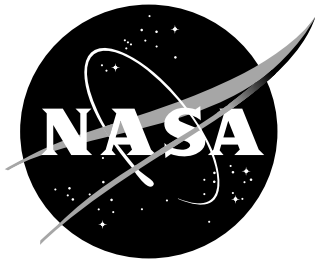


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Integrating LMINET With TAAM and SIMMOD

A Feasibility Study

*Dou Long, Virginia Stouffer-Coston, and Peter Kostiuk
Logistics Management Institute, McLean, Virginia*

*Richard Kula and Berta Fernandez
Landrum & Brown, Chicago, Illinois*

June 2001

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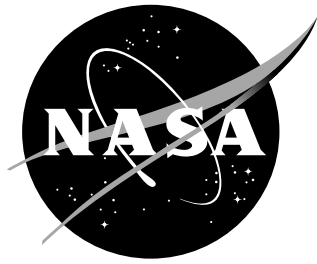
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National Aeronautics and
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Chapter 1

Methodology for Integrating Air Traffic Simulation Models

INTRODUCTION

The National Aeronautical and Space Administration (NASA) is undertaking an ambitious program in advanced air traffic management (ATM) research to explore, test, and demonstrate 21st-century technologies required to enable safe and efficient air travel. With significant changes expected in technologies, ATM procedures, and roles and responsibilities of various interested parties, it is necessary to construct a modeling and simulation infrastructure to explore the multidimensional performance of proposed concepts and system changes.

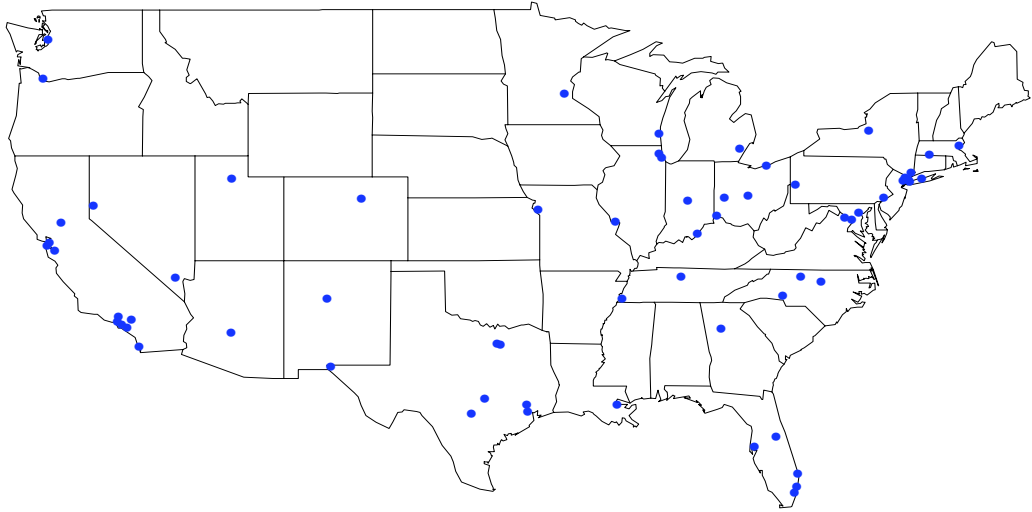
LMINET is a queuing network model of the entire National Airspace System (NAS) developed by LMI for NASA [1,2,3,4]. Presently, LMINET is implemented at 64 airports (Figure 1-1).¹ These airports account for approximately 85 percent of domestic commercial air transport enplanement and more than 80 percent of air carrier operations. The LMINET airports are a superset of the Federal Aviation Administration's (FAA's) 57 pacing airports in air traffic studies.

In general terms, LMINET models flights among a set of airports by linking queuing network models of airports with sequences of queuing models of the Terminal Radar Approach Control (TRACON) and Air Route Traffic Control Center (ARTCC) sectors. Based on the solutions of the analytical queuing equations, LMINET offers a fast simulation mode of the NAS. Because the network effect of the delays are considered for the moving aircraft, it is a valuable air traffic simulation model for a national air traffic study.

The Total Airspace and Airport Modeler (TAAM) and SIMMOD are two widely used simulation models of airport and airspace with varying degrees of sophistication [5,7]. These event-driven simulation models consider all aircraft operations second-by-second. A high degree of fidelity is achieved with TAAM or SIMMOD; thus, these models are more accurate in generating the air traffic statistics. Appendices A and B provide brief introductions to TAAM and SIMMOD, respectively.

¹ The 64 airports, by their codes, are ABQ, ATL, AUS, BDL, BNA, BOS, BUR, BWI, CLE, CLT, CMH, CVG, DAL, DAY, DCA, DEN, DFW, DTW, ELP, EWR, FLL, GSO, HOU, HPN, IAD, IAH, IND, ISP, JFK, LAS, LAX, LGA, LGB, MCI, MCO, MDW, MEM, MIA, MKE, MSP, MSY, OAK, ONT, ORD, PBI, PDX, PHL, PHX, PIT, RDU, RNO, SAN, SAT, SDF, SEA, SFO, SJC, SLI, SMF, SNA, STL, SYR, TEB, and TPA.

Figure 1-1. LMINET Airports



Because TAAM and SIMMOD must consider every detail of an aircraft operation, building a model for an airport or an airspace takes a long time. The data and effort required to develop network versions exceed the resources available for most studies.

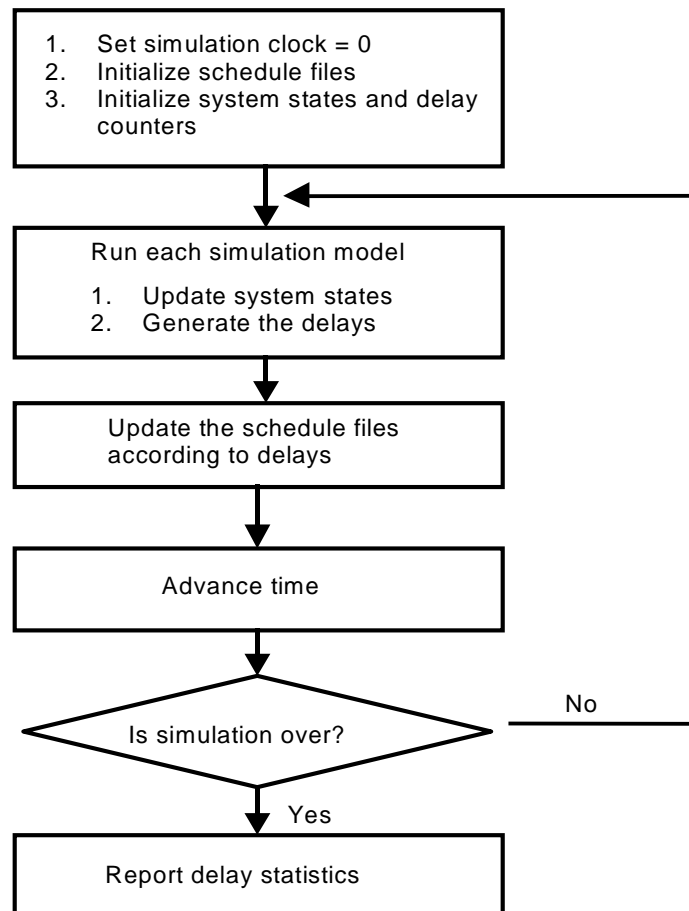
This report details the results of a feasibility study for integrating LMINET with TAAM and SIMMOD. The perceived benefits of such integrated models are two-fold: With a high-fidelity TAAM or SIMMOD model to substitute for a local model in LMINET, we improve the accuracy of reported air traffic statistics for the NAS. With LMINET regulating the demand to an airport modeled by TAAM or SIMMOD, the demand to the airport better reflects the network effect of the NAS and the reported air traffic statistics at the airport will be more accurate. For this project, we performed the following tasks:

1. Propose the model integration methodology.
2. Demonstrate the feasibility of the model integration.
3. Demonstrate the benefit of the integrated simulation.
4. Identify issues for a full-blown integrated model.

INTEGRATION METHODOLOGY

In an integrated air traffic simulation model, although we may be interested only in air traffic statistics and delays reported in specific areas or for the whole system, the entities being modeled are moving aircraft, which result in inter-related air traffic demand. The general methodology of an integrated air traffic simulation model is depicted in Figure 1-2. This figure is a general schematic at the conceptual level, where the individual models can take any form from LMINET, to TAAM and SIMMOD, or any other simulation models, regardless of the simulation methodology and data requirements. Before the start of the simulation, one should prepare the initial flight schedule files for all of the models involved and initialize the system state and the various statistic counters. The initial flight schedule file can be based on the published schedule, which is a place-time table that—barring any disturbances resulted from bad weather, mechanical failure, airport or airspace congestion, and so forth—all aircraft will meet. Although the physical computer schedule files are created by convenience of management (e.g., a schedule table for all models), there should be a separate schedule file for each air traffic management entity conceptually (i.e., airport or airspace).

Figure 1-2. Schematic of General Integrated Simulation Models



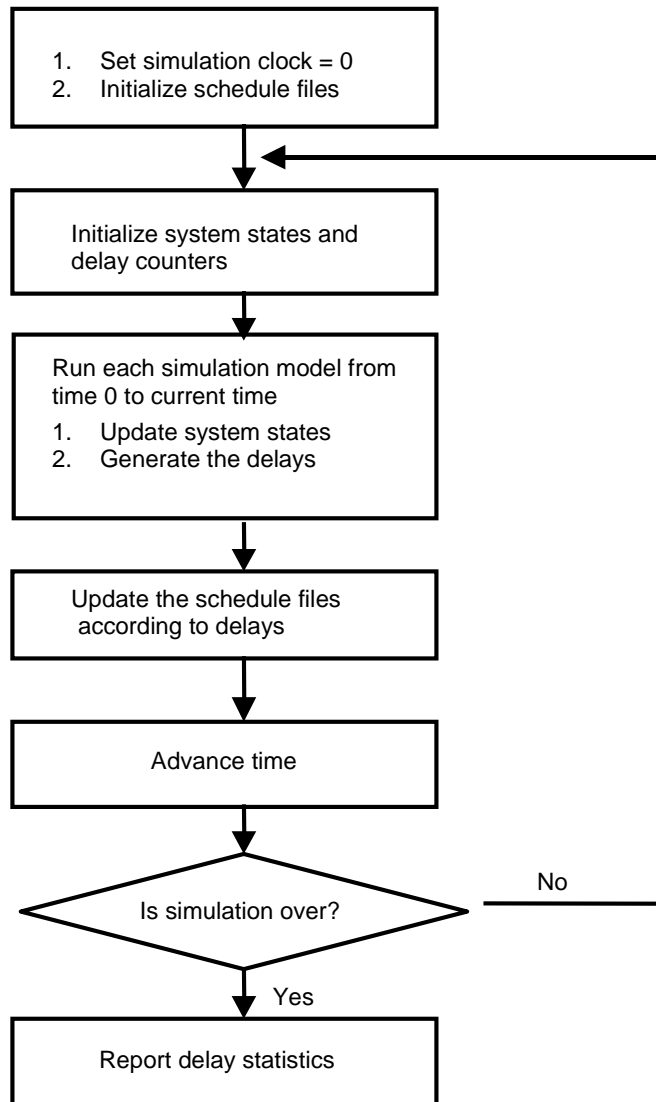
Simulation models will be run at one time unit at a time, typically for a few representative days. Because most commercial flight schedules repeat daily, we must run the model for a whole day. The daily difference in schedules can be analyzed by running the schedules for different days. At the end of each simulation epoch, the delays are computed and are fed to modify each schedule file in the integrated model. Aircraft delays and schedule modifications are the only link between the models. LMINET, which is an air traffic simulation model of the entire NAS, is actually modeled in this fashion. Within LMINET, 64 airport delay models and a couple of hundred airspace delay models run simultaneously within each time epoch (one hour); at the end of each epoch, the delays are computed and are fed to schedule files of each airport and air traffic control sector to modify the schedule for the rest of the day. Constructing the aircraft schedule file is much less time-consuming than building other parts of the model for TAAM and SIMMOD, so integrating LMINET with TAAM or SIMMOD is a quick way to gain the benefit of both models.

Although TAAM and SIMMOD take detailed consideration of aircraft operations, the aircraft interactions considered are all within the perimeter of the model (e.g., an airport). As outlined by our general methodology, the interaction of aircraft operations outside the perimeter of the model is through modification of aircraft schedules. TAAM and SIMMOD cannot be run interactively, or they can be run only in the batch mode that the models run the simulation through once the schedule is given. One cannot modify schedule files even for flights that occur before the system clock. Thus, TAAM and SIMMOD must be stopped at the end of each epoch in order to collect delays and modify the schedules for the rest of the day. Worse yet, TAAM and SIMMOD can have only a “cold start”—that is, at the beginning of the each simulation model, the airport is assumed to be completely empty. If we assume the schedule is fixed for an air traffic simulation at an airport, “cold start” is a reasonable assumption if one uses the model to simulate air traffic on a day that typically starts in the early morning when air traffic demand is nonexistent or close. “Cold start” rules out another possibility of running the model at a time with the most current schedule but with the system state at the beginning of the epoch the same as at the end of the previous epoch.

