Proceedings of the 2005 Winter Simulation Conference
M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, eds.

COMMUNICATIONS, NAVIGATION, AND SURVEILLANCE EVENTS SIMULATION FOR THE NATIONAL AIRSPACE SYSTEM

Paul T. R. Wang
Leonard A. Wojcik
Scott B. Mayer

The MITRE Corporation
Center for Advanced Aviation System Development
7515 Colshire Drive
McLean, VA 22102, U.S.A.

ABSTRACT

The National Airspace System (NAS) is a large and complex system encompassing a wide-range of resources to enable safe and efficient air transportation. To effectively manage the NAS, it is very important to be able to reliably assess current and future demand for communications, navigation, and surveillance (CNS) resources as they are triggered by air traffic control (ATC) events. The authors present an integrated model that is capable of relating NAS ATC events to NAS CNS demand. Model validation with a subset of recorded ETMS CNS statistics will be presented. Combining such a model with NAS future demand predictors such as Terminal Area Forecasts (TAF) and Future Aviation Timetable Estimator (FATE), it becomes possible to estimate the increase in CNS demand and future requirements for CNS capacity, for resource planning purposes. The model presented in this paper includes tracking of radar-related messages and sector workload.

1 INTRODUCTION

The MITRE Corporation's Center for Advanced Aviation System Development (CAASD) has developed a suite of state-of-the-art simulation tools for the National Airport System (NAS). One of the tools simulates both international and NAS-wide air traffic control events at progressively detailed levels of granularity (Wieland, 2004). The model is written in Simulation Language with eXtensibility (SLX) (Wolverine Software Corporation, 2003). This paper shows how such a simulation tool can be extended and used to generate communications, navigation, and surveillance (CNS) events that are triggered by air traffic control (ATC) events such that the demand on resources related to NAS CNS may be simulated, predicted, and quantified. ATC events and NAS CNS events are coupled and so the impact of ATC procedural changes needs to be analyzed in the context of CNS capabilities. Similarly, deployment of new CNS capabilities needs to be analyzed in the context of ATC procedures. To capture the coupling between CNS and ATC, the model described in this paper includes simulation of ATC-triggered CNS events. Some limited validation of this approach is provided.

2 THE NAS TRAFFIC SIMULATION MODEL

The scope of the NAS simulation includes the following major components: flight itineraries, airspace geometry, airport operations, en route activities, traffic flow control procedures, and aircraft maneuvers. CNS messages between ground facilities and aircraft can take the form of periodic radar signals, event-driven data packets, and voice messages. The scope, intensity, occurrence, and distribution of both the periodic and event-driven CNS messages provide a useful reference for CNS resource planning and procedural changes. The profiles for peak and future CNS demand are also very useful simulation results. The following events are simulated in the model: airport operations such as taxiing in and out, queuing for takeoff or landing, handoff between the terminal area and en route sectors, handoff between en route sectors, center crossing, flight conflict detection, flight amendments, and headlight events for top descend, center crossing, sector crossing, aircraft proximity, etc. are also simulated. CNS messages that are transmitted or triggered by these ATC events are identified and simulated as well. The resulting discrete event simulation was implemented using SLX through the technique of triggering related events from among parallel threads of processes. Future enhancements to the model may include the tracking of flight amendments, flight reroutes, and surveillance-related triggering events such as conflict detection and early warning simulation. Model animation in Proof (Wolverine Software Corporation, 2004) is also facilitated by the model

3 TRIGGERED CNS EVENTS SIMULATION FOR NAS

CNS events associated with NAS may be grouped into three major categories: navigation and surveillance-related radar messages, data communications, and voice communications between pilots and air traffic controllers. Various messages may be generated to effectively facilitate the management of these events.

Figure 1 illustrates the coupling of the ATC simulation with the CNS simulation. The detailed simulation of CNS can provide input to the ATC simulation, including message type and size, protocol-related overhead, and channel utilization. And, CNS demand profile and resource utilization may be derived from the output of appropriate simulated ATC scenarios that include CNS event triggering.

