrate functions in an attempt to gain consensus among the user representatives. Consensus regarding a design is tantamount to success and concludes the evaluation. The problems with this definition of programmatic success are the potentially false assumptions that acceptability equals usability, and that users can determine which way of integrating functions will produce the best performance. Many studies have shown that people are not reliable judges of control and display attributes that lead to better performance (see Andre and Wickens, 1995 for an overview). As a recent example, the CCFP was deemed acceptable for approximately four years and had been integrated into ETMS before it was found that users incorrectly treated the forecast polygons that represented possible convective activity as “no fly zones” (Sims et al., 2004). The solution included format modifications, displaying less default information and enabling TMCs to remove some of the remaining information from the display. As in this example, user preference and performance dissociations appear to be common with

HSI attributes related to the amount of information to present and how it should be coded to distinguish it from other information (Cardosi, 2004). Users often prefer to have more information than the task requires even when the additional information reduces usability and degrades system performance. Dissociation between user preference and performance is particularly common in the use of color.

With the planned integration of the Weather and Radar Processor (WARP) and Integrated Terminal Weather System (ITWS) forecast products within TFM tools such as TMA and ETMS (Souders et al., 2004) information coding issues will require attention. Although users typically will prefer more color and control over which colors are used, research has shown that gray-scale is more useful than color for certain kinds of decisions (Merwin and Wickens, 1993). Human factors guidelines on the use of color for information display (e.g., Cardosi and Hannon, 1999) should be consulted when planning the integration of weather forecast products with displays of predicted traffic position. Issues such as how to use color-coding to help TMCs discriminate traffic bound for particular fixes or destinations, or traffic that is suitably equipped for particular flight applications could also benefit from an examination of pertinent human factors literature. The third human factors challenge for TFM integration is to apply what is known about how design alternatives are likely to affect operator performance to decisions regarding the requirements for the integrated system.

In addition to helping the development program to meet these challenges, human factors expertise can benefit TFM integration by continuing to provide consistent support to traffic manager user groups to assist in identifying issues and when issues are identified, in helping to design changes that engineers can implement. Human factors specialists can also continue to work with engineers on options that would satisfy user requirements for both usability and usefulness, and help to distinguish HSI attributes that are nice to have from those that are necessities. As scientists, they have the expertise to identify options that are consistent with well-supported principles and evidence as opposed to opinions or preferences. They can design and conduct studies to provide reliable evidence about potential alternatives and evaluate the results of tests to ensure proper interpretation.

- *The first human factors challenge to human-system integration for TFM is to ensure that information requirements have been fully assessed and that the plan for HSI integration will fulfill the requirements for information and information flow.*
- *The second human factors challenge is to ensure that performance is assessed during human factors evaluations.*
- *The third human factors challenge for TFM integration is to apply what is known about how design alternatives are likely to affect operator performance to decisions regarding the requirements for the integrated system.*

5. SUGGESTIONS FOR INFORMATION DEVELOPMENT

Prototype tools are sometimes placed in TMUs for informal operational evaluation. However, unless training and technical support accompany the prototypes and a structured evaluation accompanies the operational experience, little may be learned about their usability, how they affect operator and system performance, or the extent of their acceptability. One issue is that individuals who have been trained to use the prototype may not remain available to evaluate it. Traffic managers are frequently recruited for ATC management positions. While technical support was observed for the CIWS prototype located in the Indianapolis Center TMU, a TMC mentioned that he could not demonstrate ARMT because it produced an error message that no one understood. Computer-based training and a way to contact the vendor with questions about the tool and for technical support should be readily available for informal evaluations. At best, however, the informal evaluation of a prototype only can provide information on the situations that occur when a TMC has the time to see what it can do. This method of evaluation will generally not reveal its usability and benefits under high workload conditions. A systematic usability evaluation by a team consisting of traffic managers and human factors professionals is necessary to identify and respond to issues before they interfere with operations.

Operational evaluation offers the validity of actual traffic and conditions, but even more than informal evaluation, it is limited to only the weather, outages, traffic load, and other conditions that occur on the day(s) of the evaluation. It is worthwhile to conduct simulations that include a full range of scenarios including some that are unusual and worst case. ATC and traffic management test facilities located at the Volpe Center, FAA Technical Center, NASA Ames Laboratory, MITRE CAASD, and METRON can be used for this assessment. Sometimes, however, activities at these facilities are limited to demonstrating new concepts and design options to user groups and rapid prototyping. While these demonstrations have a legitimate role in system design, only well-designed comparative studies can lead to targeted and reliable results. The documentation of the results also has long-term benefits beyond the resolution of specific issues tied to the current integration effort.