Our proposed approach to circumvent “cold start” and the rigid schedule files in TAAM and SIMMOD is the Progressive Augmented Window (PAW), depicted in Figure 1-3. Under PAW, the window or period of the simulation is successively increased until the end of the time clock is reached. After initialization of the system clock, the simulation begins. At each iteration, all of the simulation models will be run from the beginning of the day (epoch 0) through the current time epoch. At the end of each iteration, delay statistics are collected and fed to modify the schedules. The window of the simulation will successively increase until it covers the entire day in the last iteration. One can see that PAW avoids “warm start” and the rigid schedule file structure in TAAM and SIMMOD, yet it properly considers the delay impact in the network. The expense of PAW is that we have to repeat the simulation of all previous epochs to run the simulation models for the current epoch. This iterative process wastes considerable computer resources. We

believe, however, that this methodology is the only one that will enable us to have an integrated LMINET-TAAM or LMINET-SIMMOD model, given the current versions of TAAM and SIMMOD.

Figure 1-3. Schematic of Progressive Augmented Window Approach



SIMULATION SETTINGS

The following settings were used in the feasibility study.

- ◆ *Period of simulation.* The integrated simulation involves a total of 21 simulation epochs, starting at 6:00 a.m. Eastern Standard Time. Each epoch lasts one hour; the period of operation covered is 6:00 a.m. through 2:00 a.m. the next day. There is hardly any traffic from midnight to 6:00 a.m.; thus, the period of simulation will give us enough time to cover the time differences in the United States and lingering delays at the end of the day.
- ◆ *Schedule selection.* The airline schedule published by the Official Airline Guide (OAG) for June 19, 1997, plus representative General Aviation (GA) flights is used for LMINET. Air traffic demand from other airports to the LMINET network also is included; this demand, however, is considered isolated and does not have any network effect. The TAAM schedule file is also derived from the same OAG schedule. A similar representative design schedule is created for SIMMOD, which also is based on a summer day OAG schedule in 1997 adjusted for GA traffic. The time and funding of this project do not allow us to create another SIMMOD schedule file; we had to use the SIMMOD model built for another task. For practical purpose, the schedule in SIMMOD model is the same as in LMINET. Maintaining the consistency of the schedule files for the different models is absolutely essential to have valid simulation results because we must ensure that the schedules deal with the same moving aircraft.
- ◆ *Simulation models.* A TAAM model at Dulles International Airport (IAD) and a SIMMOD model at Chicago O'Hare International Airport (ORD) were selected for an integrated LMINET-TAAM and LMINET-SIMMOD feasibility study, respectively. Because the airspace delay is negligible for the total delay in the NAS under good weather conditions reported by LMINET, we omit the airspace delay model runs in LMINET for the integrated study without jeopardizing the validity of the feasibility study [3,4]. Including airspace delay models in LMINET requires more effort and much more computer time to execute LMINET.
- ◆ *Simulation weather.* The actual weather of the NAS for April 8, 1996, is selected. During that day, the NAS enjoyed generally good weather, except isolated bad weather for a few hours in Boston, Seattle, and San Diego [3,4]. Our TAAM model at IAD and SIMMOD model at ORD assume good weather conditions throughout the day.
- ◆ *Collection of delay statistics and modification of schedule.* LMINET can generate the average delay for all departures and arrivals during each epoch at each LMINET airport; TAAM and SIMMOD can generate delay

statistics for each aircraft, as well as average delays. For the feasibility study, we have considered only average delays reported by LMINET, as well as by TAAM and SIMMOD. We did not take full advantage of delay reporting by TAAM and SIMMOD, for this feasibility study. Although LMINET uses the schedule only in terms of aggregate demand for an origin and destination pair within one time epoch, assignment of delays to flights to the TAAM or SIMMOD airport is still possible if all of the schedules used by LMINET, TAAM, or SIMMOD are based on the same schedule. This is why it is so important to use the same schedule to derive the schedule files.

Chapter 2

Integration of LMINET with a TAAM Plus Simulation Model at Washington Dulles International Airport

INTRODUCTION

LMINET is capable of scaling the traffic level of the entire NAS and deriving national schedules. TAAM is capable of very detailed simulations in local areas such as TRACONs or traffic corridors and producing realistic delay measurements. If the two models could be used in tandem, sharing data, the integrated whole would be capable of producing detailed local results and commensurate national traffic levels.

In this chapter we discuss the process we used to integrate TAAM and LMINET, TAAM preprogramming, the challenges and issues in integrating the models demand files and our resolution of those issues, and a flight delay comparison resulting from TAAM simulation runs.

INTEGRATION PROCESS

Integration is being attempted in small steps. For this first project, we first identified inputs and outputs needed to flow between LMINET and TAAM. Because of the nature of each model, we determined that LMINET and TAAM should be run in turns, sharing data, so that the models develop “agreement” on delay and traffic levels. For example, LMINET will be run on a traffic demand file, determine national delay levels commensurate with that demand, then adjust the number of flights and flight times to reflect an acceptable level of delay. One or more hours of LMINET-adjusted flight times (from a limited area of the country) can then be run in a detailed TAAM simulation. TAAM will determine per-flight delays for that area, taking into account current runway capacity, technological enhancements available in that area, and the interaction between flights caused by airspace constraints. Given a newer and more locally accurate level of flight delay for a given area, LMINET can recalculate the day’s schedule. Because LMINET calculates schedules one hour at a time, we decided to proceed by iterating schedules and delay data one hour at a time. This iterative process transfers data between the two models as follows:

1. Appropriate set-up data are input into both models.

-
2. An LMINET-generated flight file is processed to produce a TAAM input flight file.
 3. TAAM is run for the first hour of the day; resulting delay data are fed into LMINET.
 4. LMINET generates a new flight file, which is processed to produce a TAAM input file.
 5. TAAM is run for the first two hours of the day; resulting delay data are fed into LMINET.
 6. And so on.

To achieve this iteration between the models, several capabilities must be demonstrated and tested.

MODEL PREPARATION:

1. Create a bug-free local area simulation in TAAM
2. Reduce OAG for input into LMINET
3. Establish dial-up or co-host connection between TAAM and LMINET

ITERATION:

4. LMINET read-in demand from OAG
5. LMINET generates a flight schedule with acceptable levels of delays for desired technology set
6. Inter-model processing program takes the LMINET flight schedule as input, manipulates it, and outputs a TAAM-acceptable demand file
7. New flight schedule sent to TAAM and loaded into existing simulation
8. TAAM simulation run
9. Inter-model processing program reads TAAM output files (*.rep, *.hst, *.msg) and outputs hourly per-flight delay for relevant flights and number of cancelled flights
10. Results of step 9 input into LMINET
11. LMINET generates second demand file

DERIVATION OF TRAFFIC DAY:

12. Repeat steps 5–11.

Considerable work underlies preparation of a bug-free TAAM simulation; some of that work is detailed in Appendix B. A brief overview is provided in the following section.

PROGRAMMING TAAM PLUS

We used the TAAM Plus simulation model, version 1.1. TAAM is an airspace modeling tool that can simulate all domains, from gate and taxiway movements through takeoff, climb-out, separation conflicts, and separation strategies. It is an aircraft characteristic-based, time-step emulation model that is ideal for detailed flight path modeling.

We modeled the Dulles terminal airspace in great detail, including actual air traffic control sector shapes, nearby airports, and all scheduled traffic flows through the area. Because of the short time allotted for this project, we did not model the ground layout of Dulles beyond the runways; there were no taxiways or gates in this simulation.

Programmed inputs included the following:

- ◆ Dulles International (IAD), Reagan National (DCA), and Baltimore-Washington International (BWI) airports
- ◆ Standard Instrument Departures (SIDs) and Standard Terminal Arrival Routes (STARs), issued October 6, 1999
- ◆ Configuration and runway usage files from Potomac TRACON
- ◆ OAG flight data

Great detail went into programming Dulles STARs and SIDs. A STAR is the arrival path an aircraft takes through the terminal area, from as much as 250 nautical miles away from its destination down to the runway touchdown. SIDs are defined routes that aircraft must follow when they exit a terminal area before entering the cruise portion of their flight. Most holding and maneuvering is made during the SID or STAR portion of the flight.

We were careful to preserve the separate routes used by jets, pistons, and turbo-props. At least one STAR and SID must be programmed for each runway to accept traffic from each arrival fix or feed traffic to each departure fix. Where there are three runways in use at an airport, we programmed three SIDs—one for each departure fix from that runway—and three STARs to route aircraft to the proper runway. To model more than one configuration (e.g., south operations and north

operations), new sets of STARs and SIDs must be programmed for each configuration. Some time can be saved if a particular runway never accepts jets or never accepts turboprops. In those cases, there is no need to program the instructions to bring that type of aircraft to and from the runway.

We mapped the endpoints of SIDs and STARs in use for each airport in each simulation. We sorted the route file for all flights to and from each airport and listed the endpoints of each route. A great deal of programming time was spent to ensure that endpoints of routes matched the endpoints of SIDs and STARs; otherwise, TAAM sends aircraft on a “default” approach or departure. These “defaults” generally contravene a terminal’s standard operating procedures and would render our careful terminal modeling useless. In most cases, we changed the route file, adding arrival fixes and departure gates; in some cases, we found that there were no defined STARs to bring in a little-used route. In those cases, we composed STARs on the basis of controllers’ flow diagrams, radar pictures, and standard operating procedures. Most STARs and SIDs for an airport resemble trees in that all the routes converge on a final pattern to or from a runway end, so there is very little guesswork involved in programming a new SID or STAR.

Separate STARs were programmed for instrument meteorological conditions (IMC) operations because operations in that visibility require a 12-mile final approach. Not all runways are open under IMC; IMC STARs and SIDs were not programmed for non-open runways.

Jets and props were instructed to fly at different altitudes, using the demand file. In the terminal environment, turboprops generally fly 2,000 feet lower than jets on the same route. There are some exceptions; in particular, slow or underpowered jets sometimes will be routed on the turboprop route, and very high performance turboprops can travel along jet routes if they prefer (when congestion is lighter on that route). For example, jets and turboprops arriving to a terminal and entering a “mixing area” often will be sent over or under crossing traffic; high-performance aircraft generally go over (at 8,000 feet or above); lower-performance aircraft go under (at 4,000 feet). An aircraft’s ability to execute steep arrival slopes determines which path it will be directed to. This performance capability is identified in TAAM’s aircraft characteristic file.

The Potomac TRACON modeling group began a convention of creating separate routes for turboprops, jets, and pistons—distinguished by a “.J” or “.P” or “.T” after the route name. For example, the route between Dulles and Orlando generally is called KIADKMCO; the Potomac group has created a new route file in which there are three routes for the same flight:

- ◆ KIAD-KMCO.J
- ◆ KIAD-KMCO.T
- ◆ KIAD-KMCO.P

This naming convention enables modelers to make slight variations of routes on the basis of group aircraft performance, such as the distance the aircraft is allowed to fly out over water or how closely the aircraft must follow navigational aids (NAVAIDS) as opposed to flying direct. Our use of Potomac's route file engendered a few changes in input programming; for example, a route name must be assigned in the demand file by the programmer on the basis of aircraft type, which meant running a few lookup and write routines on all of our demand files. Otherwise, TAAM would assign the first route it saw to all aircraft traveling that city-pair; in this case, the ".J" route because it occurs first in the alphabet. We still had to define just as many STARs and SIDs.

In Washington, all aircraft tend to use the same arrival and departure fix. In this case, the performance variables in the STAR and SID files were set to limit which aircraft opted for a particular SID or STAR. For instance, KIAD_01R_ROBRT_1.sta and KIAD_01R_ROBRT_2.sta are the STARs for jets and turbos, respectively, arriving to Dulles from the arrival fix Robert. In the first file, altitudes are set higher and the set of aircraft using the STAR is restricted to high-performance jets and turbos; all other aircraft use the second STAR, which has lower altitudes.

Because we had to program almost all of our SIDs and STARs from scratch, we consolidated some arrival fixes; for example, all aircraft arriving to Kessel (ESL) always continue on to Armel (AML), so we eliminated Kessel as an arrival fix. We then searched the route file to write ESL AML KBWI on the ends of all routes that formerly ended as ESL KBWI.