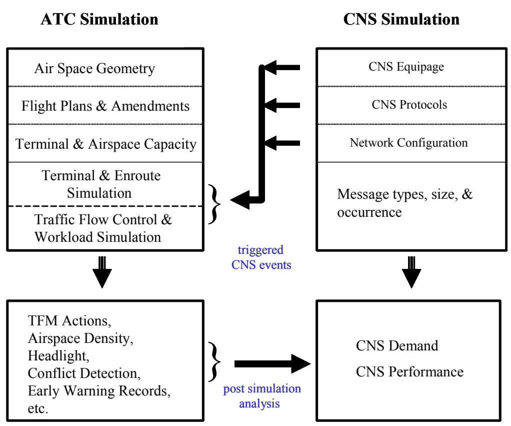

Figure 1: Coupling ATC Simulation with CNS Events

As a test case for simulating CNS in the NAS, we considered key CNS messages recorded in the Enhanced Traffic Management System (ETMS) (Volpe Center, 2000) and National Offload Program Archive (NOP) (The CAN Corporation, 2004) databases. Table 1 illustrates different types of recorded ETMS messages and their associated ATM events.

Messages recorded in ETMS containing aircraft tracking messages such as HB, TZ, and TO are transmitted periodically while flight control messages such as FZ, DZ, AZ, UZ, RT, and AF are triggered as ATM-related events. Flight control messages may or may not trigger data and/or voice messages between the pilot and air traffic controller.

The occurrence, intensity, size, and scope of CNS messages are determined by several factors: aircraft type, onboard equipage, air/ground communication protocol and procedures, and terminal or en route events. For example, the volume of air/ground data and voice communications is related to both the density of aircraft and the spacing of these aircraft within a given airspace. Such tightly coupled relationships between ATC events and CNS events provides the argument that the discrete event simulation of NAS-wide ATC events can also be a very powerful tool for the study of CNS requirements and resource planning for the NAS. The NAS-wide ATC simulation tool used at MITRE does provide the following key capabilities:

1) Gate-to-gate simulation of both scheduled and unscheduled flights
2) Flight spacing at selected control points
3) Conflict detection and aircraft proximity
4) Aircraft density over specified airspace
5) Key traffic management procedures such as ground delay programs (GDP), ground stops (GS), and miles-in-trail (MIT) restrictions
6) Predictive dynamic airspace aircraft density (sector loading)

Table 1: ATM Messages in ETMS

ETMS Message Type	ATM Events	ETMS data size
FZ	Flight Plans	26 to 62 byes or more
DZ	Flight Departures	30 to 59 bytes
RZ	Flight Cancellations	12 to 41 bytes
UZ	ARTCC Boundary Crossing	30 to 55 bytes
AZ	Flight Arrivals	15 to 41 bytes
AF	Flight Amendments	15 to 46 bytes
RT	Route Messages	15 to 72 bytes or more
TO	Oceanic Position	35 to 80 bytes
TZ	Flight Tracking	26 bytes to 36 bytes
HB	N/A	14 bytes

Table 2 lists most of the ATC related events that are available to trigger data or voice messages for CNS activities.

Table 2: ATC Related Data and Voice Messages

ATC Events	CNS Messages	Major Type
Flight Takeoff	Request, Deny, Ack, Accept, On Hold, etc.	voice & data
Aircraft Maneuver	Descend, Ascend, Heading, Speed Changes, etc*.	voice & data
Boundary Crossing	Request, Reject, Ack, Accept, Wait etc.	voice & data
Anticipated Events**	Proximity (crossing), Early Warning (conflict)	voice & data
Flight Landing	Request, Deny, Ack, Accept, On Hold etc.	voice & data
Taxiing In/Out	Request, Assign, Ack, Accept, On Hold etc.	voice & data
Route Tracking	Report	data
Route Changes	Request, Ack, Accept, and Report	voice & data

* spacing & vectoring inculded ** referred to as headlight events

4 COUPLING ATC EVENTS WITH CNS EVENTS IN SIMULATION

The coupling of ATC events and CNS events may be implemented in many different ways. For irregular or non-periodic CNS events, a single CNS statistics generator may be created to manage all CNS events embedded within various ATC events as shown in Table 2. For CNS messages that are generated periodically such as the TZ and TO messages produced when a flight is airborne, dedicated CNS event generators may be created for the specific time period when a flight is airborne and the generators can be deactivated when the flight is no longer airborne. For anticipated CNS events such as boundary crossings, scheduled CNS messages, and early warning for conflict avoidance, the events can be embedded within the existing ATC en route simulation relatively simply.