Several simulations, and operational exercises and evaluations are currently planned or are in progress and it is anticipated that they will include the collection of human factors data. A final human factors evaluation of SMS was completed in December 2003 and documentation is currently undergoing review. Simulation activities involving TMA-MC were reported in 2001 and additional operational exercises have been proceeding. An operational evaluation of IIA is also planned. Suggestions for further study of these and other tools have been made in earlier sections of this report. It is believed that the recommended assessments would develop information that will be useful for the integration of those tools. The following suggestions for more in-depth study arose from the preceding discussion.

1. Develop a TFM Human-System Interface Standard. Determine how the human-system interface can encourage the use of the information attributes that produce the best decisions and inhibit strategies that lead to poor decisions. Using findings from this research, develop a human-system interface standard for controls, color, symbols, and other graphic devices in traffic management workstations. The standard would permit

developers to design future tools that are consistent with TFM-M, promote the best decisions, and incorporate boundaries for individual preference sets that discourage errors. It should account for the interdependence of tactical air traffic control and strategic traffic management in terms of staffing, tools, and objectives.

Future displays of traffic situation, metering fix arrival, and NAS resource demand are likely to present additional categories of information about traffic, airspace, and constraints and require additional controls. Decisions about what to code using colors, symbols, graphical features, and text, which attributes and features to present together, and how to make additional details available as needed will become increasingly important to at least maintain the current ease of using ETMS, FSM, and other tools. These decisions should facilitate TFM decision making by presenting only the required information and only when it is needed. Although it may appear simplest to allow traffic managers to choose their own individually preferred display attributes, a standard for new tool developers on the boundaries for these “individual preference sets” is needed to prevent inappropriate choices.

A comprehensive examination should be conducted to fill gaps in the understanding of how TFM decisions are made. It should include identifying factors that contribute to particular types of error or non-optimal decisions, and whether the way in which information is presented contributes to or can prevent them. It should also determine whether different strategies are employed by different TMCs and with what results. If different strategies are used and some lead to better and some to worse system performance, then it may be possible to use information display to encourage TMCs to use the better strategies. This examination must take into account the collaboration and time constraints that typify effective TFM decision-making.

The effort should result in a human-system interface standard for controls, color, symbols, and other graphic devices in traffic management workstations. It should update and extend previous recommendations for the use of color in ATC displays (Cardosi and Hannon, 1999) and incorporate relevant, recent results (e.g., Yuditsky et al., 2002). The standard would promote color and symbol choices that would be easily identified and discriminated and would prompt traffic managers to adopt beneficial TFM strategies. It should account for the interdependence of tactical air traffic control and strategic traffic management in terms of staffing, tools, and objectives.

Failure to adopt an HSI standard would adversely affect the development of a consistent, usable interface and would thus increase the likelihood of human error. Developers would continue to produce tools that differ in important respects from the legacy system, which would first need to be identified, and then require costly late design modifications prior to their integration. The opportunity to improve system performance through a standard based on research on how the HSI affects TFM decisions should not be wasted.

2. Conduct an experimental evaluation that compares implicit to explicit coordination.

Farley et al. (2001) conjecture that increased awareness of traffic conditions in neighboring facilities would result in “implicit coordination” yielding a reduction in communications workload. It is necessary to examine this effect particularly because uncoordinated actions could have positive or negative consequences. For example, it is possible that a TRACON would slow the traffic rate approaching a runway at the same time that the tower decides to use an additional runway to handle the approaching traffic. Several questions should be examined:

- Does implicit coordination occur and if so, how often and to what extent does it reduce the need for explicit coordination?
- Is there evidence of duplicative or incompatible actions?
- Considering the frequency and extent of the reduction in explicit coordination, what is the effect of implicit coordination on communications workload?
- If negative effects of implicit coordination are found, do the findings suggest procedural ways of preventing their occurrence while retaining all or some of its benefits?

A true business case for TMA and SMS cannot be obtained if the verification of anticipated workload benefits is omitted. This study is also required to support the development of procedures to prevent the omission of necessary coordination while accommodating implicit coordination when and where it is safe.

3. Investigate whether tools such as TMA increase situational awareness of neighboring facilities, increase traffic flow, and/or enhance inter-facility cooperation.

A TMC at Los Angeles Center reported that TMA appeared to increase the acceptance rate at Southern California TRACON. Assuming this is correct, a possible explanation is that the CTAS timeline display allows TMCs at a TRACON to understand the urgency of the demand at the overlying ARTCC. For example, it could show that the demand is about to result in a need for the Center to hold traffic at a Center-TRACON boundary fix. This understanding may provide them with a rationale to increase their acceptance rate, justifying the additional workload. Alternatively, the ability of Center TMCs to use CTAS timelines to monitor TRACON traffic could cause or contribute to the higher acceptance rate because Center TMCs would see whether it was reasonable for the TRACON to refuse to accept additional traffic. If the first explanation is correct, then one could expect a TRACON to increase its acceptance rate or take other actions to reduce Center traffic demand without explicit coordination (apart from potential issues concerning “implicit coordination”). If TMA enhances inter-facility cooperation, one could expect TMA to alleviate some of the “environment of ‘protectionism’” that Farley et al. suggest (2001, p.6) is “not conducive to productive collaboration.” However, the highly differing views on the usefulness of TMA from TRACON and ARTCC that were found in this study suggest that the opposite may be occurring.