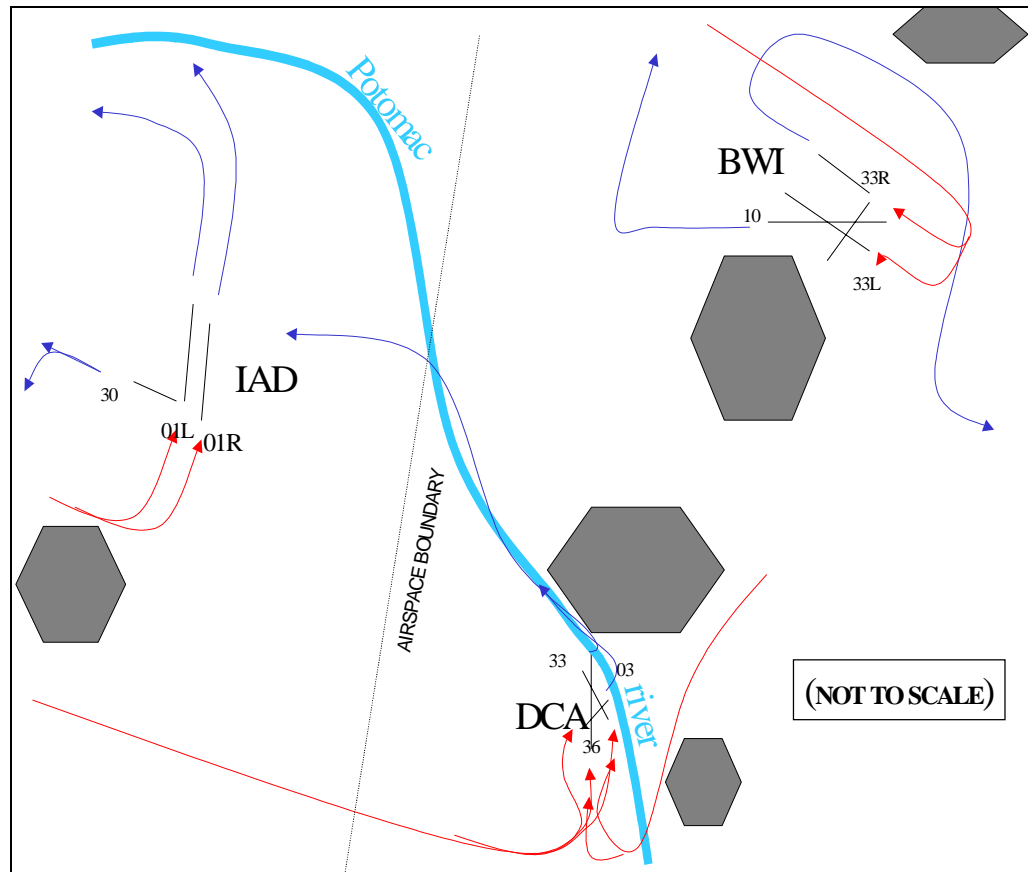
Airspace Routes

We are indebted to the FAA's Potomac Metropolitan Control Facility Planning Office for sharing Washington-Dulles TAAM program files. The Potomac office provided configuration advice, traffic counts, electronic airport runway layout files, some electronic SIDs and STARs, and instructions for executing the remaining SIDs and STARs.

Dulles operates in two basic configurations: south or north. It runs north approximately 75 percent of the time. Dulles has two main parallel runways (01/19) that handle most of the traffic. In visual meteorological conditions (VMC), Dulles staggers jet departures and arrivals, with arrivals on one parallel runway and departures on the other. Turboprops arrive or depart on the overflow runway (12/30) and on one of the parallels, depending on whether there is an arrival or departure push; moreover, runway assignment varies with destination. Dulles is busy with alternating arrival and departure pushes all day; there are six arrival pushes and six departure pushes between 8:00 a.m. and 10:00 pm. For our study, we picked the north configuration, which in VMC means jet arrivals on 01R, jet departures on 01L, turboprop arrivals on 01L, and turboprop departures on 30.

Reagan National Airport operates either north or south and experiences the same winds as Dulles. In VMC, National takes arrivals on its main runway, 18/36, and on one or two crossing runways—03 and 33 or 21, depending on winds. In the north configuration, jets and props are landing on 36, and props are landing on 33 and 03. Jets depart 36, and turbos depart on 03. Figure 2-1 provides an illustration; the shaded hexagons in the figure represent special-use airspace that is not open to commercial aircraft.

Figure 2-1. Washington Airspace Flows in VMC



Through meeting and discussion, Potomac office personnel assisted us in modeling air routes as close to reality as possible. Dulles' easternmost runway's airspace abuts airspace owned and used by Reagan National Airport. There is room for an arrival flow but not sequencing along the eastern side of the airport; that corridor is used during north operations. In terms of land use, the area west and south of Dulles is airport owned and undeveloped; there is a great deal of room for expansion—although the terminal is on the northeast end of the airport, which would make for a long taxi. To the east of the airport is a six-lane highway, as well as office space on the other side of the highway, including the FAA's national traffic management office (formerly known as the Central Flow Control Facility). To the north there is greenspace and then residential area. Leesburg Airport, with a single runway, is located 7 miles to the northwest.

Current plans are for airspace changes to be made only every 5 years. Washington recently completed an airspace redesign study. The configurations depicted in Figure 2-1 should be accurate until about 2004.

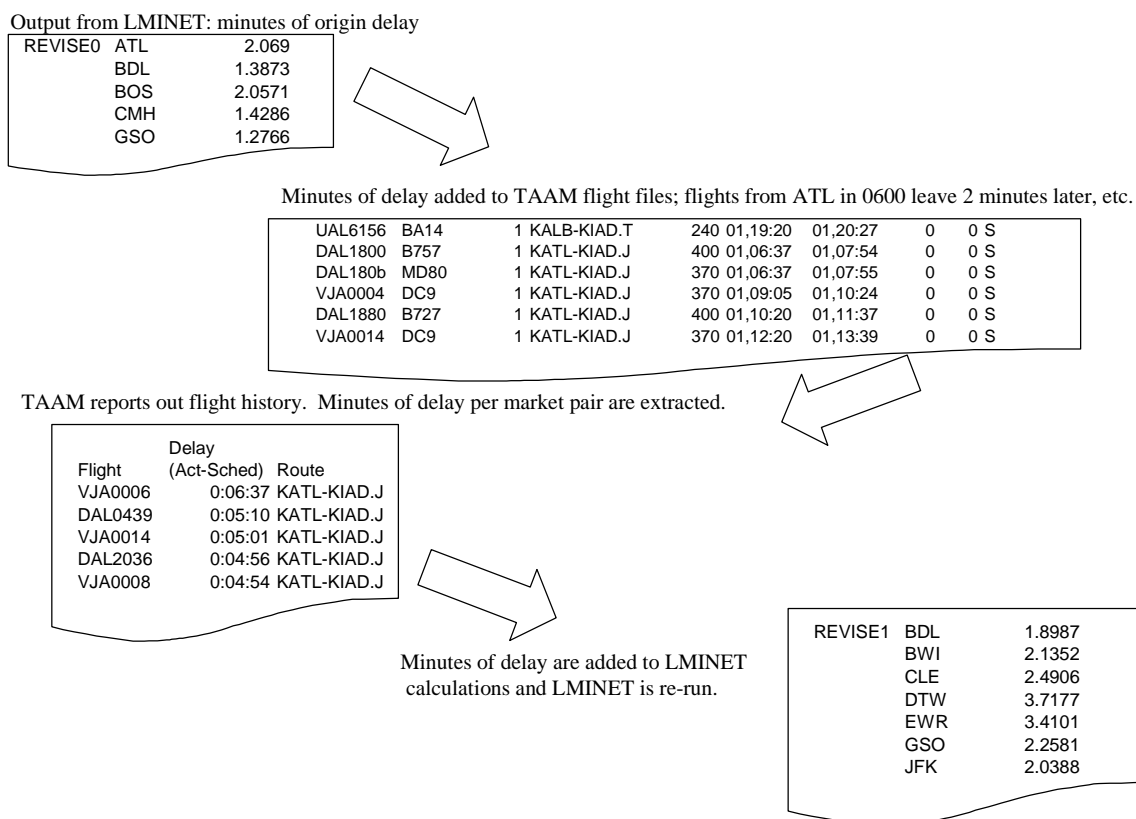
We did not validate the simulation setup against actual flight time and delay data.

Creating Demand Files

The Official Airline Guide (OAG) schedule published for June 12, 1997 was used as the basis of our traffic schedule. The schedule was increased slightly to account for unscheduled and general aviation operations traffic .

The LMINET and TAAM demand files were derived from a common source—the 1997 OAG—and so schedule adjustments were passed from one model to another as schedule perturbations. The process is illustrated in Figure 2-2.

Figure 2-2. Iterating Intermodel Schedule Perturbations



As Figure 2-2 shows, LMINET is run for the nation, and origin airport delays are reported out. The origin airport delays in the first hour of flying are then used to perturb the TAAM flight file. TAAM is then run, and delays by market pair from TAAM are sent to LMINET and input as a more accurate picture of a locally modeled airport. LMINET is run again, and origin (airport) delays in the second

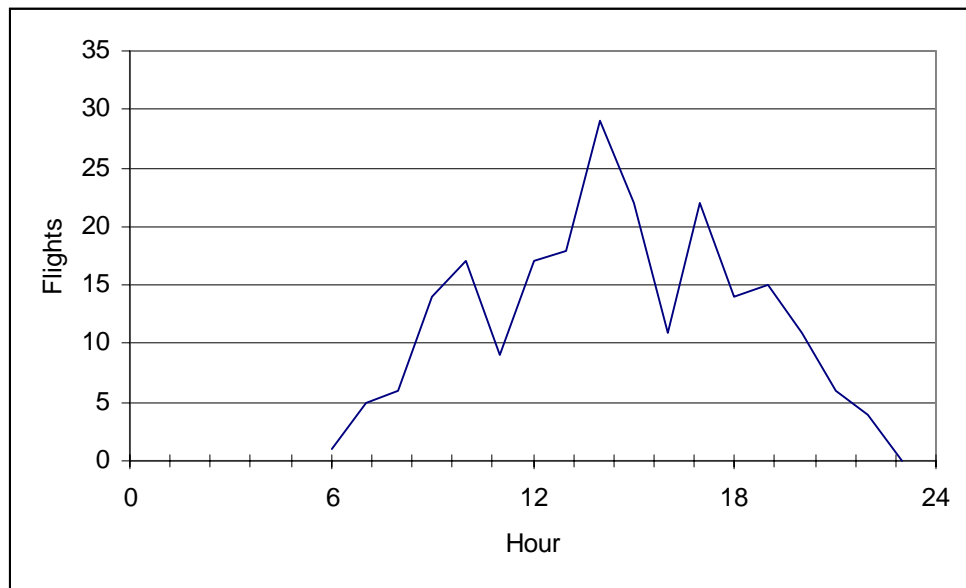
hour are captured and sent to TAAM. TAAM's flights leaving in the second hour are delayed by the amount indicated by LMINET, and TAAM is re-run. The delays at the locally modeled airport in TAAM are reported back to LMINET by market pair again, and so on.

DELAY COMPARISON

Once the integration was accomplished and the intermodel iteration begun, delay numbers came in. Ordinarily, delay numbers are the calibrating point of a model or model interaction. In this case, however, the models are very different; thus, the outputs are very different. We believe that none of the outputs can be compared. We cannot compare flight time to flight time because there are no individual flights in LMINET. We cannot compare delay times at IAD. We also cannot compare nationwide delay figures because TAAM is not reproducing national delay figures in any measure that could be expected to reflect reality.

The net effect of LMINET perturbations on the TAAM flight schedule was to introduce delays. In three separate periods during the day, ground holds were established for Boston arrivals; in one period there also was a brief ground hold for Seattle arrivals. Mostly, however, terminal delays created departure delays for flights bound to Dulles. Figure 2-3 shows the number of flights with departures perturbed by LMINET, by hour. The peak hourly number of perturbed flights was 29, out of a total of 800 flights for the entire day.

Figure 2-3. Number of Flights With Adjusted Departure Times, by Hour



The departure delays, particularly the ground holds, sometimes were enough to push a departure from one hour into the next hour. Figures 2-4 and 2-5 examine

arrival and departure demand in the TAAM simulation alone (dotted lines) and after the cumulative effect of LMINET-produced perturbations.