5 VALIDATION OF ETMS CNS MESSAGES SIMULATION

One way to begin validation of a CNS event simulation is to determine how close the profile of recorded NAS CNS data matches with the simulated results. The profile of CNS statistics includes both event and the related message size distribution. It is possible to simulate both the CNS event occurrence and the distribution of recorded message size. In this paper, we show an example where the occurrence of recorded CNS events closely matches with simulation. This validation test requires detailed profiling of recorded CNS statistics in actual operations; these data can then be compared using appropriate statistics functions applied to CNS events generated by the simulation.

Figure 2 plots recorded NAS ATC event message counts in ETMS for a typical good weather weekday (June 15, 2004).

We have embedded the key NAS surveillance radar and ATC event messages, namely, AZ, DZ, UZ, RT, and TZ within the SLX NAS-wide simulation. Figure 3 shows results for a three-day simulation that used ETMS as the data source for demand. The results would be much closer to that of Figure 2 if flight amendments are also simulated.

A comparison of the recorded ETMS ATC event message counts with the simulated message counts is shown in Figure 4. Note that this comparison includes only those messages embedded in the simulation.

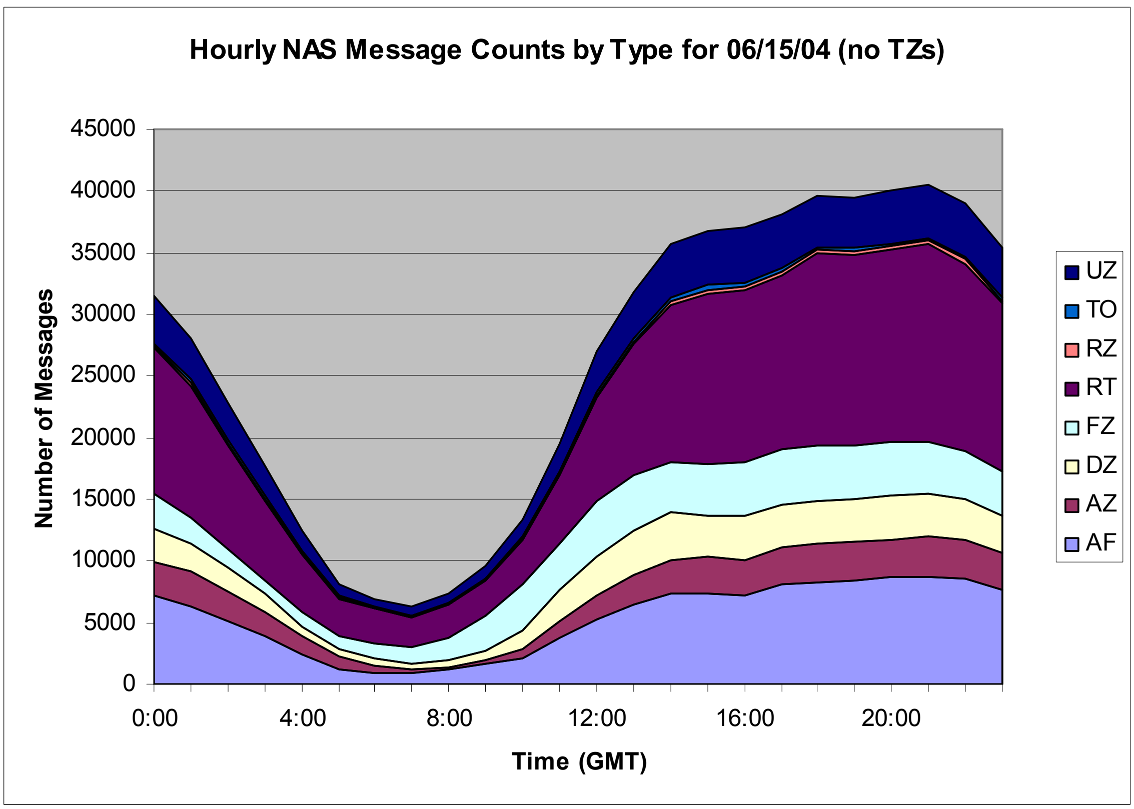

Figure 2: Recorded NAS ATC Event Messages

As CNS events are triggered and embedded in the ATC simulation, it is possible to track specific message counts by time (hourly, daily, etc.) or regions (centers, sectors, terminals, etc.).