Reports that controllers do not accept the time-based metering that forms that basis of TMA (National Research Council, 2004) should motivate a comprehensive examination that goes beyond its effects on traffic flow, per se. The examination should also include its effect on TMC awareness of other neighboring and under/overlying facilities’ traffic situations, whether it encourages cooperative decisions, and its effects on other aspects of CDM such as the time taken to reach agreement on initiatives. These effects should be better understood before TMA is further integrated into TFM workstations. If they are not, then the risk will remain that further integrating TMA into TFM could interfere with CDM.

4. Determine whether additional NTML functionality would further reduce the amount of telephone communications required to implement traffic management initiatives and restrictions.

Human factors study is needed to determine the categories of information that can be transmitted “electronically” through NTML and those that will continue to require telephone or person-to-person voice communication. When traffic managers are working under time pressure, telephone calls should be reserved for urgent and time-sensitive communication, such as calls from OS/CICs regarding sector conditions, and calls requesting release of APREQ departures in the immediate future. In contrast, inter-facility discussion of developing NAS constraints can probably not be efficiently conducted electronically. An analysis of the number and purpose of TFM communications that occur during the development and implementation of TMI initiatives, altitude and speed restrictions, and their revision, is needed as a first step in deciding whether additional NTML functionality could reduce the telephone communications that these activities currently require. It would also indicate the types of initiative that would yield the highest reduction in communications workload if the appropriate functionality were incorporated into NTML. Some messages will require explicit acknowledgment that they were received. Although this currently occurs by telephone, at least some types of acknowledgement could probably occur electronically. If a facility needs to repeat specific routes, MIT values, or aircraft identification to ensure mutual understanding the electronic acknowledgement could include a checklist with these specifics. Traffic manager interaction with the NTML HSI must require the least amount of time possible because many entries are currently required and there are plans to increase NTML usage. The additional functionality may require HSI modifications, for example, to group entries and information display by type of initiative and/or restriction. Issues such as the potential for data entry errors would require evaluation, as would time and workload comparisons between NTML and telephone or person-to-person communication. The occurrence of follow-up telephone calls should be examined as possibly indicating that insufficient information is available from NTML for coordinating the particular initiative or restriction.

GLOSSARY

AAR	Airport Acceptance Rate
ACD	ARTS Color Display
ADTOT	Arrival/Departure Tradeoff Optimization Tool
ASDE-X	Airport Surface Detection Equipment Model X
APREQ	Approval Request
ARMT	Airport Resource Management Tool
ARTCC	Air Route Traffic Control Center
ARTS	Automated Radar Terminal System
ASP	Arrival Sequencing Program
ATCSCC	Air Traffic Control System Command Center
ATCT	Air Traffic Control Tower
CCFP	Collaborative Convective Forecast Product
CDM	Collaborative Decision Making
CIC	Controller-in-Charge
CIWS	Corridor Integrated Weather System
CTAS	Center TRACON Automation System
CWSU	Center Weather Service Units
DSP	Departure Spacing Program
DST	Decision Support Tool
DSR	Display System Replacement
EDCT	Estimated Departure Clearance Time
EPIC	Enhanced Planning and Integrated Coordination
ESIS	Enhanced Status Information System
ETMS	Enhanced Traffic Management System
FCA	Flow Control Area
FDIO-GI	Flight Data Input Output - General Information
FSM	Flight Schedule Monitor
GDP	Ground Delay Program
GOES	Geostationary Operational Environmental Satellite
HSI	Human-System Interface
IIA	Integrated Impact Assessment
ITWS	Integrated Terminal Weather System
MAP	Monitor Alert Parameter
MIT	Miles-in-Trail
MOA	Military Operations Area
NAS	National Airspace System
NCT	Northern California TRACON
NOTAM	Notice to Airmen
OIS	Operational Information System
OS	Operational Supervisor
RAPT	Route Availability Planning Tool
SAIDS	Systems Atlanta Information Dissemination and Display System

SCT	Southern California TRACON
SMS	Surface Management System
TBM	Time-Based Metering
TFAS	Traffic Flow Automation System
TFM	Traffic Flow Management
TFM-M	Traffic Flow Management Modernization
TFMRD	Traffic Flow Management Research and Development Plan
TMA	Traffic Management Advisor
TMA-MC	TMA Multi-Center
TMA-SC	TMA Single Center
TMC	Traffic Management Coordinator
TMI	Traffic Management Initiatives
TMS	Traffic Management Specialist
TMU	Traffic Management Unit
TRACON	Terminal Radar Approach Control
TSD	Traffic Situation Display
WARP	Weather and Radar Processor

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