Figure 2-4. Arrival Demand at IAD

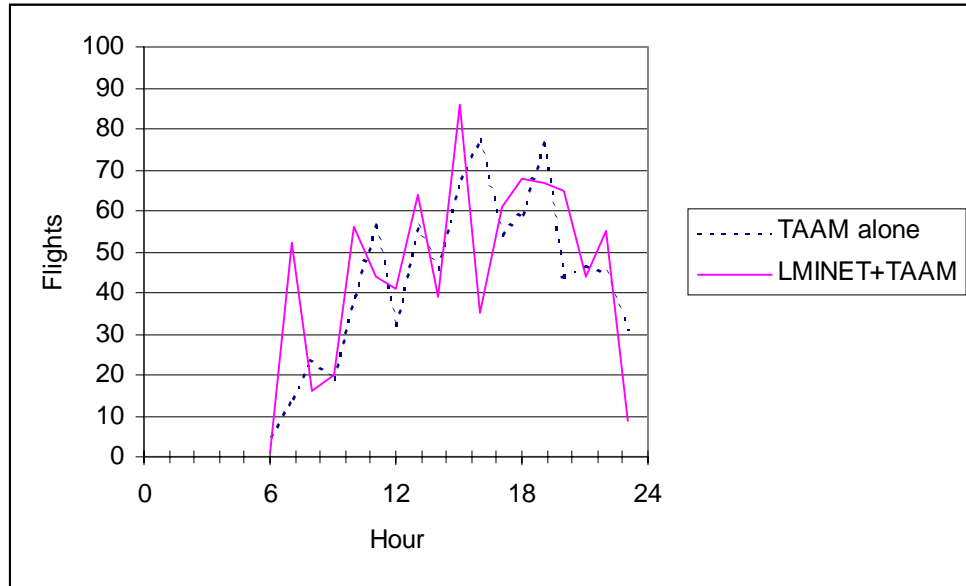
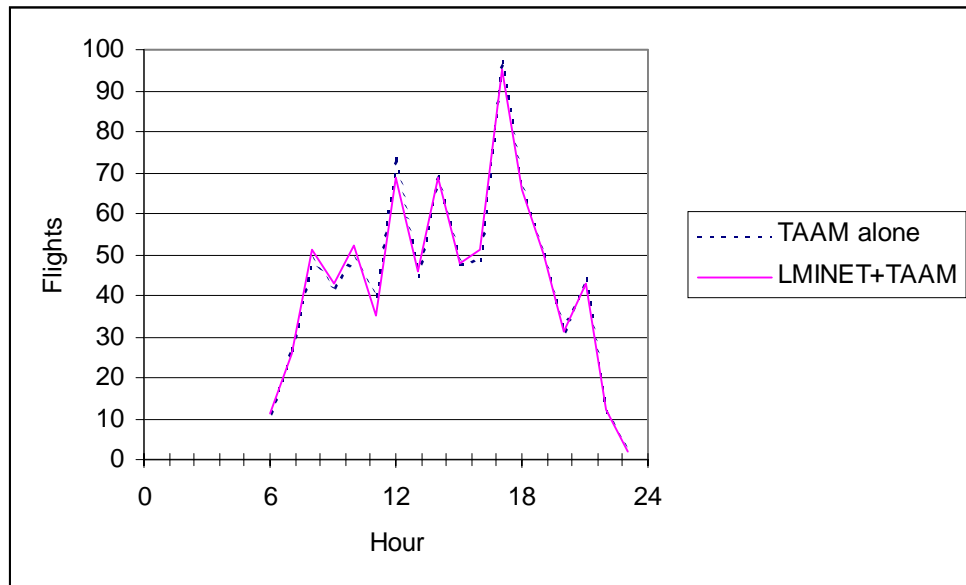


Figure 2-5. Departure Demand at IAD



Although on first inspection arrival peaks appear to move *back* in time (are pushed earlier) in the LMINET plus TAAM simulations, this result is a kind of optical illusion; in fact, arrivals are pushed forward in time starting from

6:00 a.m., but they are pushed forward far enough that they appear to move backward.

Because the ground movements (taxiways and gates) were not modeled in the TAAM simulation, the numbers depicted are truly departure demand and arrival demand. Because of ground congestion, it is unlikely—though possible—that the actual Dulles could achieve the peak arrivals and departures depicted.

The differences between the dotted (TAAM alone) and solid (TAAM and LMINET) lines is the added delay imposed when NAS feedback with LMINET is included. The differences in departure time and arrival times from the TAAM-only run and the TAAM-LMINET integration are reproduced in Figures 2-6 and 2-7. The measurements in Figure 2-6 were produced by sorting flights by (unperturbed) departure time, then comparing the departure time of each flight (by flight number) in TAAM-only and TAAM-LMINET runs, and summing the differences for all flights departing each hour.

Figure 2-6. Differences in Departure Time

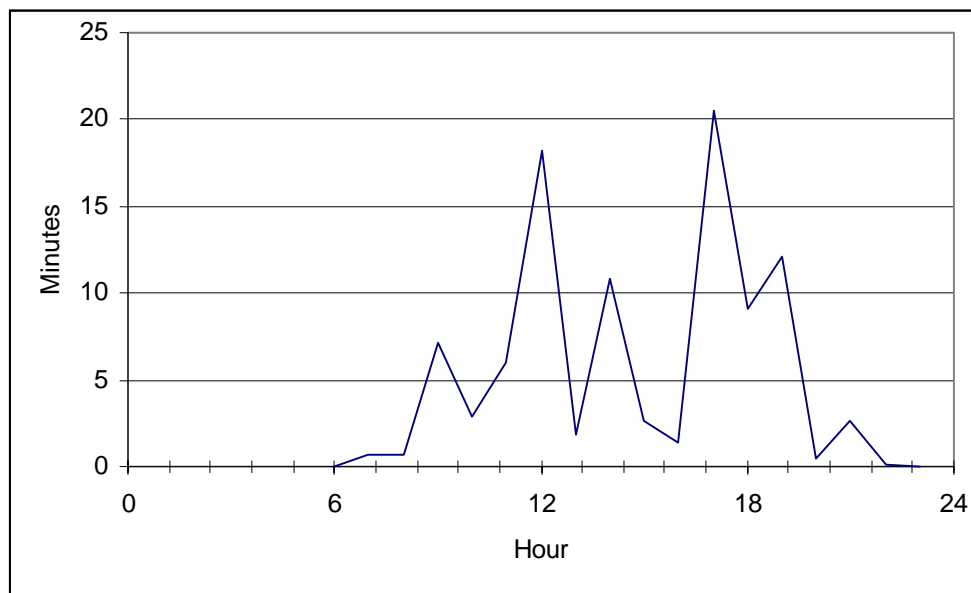
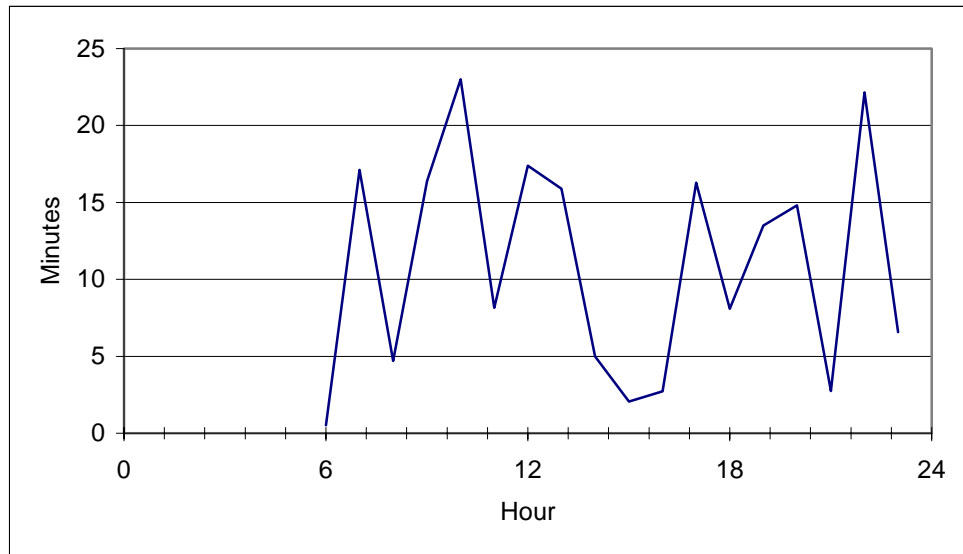


Figure 2-7. Differences in Arrival Time



The measurements in Figure 2-7 were produced by sorting flights by (unperturbed) arrival time, then comparing the arrival time of each flight (by flight number) in TAAM-only and TAAM-LMINET runs, and summing the differences for all flights arriving each hour.

Total flight delays, sorted by hour of departure and arrival for TAAM alone and the TAAM-LMINET combination are given in Figures 2-8 and 2-9.

Figure 2-8. Comparison of Total Departure Delays by Hour

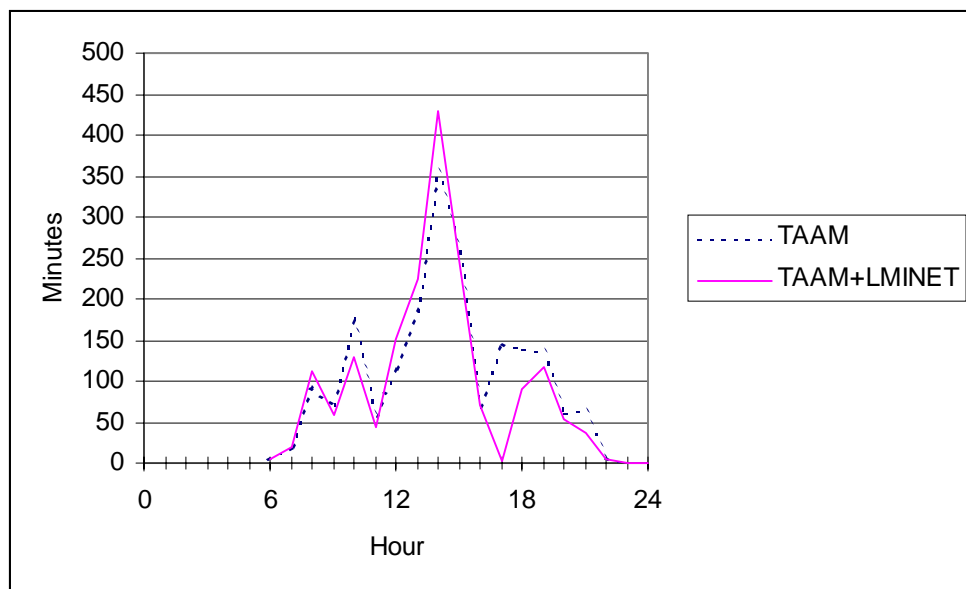
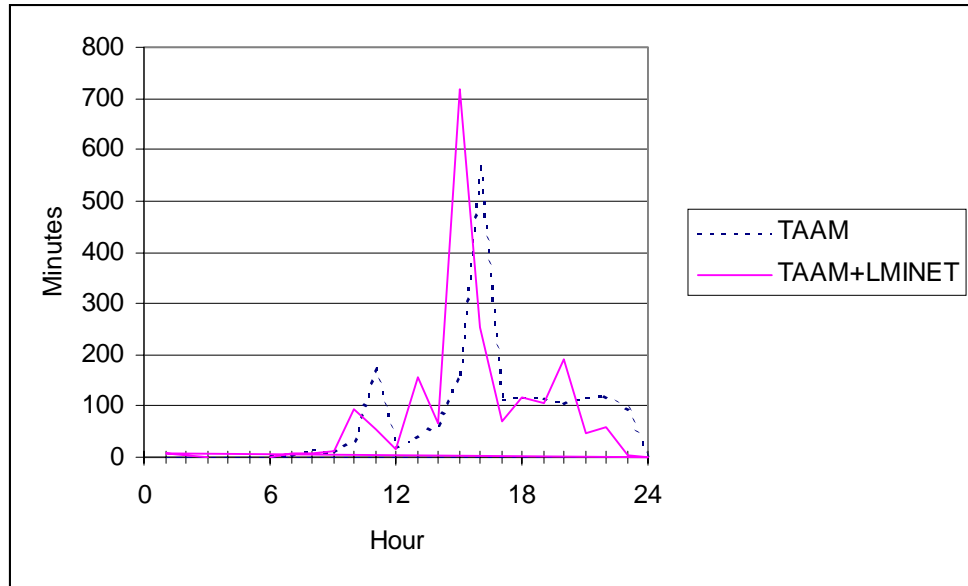


Figure 2-9. Comparison of Total Arrival Delays by Hour



Conclusions

Previous simulations at Dulles revealed that the airport is very near capacity, and adding flights or changing the runway configuration can lead to disproportionate increases in delays. We see this behavior confirmed in the larger spikes in differences in arrival time (Figure 2-7) over differences in departure time (Figure 2-6). Perturbations in the flight demand schedule from LMINET seemed to have the effect of further bunching peak traffic at Dulles and increasing delays, which probably is an accurate representation of the real impact of NAS perturbations on an otherwise balanced airport schedule. A more thorough examination of this capability should include the ground movement component at Dulles and verification of pre-integration (i.e., TAAM only) flight times and delays.

Chapter 3

Integration of LMINET with a SIMMOD Model at Chicago O'Hare International Airport

The purpose of this study was to demonstrate the feasibility of integrating LMINET and SIMMOD. This analysis of airspace and airfield performance was conducted using SIMMOD *Plus* and LMINET. The analysis simulated the movement of arriving aircraft from the entry point in the Chicago TRACON (approximately 40 nautical miles from the airport) to a representative gate location and departing aircraft from a representative gate location to their exit from the TRACON airspace. The SIMMOD *Plus* and LMINET models produce output measures of aircraft travel time and delay.