Figure 5 illustrates the matching of simulated TZ message counts with that of the recorded data in ETMS over a 24-hour period. Note that the difference between recorded profile and simulated profile is partially due to weather, wind, and other ATC events that were not simulated. The difference between recorded ETMS profiles on different days can far exceed the difference between the recorded ETMS profile and the simulated profile for the same day generated by our model due to the unpredictability of daily ETMS profiles.

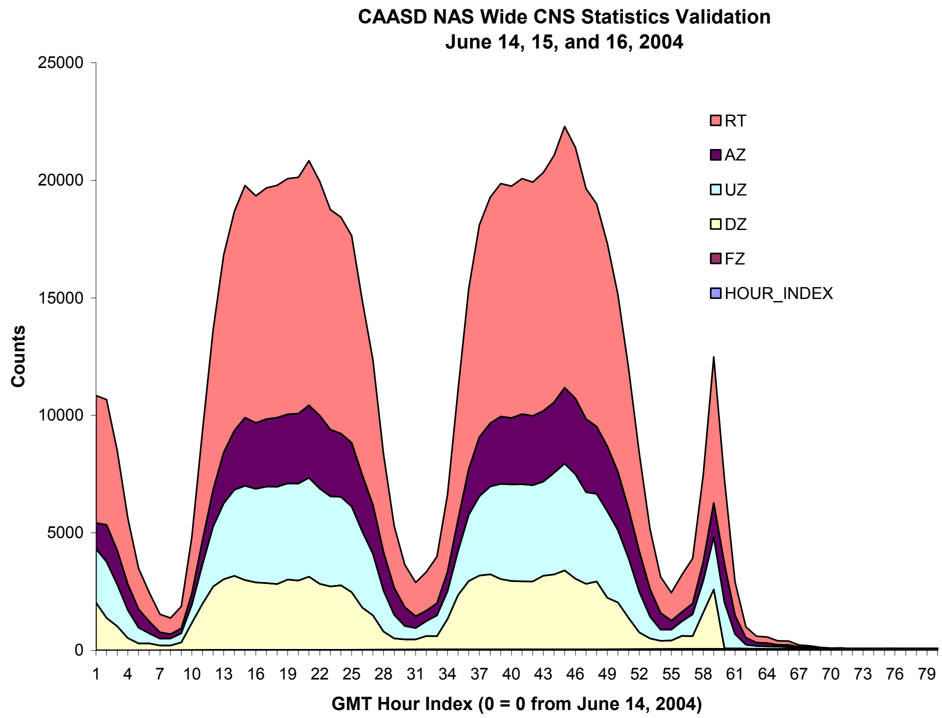

Figure 3: Simulated NAS Surveillance Radar Messages

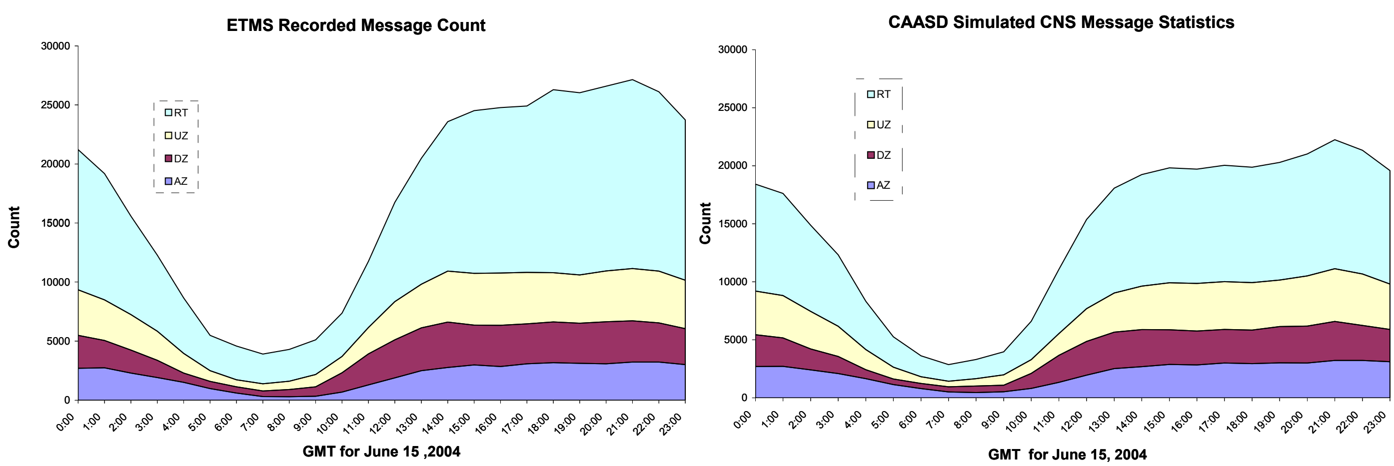

Figure 4: A Validation of NAS CNS Message Simulation

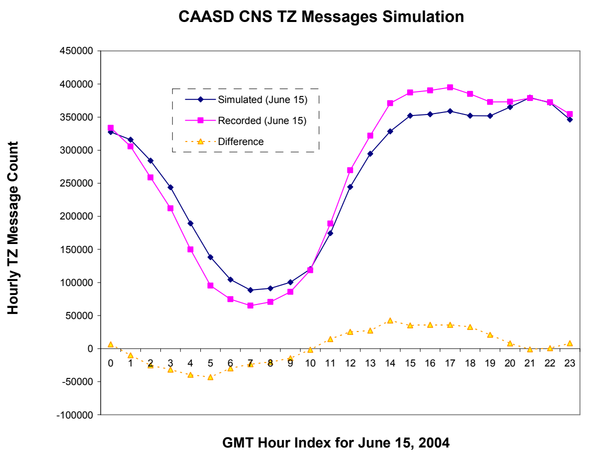

Figure 5: A Simulated TZ Message Profile Over Time

6 CNS WORKLOAD SIMULATION

Embedded CNS events within a NAS simulation can also reflect demands or workload for both ATC controllers and CNS equipment. For example, the workload (controller or CNS messages) related to flight handoffs from sector to sector may be computed and simulated as the following sum:

$$W_x(\Delta T) = \sum_{s=1}^{N_x} \{ f_{si}(\Delta T) w_{si} + f_{so}(\Delta T) w_{so} \}$$

$$W(\Delta T) = \sum_{x=1}^{N} W_x(\Delta T)$$

where ΔT is the simulated time interval.
$\boldsymbol{x}$ is a sector identifier.
N_x is the number of sectors adjacent to *x*.