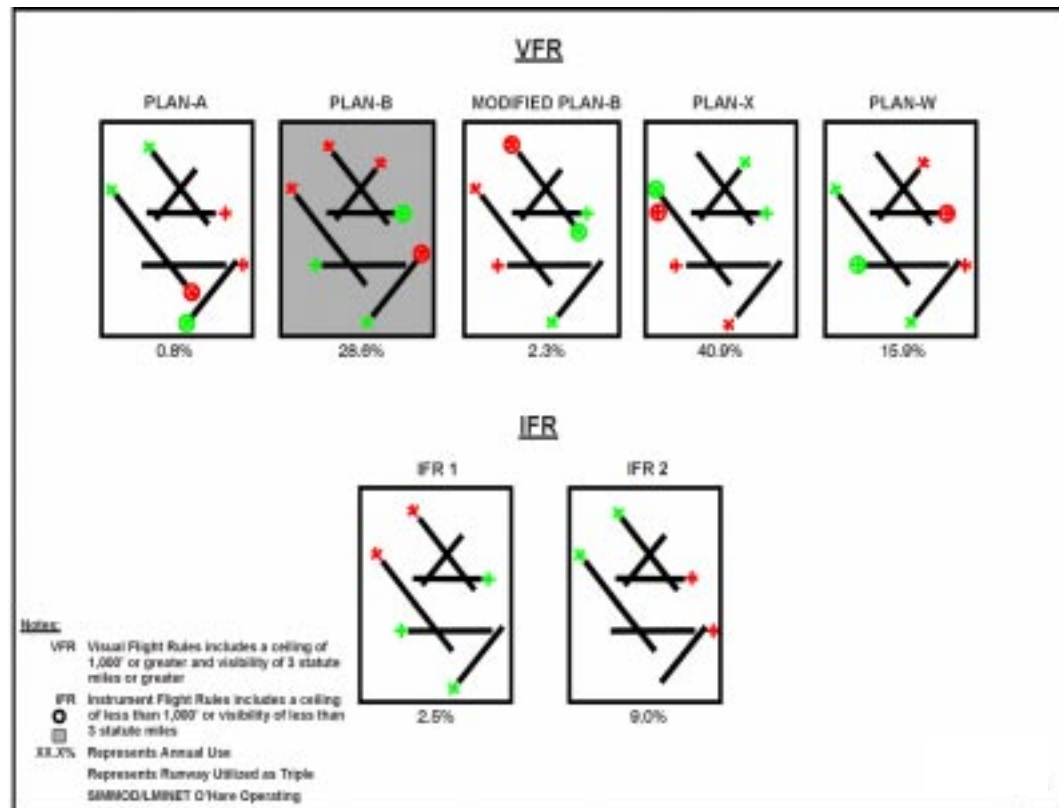
The city of Chicago recently completed a simulation analysis of the World Gateway Program, which was the basis for a benefit cost analysis and supported ongoing environmental assessment of a proposed project at Chicago O'Hare International Airport ([5]). The city of Chicago agreed to share its SIMMOD study for the purposes of this project. For this analysis, one primary good weather operating configuration was selected from the city of Chicago's study.

SIMMOD MODEL AT CHICAGO O'HARE INTERNATIONAL AIRPORT

The runway layout and varying wind and weather conditions at O'Hare allow for up to 70 unique runway operating configurations. Historical analysis of runway use at O'Hare, using the Airport Noise Monitoring System (ANMS), revealed that there are four primary Visual Flight Rule (VFR) or good weather operating configurations and two primary Instrument Flight Rule (IFR) or bad weather operating configurations. VFR conditions are defined as when the cloud ceiling is 1,000 feet or greater and ground visibility is 3 statute miles or greater. IFR conditions are defined as when the cloud ceiling is less than 1,000 feet or ground visibility is less than 3 statute miles.

Figure 3-1 illustrates the primary operating configurations at Chicago O'Hare, along with the configuration utilization. Operating configuration Plan B, shaded in gray, was selected as the basis for this study.

Figure 3-1. Operating Configurations at Chicago O'Hare International Airport



INTEGRATION PROCESS

The LMINET simulation model and SIMMOD *Plus* model were run on one-hour time increments, starting at 5:00 a.m. local time. Information gathered from the LMINET model was used to determine the number of flights and which city pairs would be delayed into the Chicago SIMMOD analysis.

The events (or schedule) file was modified on the basis of city pairs and delay statistics from LMINET prior to running the same hour through the SIMMOD model. This process was replicated 21 times throughout the day to ensure that all activity was captured.

The LMINET model indicates which city pairs are being delayed into the Chicago area. This information is listed by departure time from the originating airport. For example, if a flight is delayed leaving Los Angeles, CA, at 8:00 a.m. local California time, it will be delayed arriving into the Chicago TRACON airspace approximately 3½ hours later. A database was created that included flight miles that each city pair is located from Chicago. From this distance, an average flying time was calculated to determine exactly when the delayed flight out of Los Angeles would arrive in the Chicago TRACON airspace. This calculation was performed for all city pairs in the design day flight schedule that were delayed.

In modifying the arrival time into the Chicago O'Hare TRACON, it was important to make sure that if the flight was a through flight, the ground time remained representative of actual airline flight operations and that the departure time was modified when necessary. A new event file (SIMU09) was created and run through SIMMOD. The output from the SIMMOD run was then used to run through LMINET, and the process was started over again.

Following our general simulation model integration methodology outlined in Chapter 1, we will use delays reported at other LMINET airports to modify arrival times at ORD and the departure delay at ORD to modify arrival times at other LMINET airports. Delayed arrivals will induce delayed departure at ORD and other LMINET airports, which are taken care of automatically by LMINET. For the SIMMOD model at ORD, we have to manually modify the induced delayed departures. The steps of the integrated LMINET-SIMMOD simulation are as follows:

1. Initialize LMINET and SIMMOD and load appropriate computer files, including schedule files, capacity and delay models, and the weather file. Set the current time epoch to zero.
2. Run LMINET, using the most current schedule file.
3. Collect departure delays at other 63 airports at LMINET run. The departure delay for a flight from a LMINET airport to ORD is assumed to be the average departure delay at that airport.
4. Delay the arrival time at ORD by the amount of departure delay at other LMINET airports.
5. The logic in this step applies to through flights only. If the ground time remains within 90 percent of the original ground service time, it is not modified. If the departure time falls to less than 90 percent of the original ground service time, it is delayed back to 100 percent of the original ground time as scheduled
6. Create a new event file (SIMU09), based on Steps 4 and 5.
7. Run SIMMOD, using the most current schedule file.
8. Collect departure delay statistics at the end of SIMMOD run. The overall departure delay for the selected configuration is picked.
9. Create a new schedule file LMINET run with delayed arrival time at other LMINET airports by the same amount of departure delays at ORD for the scheduled flights.
10. Advance time epoch by 1.

-
11. Repeat steps 2–10; the integrated simulation ends once the time epoch is through 20.

Because of the flight time, departure delays will only delay arrivals sometime later in the day. LMINET has a feature that reports the number of flights being “ground-delayed”—a phenomenon in which a flight may be forced to delay its departure at the destination airport because of an imbalance of arrival demand and airport capacity. Most ground delay programs enacted by the FAA are related to inclement weather. For the weather date selected (April 8, 1996), Boston issued the ground delay for a few hours in the morning because of bad weather there. Seattle and San Diego also issued a ground delay for a few hours. Although LMINET follows the same logic, its report of affected flights is at the time of scheduled arrival rather than at the departure time. Thus, the modification of departure time at ORD because of the ground delay logic is retroactive. Because our event files are modified cumulatively, this retroactive modification does not have any impact on the simulation results at the end.

Although 21 iterations theoretically are required, we end the integrated simulation after Epoch 17 because there is no schedule modification thereafter.

RESULTS COMPARISON

Results of the simulation were compiled for each of the following alternatives:

- ◆ SIMMOD only
- ◆ SIMMOD-LMINET integration

SIMMOD Only

The initial simulation run was for SIMMOD only. Chicago O’Hare International Airport Operating Configuration Plan B was run from 5:00 a.m. local time through 1:00 a.m. local time the next day. The results of this simulation run are the basis for comparison with the output from the SIMMOD-LMINET integration simulation runs.

SIMMOD-LMINET Integration

Figure 3-2 presents delay and travel time statistics for the SIMMOD-only and SIMMOD-LMINET integration simulation runs. This table also compares the simulation results for both methodologies. Overall, there is a difference of 0.17 minutes per operation between the SIMMOD-only and SIMMOD-LMINET integration runs—a difference of approximately 1 percent.

*Figure 3-2. SIMMOD-Only Versus SIMMOD-LMINET:
Comparison of Performance Results*

		Delay (minutes per operation)									Average Unimpeded Taxitime (minutes per operation)			Average Delay and Taxitime (minutes per operation)			
SIMMOD Only		Arrivals			Departures				Average			Arr.	Dep.	Avg.	Arr.	Dep.	Avg.
		Air	Ground	Total	Air	Ground	Queue	Total	Air	Ground	Total						
	Plan B	3.40	0.71	4.11	0.23	2.50	1.51	4.24	1.82	2.36	4.175	7.57	8.80	8.185	11.68	13.04	12.36

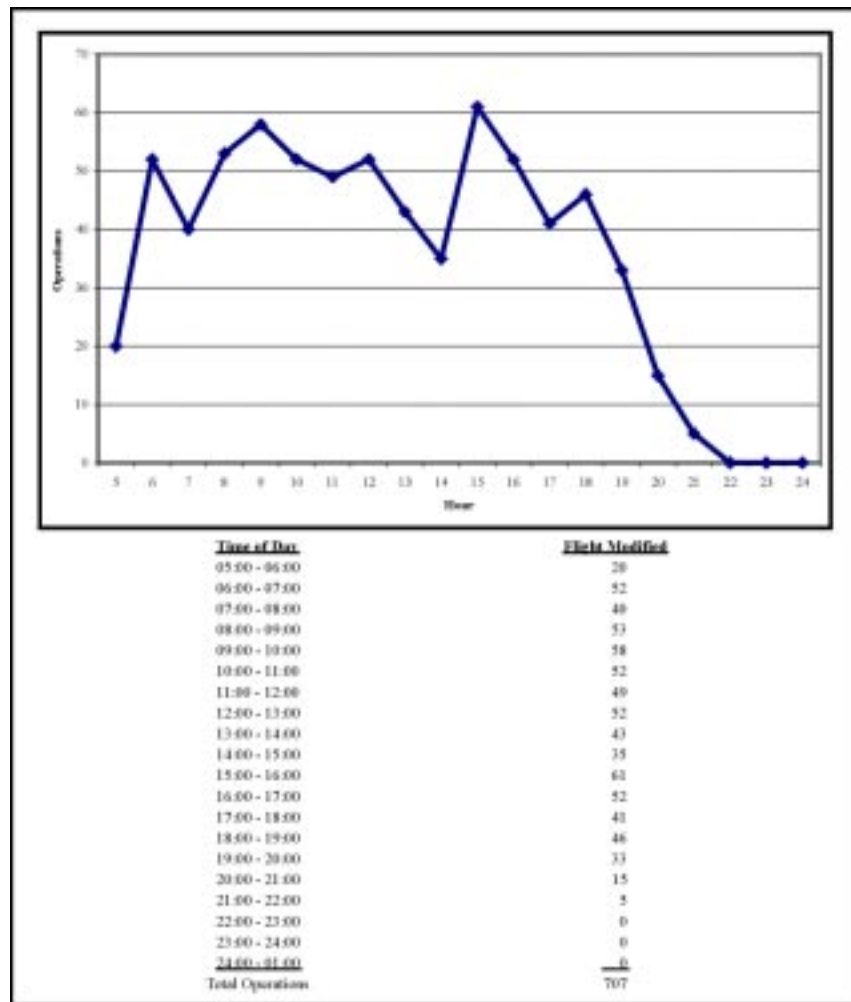
		Delay (minutes per operation)									Average Unimpeded Taxitime (minutes per operation)			Average Delay and Taxitime (minutes per operation)			
SIMMOD-LMINET		Arrivals			Departures				Average			Arr.	Dep.	Avg.	Arr.	Dep.	Avg.
		Air	Ground	Total	Air	Ground	Queue	Total	Air	Ground	Total						
	Plan B	3.64	0.83	4.47	0.23	1.83	1.50	3.56	1.94	2.08	4.015	7.53	8.82	8.175	12.00	12.38	12.19

		Delay (minutes per operation)									Average Unimpeded Taxitime (minutes per operation)			Average Delay and Taxitime (minutes per operation)			
SIMMOD Minus SIMMOD-LMINET		Arrivals			Departures				Average			Arr.	Dep.	Avg.	Arr.	Dep.	Avg.
		Air	Ground	Total	Air	Ground	Queue	Total	Air	Ground	Total						
	Plan B	-0.24	-0.12	-0.36	0.00	0.67	0.01	0.68	-0.12	0.28	0.16	0.04	-0.02	0.01	-0.32	0.66	0.17

The largest change of any of the performance measures was the departure ground delay; the change was 0.67 minutes per operation. The primary contributing cause of this reduction in delay could be flattening of demand throughout the delay as a result of delays incurred outside the Chicago area. As flights are delayed outside the Chicago system, they arrive into the TRACON airspace later than scheduled. This factor causes a flattening of the schedule and results in fewer delays.