N is the total number of sectors.
f_{si} is the number of handoffs from the *s*-th adjacent sector during ΔT.
f_{so} is the number of handoffs to the *s*-th adjacent sector during ΔT.
w_{si} is the workload associated with a handoff request from the *s*-th adjacent sector .
w_{so} is the workload associated with a handoff request to the *s*-th adjacent sector.

Note that $W(\Delta T)$ and $W_x(\Delta T)$ are related to the staffing or CNS equipage requirement during the time period ΔT. With CNS events embedded in the ATC simulation, one can start a scenario with flight plan or scheduled itinerary information, and dynamically update $W(\Delta T)$ as both ATC and CNS events unfold during the simulation.

Similarly, we can quantify some of the workload (either communications or controllers), $W_a(\Delta T)$, attributed to flight amendments (AF) as follows:

$$W_a(\Delta T) = \sum_{i=1}^{n} f_i(\Delta T) w_a$$

where n is the number of flights simulated
f_i is the number of amendments applied to the *i*-th flight
w_a is the workload associated with each flight amendment.

Figure 6 illustrates a snapshot of a typical simulated $W(\Delta T)$ for a selected region within the NAS. For each sector, *x*, we simplify its total workload by setting $w_{si} = w_{so} = 1$ for every handoff to or from the sector; hence, the simulated $W_x(\Delta T)$ is the count of handoff requests to and from sector *x* during ΔT.

Figure 6 presents a sample workload profile over time for a selected region within the NAS. This workload matrix is simulated and recorded during initialization; it is dynamically updated as the simulation clock moves forward in time. Profiles such as Figure 6 may reveal where peak demand in ATC or CNS may occur and its intensity quantified. Such workload profiles produced by simulating the coupling of ATC and CNS events can be used to predict and allocate communication equipage, staffing and other resources. Together with other CNS simulations in protocols, signal in space, and channel utilization, near optimal usage of both human and equipment resources may be accomplished.

7 SUMMARY

In summary**,** we illustrate the concepts of embedding CNS events in one of the existing NAS-wide ATC simulation model at CAASD to produce CNS message counts and statistics that can be validated with recorded ETMS message counts. We also illustrate the feasibility of producing quantified controller or CNS workload associated with key ATC events over specific region of airspace and time interval and its potential applications in predicting NAS-wide hot spots and its workload intensity contributed by flight schedules, simulated flight delays, weather conditions, operation procedures, and/or route changes for more effective air traffic flow control, staffing, and CNS resource allocation.

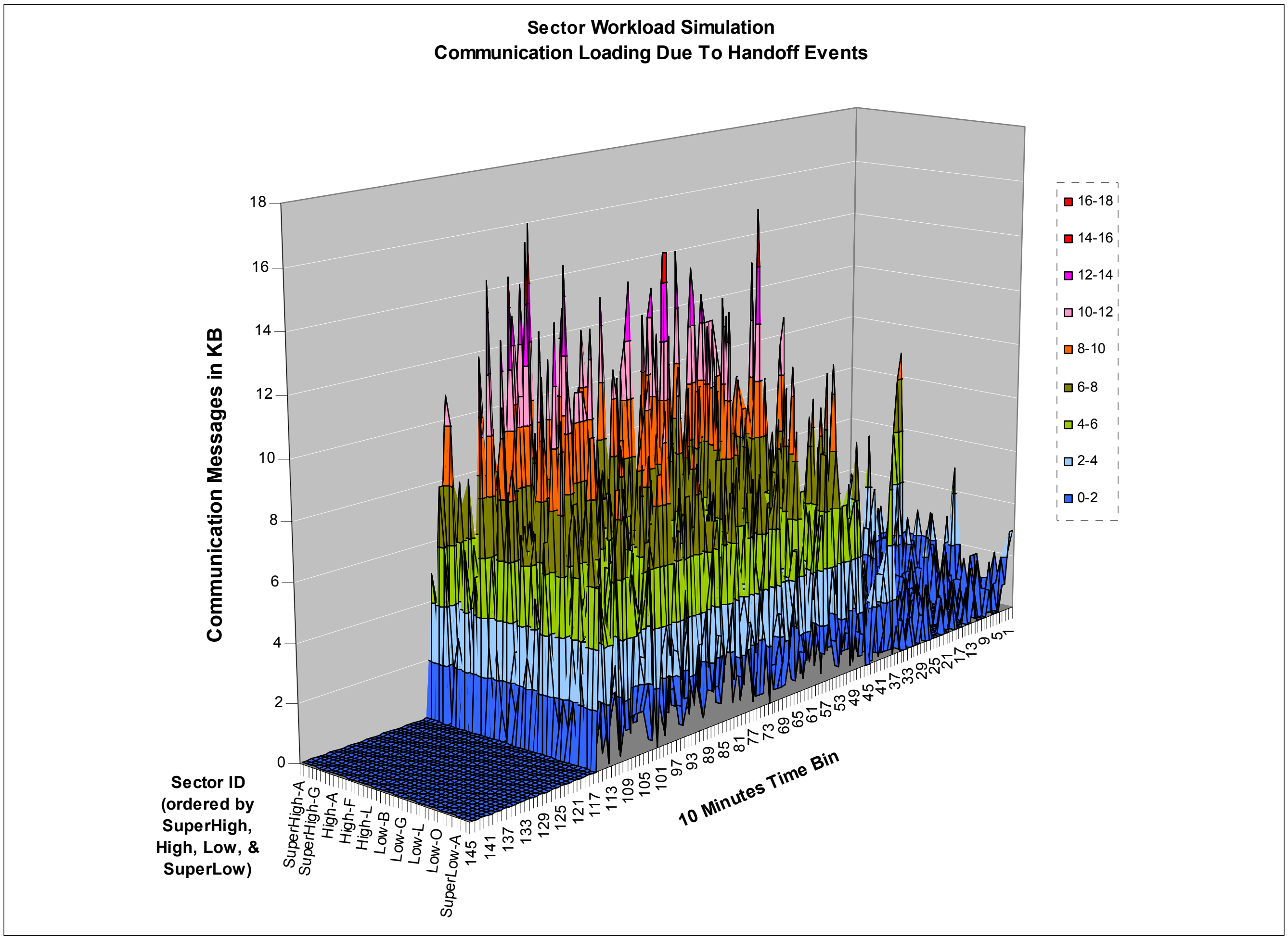

Figure 6. Sample NAS Airspace Workload Simulation

ACKNOWLEDGMENTS

The authors acknowledge Dr. Frederick P. Wieland for leading the team that developed MITRE's NAS-wide ATC simulator in SLX. We also acknowledge our colleagues, Thomas C. Holden and Noam Tene for their efforts in providing queries that prepared input data for this study. Peer review of the paper by Dr. Leone Monticone, and Mr. George H. Solomos are also greatly appreciated.

DISCLAIMER

The contents of this document reflect the views of the authors and The MITRE Corporation and do not necessarily reflect the views of the Federal Aviation Administration (FAA) or the Department of Transportation (DOT). Neither the FAA nor the DOT makes any warranty or guarantee, expressed or implied, concerning the content or accuracy of these views.

REFERENCES

Daniel T. Brunner and James O. Henriksen, 2003. Wolverine Software Corporation, Simulation with SLX.

Dipasis Bhadra, Jennifer Gentry, Brendan Hogan, and Michael Wells, 2003. Future Aviation Timetable Estimator, MITRE/CAASD.