Figure 3-3 presents, in tabular format as well as graphically, the number of flights that were modified by hour for each hour of the simulation analysis. By the late evening hours, delayed arrivals had been reduced to a few flights.

Figure 3-3. Hourly SIMMOD-LMINET Modifications



Except for some lengthy delays caused by bad weather at Boston and a few lengthy delays caused by bad weather at Seattle, most of the delays are small. Therefore, hourly demands are modified slightly, as illustrated by Figures 3-4 and 3-5.

Figure 3-4. Arrival Demands at ORD

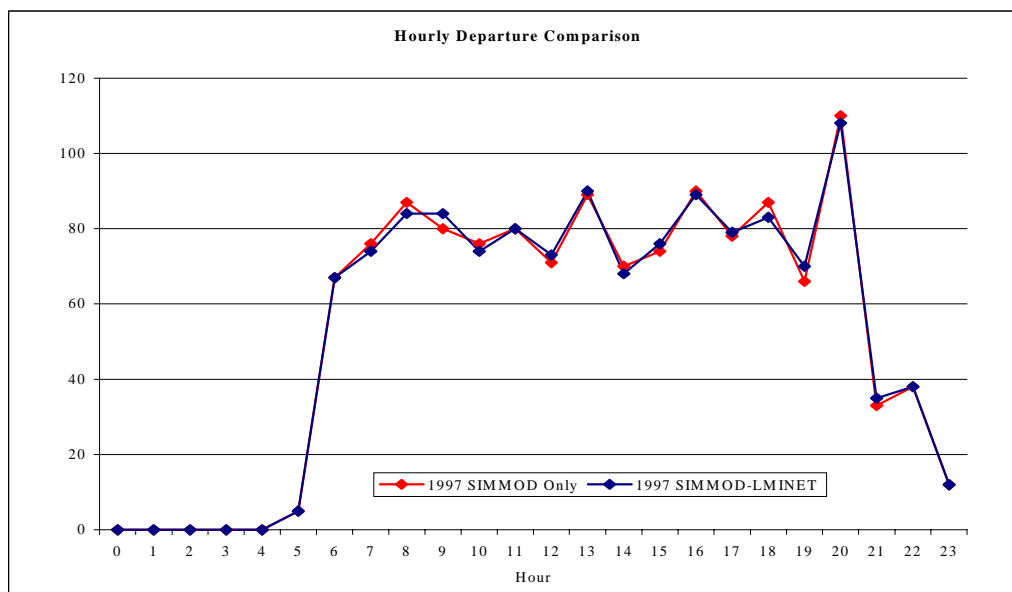


Figure 3-5. Departure Demands at ORD

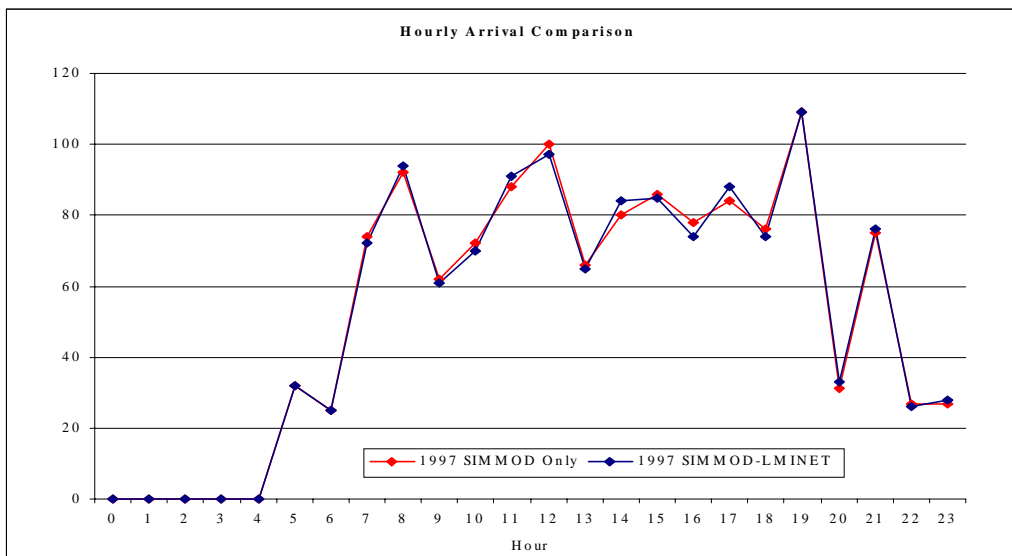


Figure 3-6 presents the daily average delay, peak delay hour, and daily delay and travel time totals for the SIMMOD-only simulation analysis.

Figure 3-6. SIMMOD-Only Delay Summary

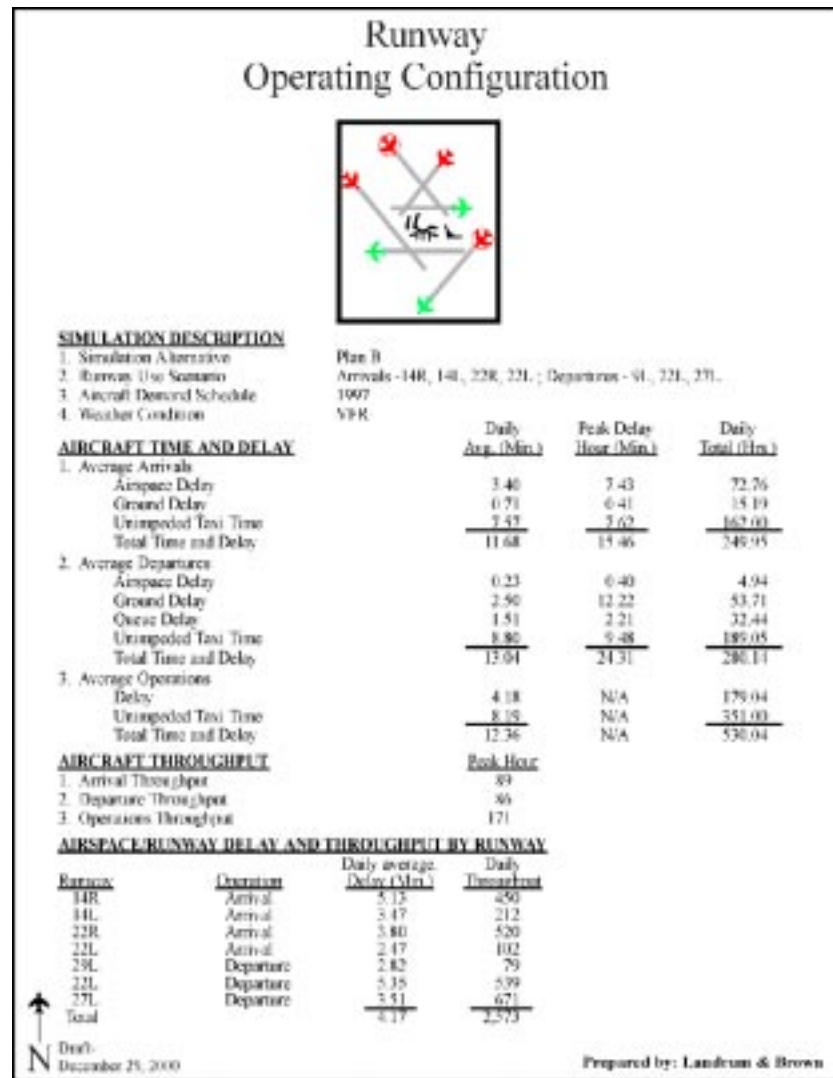
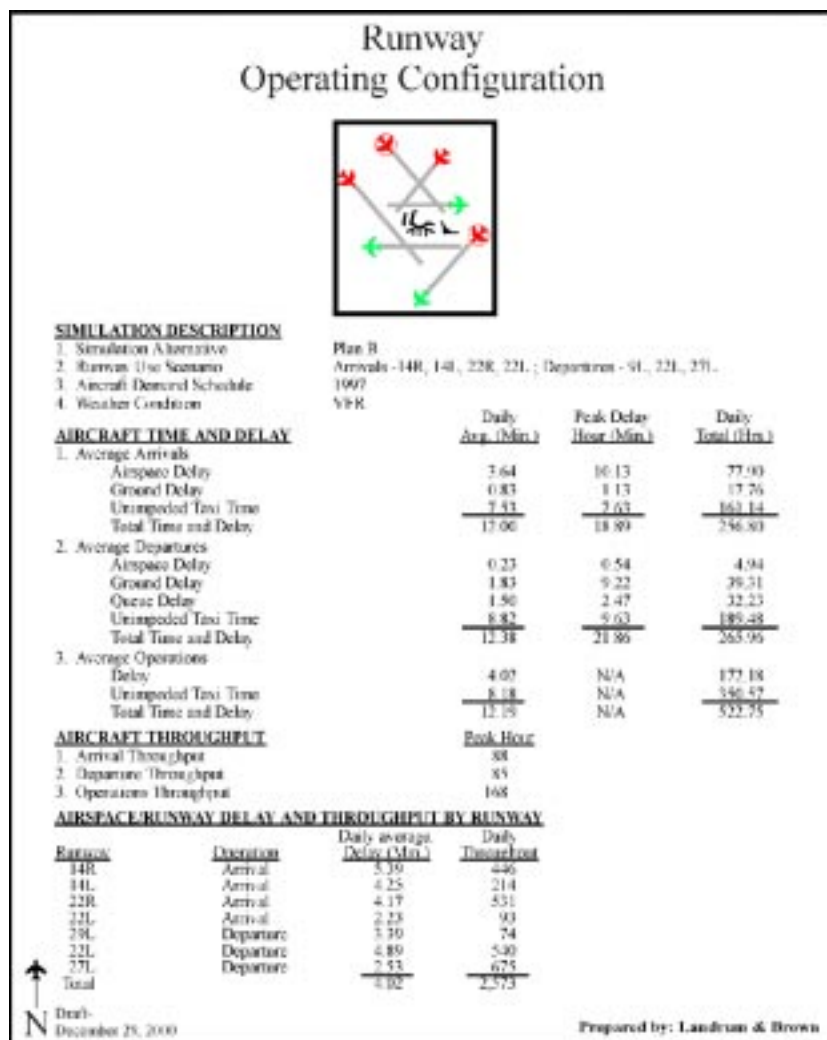


Figure 3-7 illustrates the daily average delay, peak delay hour, and daily delay and travel time totals for the SIMMOD-LMINET integration analysis.

Figure 3-7. SIMMOD-LMINET Delay Summary



Figures 3-8 and 3-9 depict arrival and departure delays at ORD for the SIMMOD-only and SIMMOD-LMINET cases. Overall, the delay and travel times, peak hour statistics, and daily delay totals are representative between the two simulation alternatives. The hourly delay curves of the two simulation alternatives are consistent, which is expected because their demand curves are close for arrival and departure demands at ORD. Nonetheless, we noticed differences—especially a large average arrival delay at 20:00. We believe that this large difference is attributable to the small difference of demands at that time. Because the airport operates at close to its capacity, any small change of demand undoubtedly will lead to a large delay change.

The value of the integrated SIMMOD-LMINET simulation is best manifested when demands are close to airport capacity. The peak demand time corresponds

to a large volume of passengers—especially business travelers, who are more sensitive to flight delay. The peak demand time also is the time when airlines and airport authorities pay the most attention to airport operations because it typically is the bank operation of a large hub of the airlines. Any delay at the bank operation will have large repercussions on an airline operation because of the ripple effect.

Figure 3-8. Comparison of Arrival Delays at ORD

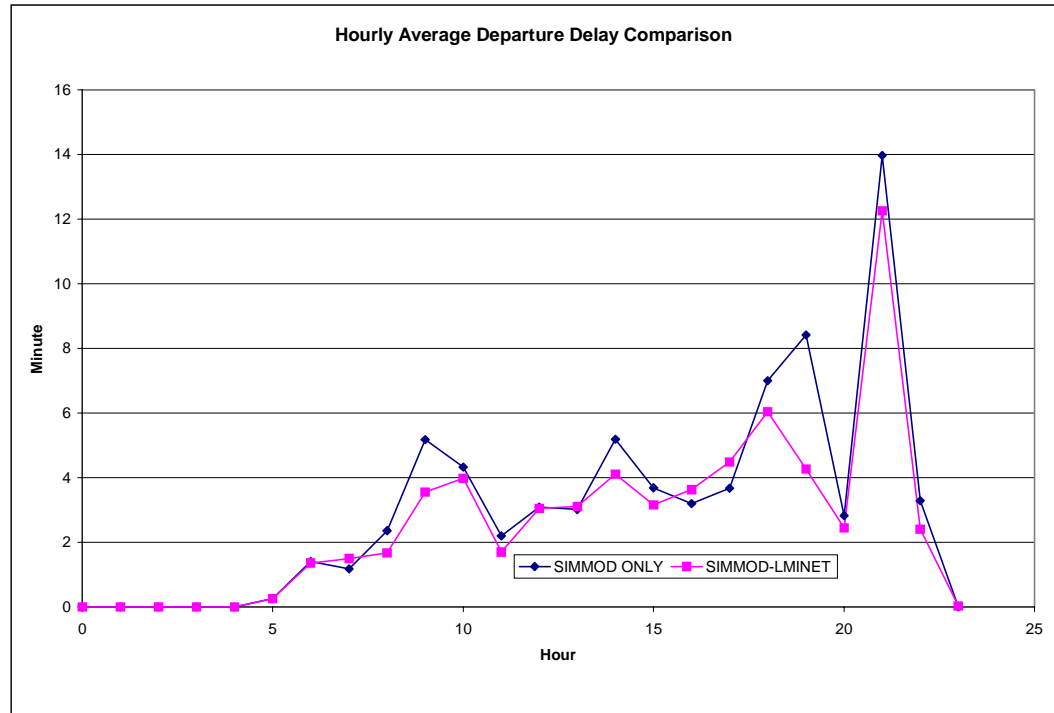
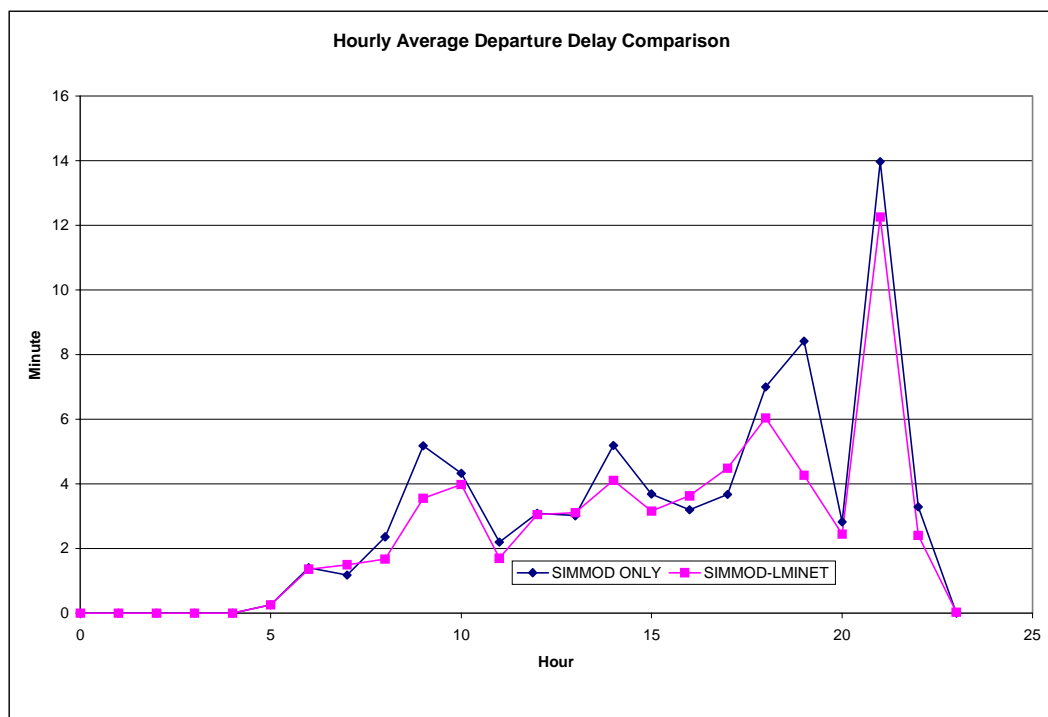


Figure 3-9. Comparison of Departure Delays at ORD



Chapter 4

Future Work

Under our proposed PAW approach (outlined in Chapter 1), we have demonstrated that we can integrate LMINET with TAAM and SIMMOD. Although the delays generated by TAAM and SIMMOD at IAD and ORD are similar before and after integration with LMINET, we do notice some considerable difference when the scheduled demand is close to airport capacity—a phenomenon that will appear more frequently in the future because of ever increasing demand and limited capacity growth. Therefore, it is very important to conduct this kind of integrated simulation if one wants to analyze future air traffic performance, which is exactly the purpose of most simulation studies.

The success of the feasibility study of LMINET integration with TAAM and SIMMOD leads us to believe that we can integrate LMINET with more TAAM or SIMMOD models in the network. TAAM, SIMMOD, or any other local air traffic simulation model can be linked through LMINET. If more TAAM or SIMMOD models are available, it would be possible to get detailed delay measurements for several major U.S. markets, such as the Northeast corridor, the Florida corridors, the Texas intercity airspace, the California interstate airports, and the Northwest corridor.

Although the feasibility study was successful, it is not a full-blown simulation study. Based on our analysis and experience of running the integrated model, the following tasks should be carried out if a full-blown integrated simulation is conducted:

- ◆ *Automate the execution process.* Collection of delays at other LMINET airports to the TAAM or SIMMOD airport and selection of delayed flights at TAAM or SIMMOD airports are automated. Collection of delay statistics in the TAAM or SIMMOD outputs is manual, as is the rest of the execution of the models, although the models themselves are computer-coded. The process is laborious and, because many manual steps are involved, error-prone. Thus, we first need some scripts to extract the right delay statistics from TAAM or SIMMOD output. LMINET is best run by a high-end Unix workstation. Although SIMMOD can be run in Unix, it is best run on a PC to take advantage of its graphics interface. The TAAM license is very expensive, so it has been purchased at only a few sites for Unix workstations. Thus, the script for the data transfer must work across computer platforms for a future integrated simulation. The second automation task is to send extracted delay statistics from one computer to another, which will likely be across platforms or across a local area network (LAN). The third automation task is to let each model—LMINET,

TAAM, SIMMOD, or any other simulation model—take delay statistics fed from other models and modify its schedule file. The last automation task requires a manager module that will carry the entire simulation without any human intervention. Essentially, the manager module will control the time clock and manage the execution of the simulation models and the data transfer from model to model.

- ◆ *Enhance TAAM and SIMMOD with the capability of “warm start” or reading the schedule file record by record.* “Warm start” will let the simulation with active flights instead of empty aircraft in the model. If we can use the system state at the end of the last epoch for the ones at the beginning of the current epoch, we can advance the simulation epoch-by-epoch without taking our PAW approach. If the models can be modified further to read the schedule records one by one, we can modify the schedule at any time when delay statistics from other models become available. We believe these two capabilities would be easy to implement by the TAAM and SIMMOD vendors. Each of these capabilities will enable us to abandon the PAW methodology and follow the original methodology without any repeated simulation runs, which will greatly enhance the speed of integrated model execution. The need for TAAM to have the foregoing capabilities is more pronounced because it takes a long time to run.
- ◆ *Develop an algorithm that can generate detailed future flight schedules and itineraries.* Although we have demonstrated the feasibility and benefit of an integrated LMINET-TAAM and LMINET-SIMMOD simulation model, the ultimate success of an integrated simulation study must rest on the availability of the detailed flight schedule that TAAM and SIMMOD require. This is necessary because the simulation models are “what-if” tools to analyze the air traffic system in an airport, a region, or the entire NAS. The most frequent use of the simulation studies is to analyze air traffic in the future under a forecast. The air traffic schedules required by TAAM and SIMMOD include detailed information about aircraft movements in time and place (as noted in preceding chapters), which can be constructed from published or observed schedules. Although air traffic forecasts are available at higher aggregate levels (e.g., national or airport level) from the FAA’s Terminal Area Forecast, the forecast of a specific flight schedule must be developed. To accompany LMINET, LMI has developed an algorithm to forecast a flight “schedule” on the basis of the current schedule, airport traffic growth rates, and a set of airline operating strategies. Although this schedule’s information on origin and destination pair and departure and arrival hours is adequate for use with LMINET, it is not detailed enough for TAAM or SIMMOD. This schedule must be augmented to include accurate departure and arrival times up to the minute, equipment type, and flight tail number to designate the flight itinerary. Even with the aforementioned shortcoming, we believe that the LMI schedule forecast model can serve as a starting point for any schedule

forecast model to be developed because it is guided by a set of solid economic and operational principles [2, 3, 4]. If airspace delays also are desired in an integrated model, we must develop another model for flight routes under the ATM paradigm, weather conditions, and air traffic congestion. LMI already has developed a model to generate optimal flight routes under the Free Flight paradigm, which we believe can be adapted for TAAM or SIMMOD use.

- ◆ *Model LMINET time frames in shorter time increments than 1 hour.* This methodology modification is related to the arrival and departure bank structures of individual airports. Currently, LMINET assumes 1-hour time frames and scheduled activity that is to occur during that hour. For example, there might be 60 arrivals scheduled for a particular hour. If that hour time frame is simulated, the airfield might be able to process all 60 arrivals with no delay. In the schedule, however, most of the 60 arrivals are scheduled to occur during the first 15 minutes of the hour. This difference would affect the amount of delay incurred during the same hour using the same schedule. If LMINET were run based with smaller time frames, the delay might be captured—which is more representative of actual delays on a flight-by-flight basis.
- ◆ *Perform sensitivity analysis of simulations.* Additional simulation runs can be performed to evaluate modifications of various input requirements for LMINET, TAAM, or SIMMOD. This analysis will lead to a better understanding of the impact of simulation inputs on the delay analysis. For example, SIMMOD contains an on-time probability distribution that attempts to capture delays that are incurred outside of the Chicago area. LMINET is modeling 64 of the busiest airports in the United States and is delaying flights into the Chicago TRACON on the basis of acceptance rates and weather information from around the country. The presence of LMINET information might warrant removal of the on-time performance distribution because theoretically, delays outside the Chicago system already are being captured through LMINET.
- ◆ *Modify arrival and departure acceptance rates for each airport, depending on anticipated activity.* Airports such as Chicago O'Hare International Airport have very dynamic runway use throughout the day. There is no specific number of arrivals and departures that can occur all day. When arrival demand warrants, a third, or triple, arrival runway can be used. This additional runway increases the acceptance rate of arrivals at the airport but decreases the acceptance rate for departures. During the next hour, there might be a departure bank, and the triple runway could be used for departure operations. This operational strategy, in turn, would affect the arrival acceptance rate. Study of the arrival and departure banks could be used to determine when arrival and departure acceptance rates should be modified.

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Appendix A

Using TAAM

This appendix contains a brief description of the TAAM model and some hints and instructions for a beginning user to begin to understand and use TAAM.

DESCRIPTION OF TAAM MODEL

TAAM has four modules: the Interactive Data Input System (IDIS); the simulation engine (SIM); the Report Presentation Facility (RPF), which reports output; and Gtool, an input mapping program.

Data Input

TAAM software is delivered with a supply of data files that the user may use to begin modeling. These data files provide a useful starting point for general modeling questions—such as, by what function do airspace conflicts increase as traffic increases? To increase the accuracy of the simulation, however, provided files should be perfected or a custom simulation created.

IDIS guides the user through creation or editing of several essential classes of files:

- ◆ Airports
- ◆ Waypoints
- ◆ Routes
- ◆ Timetables
- ◆ Maps
- ◆ Project file.

In addition to the foregoing list, several data files that are not accessed through IDIS also are essential to the simulation:

- ◆ The aircraft performance file
- ◆ The aircraft cross-walk file (which equates aircraft with similar performance characteristics to a single performance model)
- ◆ The conflict resolution strategy file

-
- ◆ The sector separation setting file.

The distinction between the first list and the second list is that the files in the first set have an obvious user interface; in effect, the model prompts the user to update those classes of files with each simulation. The files in the second set are in text format but have to be edited with a text editor; there is no built-in interface from IDIS to view or edit them, and there is no explicit mention of their use in the project file. Many beginning users remain unaware of the influence of the second set.

In the following section, we discuss each class of data file by functions.

IDIS-Definable Files

AIRPORT FILE

The airport file lists the location of every airport in latitude, longitude, altitude, and magnetic deviation. It is used to stake out the points in three dimensions for aircraft objects to fly to. Creation of the airport file allows the user to model ground layouts of the listed airports. Every airport listed in the overall airport file is treated as a point airport unless the modeler specifies a ground layout for that airport. Once an airport's ground layout is added to a project, the user would find additional data classes available under each airport, as illustrated below. These additional data classes can be filled in by the user.

- ◆ Airports
 - Airport list file, often called "Master.APT"
 - KATL
 - Layout
 - SIDs
 - STARs
 - Usage
 - KIAD
 - Layout
 - SIDs
 - STARs
 - Usage

➤ ...

A layout file is a digital map of the airport surface; it can include runways, taxiways, aprons, de-icing stations, gates, buildings, and obstructions. The layout is a visual backdrop for the simulation; it also provides programmed routes for aircraft to travel on the ground.