Emily Beaton and Scott Mayer, 2004. Workload Analysis Update, MITRE/CAASD.

Federal Aviation Administration, 2003. U.S. Department of Transportation, Terminal Area Forecast Summary, FAA APO-03-2.

Fredrick P. Wieland, 2004. Next Generation Model of the National Airspace System, MITRE Technology Program briefing at MITRE/CAASD.

Jim Baney, 2004. The CAN Corporation, Overview of National Offload Program Archive.

Transportation Research Board, 2002. The National Academies, A Review of the Small Aircraft

Transportation System Concepts, Special Report 263.
Volpe Center, 2000. Aircraft Situation Display To Industry:
Functional Description and Interface Control Document, Version 4.0.
Wolverine Software Corporation, 2003. Simulation with SLX, by Daniel T. Brunner and James O. Henriksen.
Wolverine Software Corporation, 2004. Using Proof Animation. Third Edition.

AUTHOR BIOGRAPHIES

PAUL T. R. WANG has been with the MITRE Corporation Center for Advanced Aviation System Development (CAASD) since 1984. He graduated from The Ohio State University with MS and PhD degrees. His interests include optimization, modeling, simulation, and queuing theory. Paul's work on simulation and optimization were published by WSC, ORSA, DASC, *Air Traffic Control Quarterly*, AIAA, and the *Journal of Computer Networks and ISDN Systems*. His e-mail address is pwang@mitre.org.

LEONARD A. WOJCIK is a Project Team Manager at the MITRE Corporation Center for Advanced Aviation System Development (CAASD). He has been at MITRE for over twenty years, and currently leads a group doing system-wide modeling of the National Airspace System. He holds a Ph .D. from Carnegie-Mellon University in engineering and public policy, and M.S. and B.A. degrees in physics from Cornell and Northwestern University, respectively. His e-mail address is lwojcik@mitre.org.

SCOTT B. MAYER has been with the MITRE Corporation Center for Advanced Aviation System Development since 1997 where he has been involved with the development and maintenance of air traffic decision support system prototypes. Prior experience included software development efforts for Singer/Link, Litton/Amecom, Ford/Aerospace, Loral, and Lockheed/Martin on a variety of applications which have included C2 & ASW Simulations, Electronic Warfare, and Satellite Ground Control Systems. His e-mail address is smayer@mitre.org.