A Standard Instrument Departure is a defined route or procedure that a pilot follows after takeoff and before entering en route airspace. Every runway generally has several SIDs, depending on weather conditions, aircraft climbing capabilities, and the desired direction of flight. In TAAM, each SID is programmed in as a separate file.

A Standard Terminal Arrival Route is a defined route or procedure that an aircraft follows when it is entering a terminal airspace. Although the aircraft remains under the control of an air traffic controller, the STAR provides standard guidance for approaching the destination airport. Generally, each runway end has several STARs—one for each arrival fix in VMC and in IMC, often with variations in altitudes for higher- or lower-capability aircraft. In TAAM, each STAR is programmed in as a separate file.

WAYPOINT FILE

The waypoint file contains the locations, names, and capabilities of the radio beacon navigational aids (NAVAIDS) that most U.S. aircraft still use to define, plan, and track their flight route. The waypoint file also contains user-defined waypoints—which may correspond to points on arrival patterns, a turn onto a radial from a NAVAID, or arbitrary points. In TAAM, the NAVAIDS in the waypoint file are referenced by the route, STARs, and SIDs files.

ROUTE FILE

The TAAM route file contains lists of waypoints that define connect-the-dots routes for aircraft to fly along. Routes can be radionavigation-limited—like the air traffic control (ATC)-preferred jetways and vectors (i.e., encompass a route that requires the aircraft to always have at least two radionavigation beacons within range)—or they can be “great circle” between the destination and origin airports. Artificial waypoints can be easily created to reflect permutations, combinations, and variations on point-to-point and great circle routes.

TIMETABLE

The timetable file—also called a flight file—is the file in which a modeler usually has the most interest; it is the “event” or “demand” file equivalent. The flight file lists, at a minimum, the flights that are flying, the day of flight, the time, the altitude, the origin and destination, and the type of aircraft. At its most detailed, the

file also lists the route taken, the altitudes en route, the SID, the STAR, and the runways used.

MAP FILES

Map files are computer aided design (CAD)-generated pictures that show functional structures and terrain features. The airport layout file is a map file. Points in map files are defined by latitude and longitude or by relative position to latitude/longitude-defined points. TAAM mosaics all of the user-selected map files together into a single view. Common map combinations include coastlines and waterlines, air traffic control sectors, airport layouts, and state or political boundary lines. Map objects can be filled in or colored so that the TAAM simulation resembles an iconographic animation of traffic.

PROJECT FILES

Each simulation project is delineated by a project file, which tells the TAAM simulation engine which data files to read into memory to run the desired parameters through a simulation. The format of the project file is a text list of the user-defined (via IDIS) data files, prefaced by a directory pointer relative to the TAAM home directory. Figure A-1 shows a sample project file. The TAAM home directory is “home/taam.”

Figure A-1. Sample Project File

```
# single_terminal
# data/map/gtool
globe_new.pol
zdcsecs.pol
zdwsecs.pol
znysecs.pol
# data/map/3d
# data/wpt
master.WPT
# data/apt
master.APT
# data/apt/KBWI/layouts
KBWI.pol
# data/apt/KBWI/sids
KBWI_33R_EMI_1.sid
KBWI_28_EMI_1.sid
...
```

Every simulation is governed by its project file. Multiple projects can reference the same files, and a multitude of projects can be easily created by changing the file selection of a project. For example, a user may build a simulation and define five different timetable files, corresponding to five different traffic connection strategies for a hub. Each simulation would have a project file that references the same master airport list, the same terminal layout, the same SIDs and STARs, and the same maps and waypoints but points to different traffic files. Having separate

project files for five different timetables allows the user to make similar changes to all projects at the same time (by changing a single file such as the waypoint file) and to re-run all alternatives in batch mode.

Files that are essential to the TAAM simulation but are not defined or edited through the IDIS interface are not listed in project files. We refer to these files as “secondary” files.

Secondary Files

AIRCRAFT PERFORMANCE AND CROSS-WALK

The flight performance file contains the minimum, average, and maximum speeds and fuel burns for hundreds of aircraft at altitude increments of about every 3,000 feet. Performance characteristics are differentiated by phase of flight; climbing, cruising, descending; and rates of turn, rates of climb, and taxi and takeoff speeds.

CONFLICT RESOLUTION STRATEGY FILE

The conflict resolution file is a set of 38 conflict resolution rules that TAAM consults when it detects a conflict. The resolutions are situation-specific; one may state, for example:

If aircraft 1 is cruising and aircraft 2 is cruising and aircraft 1 is approaching from behind at the same altitude, then:

1. aircraft 1 speed up and head right 15 degrees
2. aircraft 2 slow down and aircraft 1 head right 15 degrees
3. ...
4. ...
5. ...

then return to flight as planned.

TAAM searches the list of resolutions until it finds the conflict described in clause 1, then applies the solutions suggested (here, nine possible ways to resolve the conflict) until the conflict is resolved. If the conflict is not resolved, TAAM continues to read the file for additional strategies and tries other conflict resolution strategies.

SECTOR SEPARATION SETTING FILE

The sector separation settings usually are set when an air traffic sector is created in Gtool. The separations are stored in “*.sec” files.

MAGNETIC DEVIATIONS, IMPROVED CONFLICT RESOLUTION, INTEGRATED NOISE MODEL

Other files that could be important to terminal modeling but are not essential to this project are the U.S. magnetic deviation table, an improved conflict resolution file, and the Integrated Noise Model. The U.S. magnetic deviation table lists the magnetic deviation of magnetic north to true north that all aircraft must compensate for in setting courses. There is a table in TAAM where the user may fill in U.S. magnetic deviations. This table must be either completely filled in or completely blank to affect the modeling simulation uniformly. The magnetic deviation is important only in vectoring instructions that might be contained in STARs, SIDs, and user instructions during the simulation. Once the user has started down this path, he or she cannot change his or her mind and input the magnetic deviation table without rewriting the SIDs and STARs.

Improvement of the conflict resolution file can be accomplished by creating new conflict situations and adding new solution suggestions to the existing 38 situations. Other users have done this with great result. The preferred method is to sit down with certified controllers watching the TAAM simulation and take note of the controllers’ expression of how they would resolve conflicts that TAAM encounters.

The Integrated Noise Model would determine the noise footprint left by virtual aircraft over virtual neighborhoods. In this simulation, approach paths are constructed to avoid noise incursions, and TAAM aircraft do not stray from their assigned paths.

User Input Data and Data Necessary to Run

The file that usually is of most interest to the modeler is the flight file, or the list of flights. This file is selected or programmed by the modeler to frame the problem being studied. Regardless of the model used, in simulation studies the event file generally does not come as part of the model. To run a simulation in TAAM, the user must first have an aircraft performance file and a flight file. One of these files tells the aircraft how to fly; the other supplies the event aircraft. In this simplest of all simulations, the user could program an aircraft flying aimlessly around empty space. Add the airport file, and the aircraft can fly to and from points in that space. With the waypoint file and the route file, the user has the ability to make complicated or realistic flight routes. With the conflict resolution file, the aircraft avoid collisions as if they were being controlled by air traffic controllers today. Add maps, and the model begins to look like the airspace above the United States.

Additions to this basic file set are the prerogative of the analyst running the model; such modifications are added to increase accuracy in specific areas. Airport points can be turned into airports with ground layouts. Airport layouts include runways, taxiways, buildings, aprons, gates, and holding aprons; they often are used in TAAM simulations to help capture ground congestion effects at busy airports, which may affect departure delays. The airport layout can significantly increase the realism of the simulation. Airport layouts in TAAM also have been programmed to solve ground movement problems.

Nonprecision approaches can be programmed as STARs. STARs are essential to TAAM for sequencing. If programmed STARs are not available, TAAM will build its own classic trombone-shaped approaches. Although this procedure will accomplish sequencing, it will not represent the airspace as it ordinarily is flown. Sequencing should be considered essential in any simulation in which timing and delays are regarded as important.

Noise abatement procedures also are implemented in TAAM, via programmed SIDs and STARs that comply with noise abatement procedures.

TAAM sequences aircraft only when aircraft are in controlled airspace. Air traffic control sectors also are used to set minimum separations and to impose flight restrictions such as mile-in-trail sequencing methods. Although most U.S. en route airspace sectors were delivered with TAAM, there were some blank spots. Instead of filling the blank spots, it may be more expedient to develop a single “supersector”—one sector that covers the contiguous United States to several miles outside its boundaries, rising from 18,000 feet to 60,000 feet. This supersector ensures that aircraft will be within controlled airspace throughout the en route phase of flight at a minimum of effort.

TRACON sectors can be drawn from individual sector position maps and from a terminal controller projection plate. These items generally are traced out in Gtool and then named, subsector by subsector. TRACON supersectors can be drawn in to ensure that the local area aircraft were always in positive control areas in TAAM. Again, these supersectors are time-saving innovations to create a workable model, using minimum memory, without sacrificing accuracy of flight time and flight path.

Modeling in fast time always involves trade-offs—in particular, the trade-off of accuracy of inputs versus time allotted to model—which is why we list minimum modeling requirements first. Other inputs we made to increase the accuracy of the model for this particular simulation include changes in the flight performance files for aircraft (as explained above); new waypoints to establish conga-line approach paths and to demarcate turning points on SIDs; the very detailed flight file (which we discuss below); and airport usage files.

Airport usage files tell TAAM which runways are in use for different types of aircraft or different airlines, as well as whether they are open for arrivals and/or departures; whether tromboning on approach is allowed; decision thresholds for sequencing to a terminal; when to cross active runways; which taxiways are in use and by which aircraft and which airlines; where the holding aprons are; which taxiways are high-speed turnoffs; which aircraft use which STARs, SIDs, and runways; and where to de-ice and activate the noise model. For example, to model the fact that all Newark arrivals from Chicago take the PENNS standard approach, the user would write a rule that is contained in the airport usage file. Airport usage files are extremely important in terminal simulations because they control the decisions of the aircraft as they enter sequencing, approach, and choose a runway, land, and taxi to the gate.

TASKS TO COMPLETE A PROJECT: FLIGHT FILES, RUNNING THE MODEL, AND DEBUGGING

As TAAM loads the airspace information files noted above, it creates an error file, sending error messages to the screen and a file. The screen alert can be turned off, if desired.

STARs and SIDS

STARs and SIDS should be programmed and loaded for the runways in use that day. Initially, STARs were programmed in from standard approach plates that pilots use to fly the approach. During testing, these “by-the-book” approaches should be calibrated in extensive discussions with local approach controllers. Textbook approaches start in the en route airspace, and the approaches listed do not cover all possible influxes of traffic; traffic often “joins” a STAR in progress. During peak periods, approach paths can turn into long, snaky conga lines that are characterized by numerous vectors. Working with the TRACON controllers, the user can enter new approaches. Template STARs can be customized to allow vectoring at certain points, resetting of the start of the STAR, and programming in vectors that controllers give to pilots orally, at the point where approach plates state, “expect vectors to final.”

Unfortunately, only one of these approaches will be used by TAAM during simulation: `waypoint_1`. The present version of TAAM simulation does not select multiple STARs from the same waypoint. This limitation is unfortunate because of the changing nature of the traffic flow and possible vectoring over time. In addition, only one altitude can be set for each STAR. In the present version of TAAM, to depict jet and prop flows with varying vectoring or with complete altitudinal accuracy, we would have to create one STAR for each option (e.g., `COATE_JETS_1`) and multiple routes to feed the STAR (e.g., `KIAHKEWR_CJ1`, `KATLKEWR_CJ1...`), and specify the route for each flight to take in the flight

file. For a large simulation, a preprocessing tool such as a data-manipulating Java script or C++ program would have to be utilized.

SIDs do not have a sequencing function. SIDs are necessary to prevent aircraft from going into free flight upon rotation (lift off) at the runway and to keep aircraft flying routes that represent reality.

SIDs also are the only data that cannot be written in standard text and copied into a Unix file because they consist of encoded numerals and symbols. All other TAAM files can be created as text files and copied into the proper file. This setup often saves time over the data input system provided by The Preston Group (TPG) (i.e., IDIS), which is easy to use but time-consuming on extremely large simulation projects.

Airports

Airport layouts are one of the most prolific sources of bugs in TAAM because the airport layout can be very complex. Often, a programmer must spend a day simply erasing programming kinks in the taxiways and gates, identifying aprons and connecting taxiway centerlines. In this simulation, the airport layout will be checked to ensure that aircraft are not landing on closed runways; that they are not overshooting open runways; and that they are achieving the rate of acceptance dictated in the terminal and airport usage files. The aircraft should be acquiring the user-input STARs and not building default approaches; they also should be tromboning automatically for sequencing.

Waypoints

Holding waypoints must be designated for airports of interest. TAAM will set its own holding waypoints if the user does not enter sufficient holding waypoints. One of the known bugs in TAAM involves holding waypoint selection: Aircraft sometimes choose their own holding waypoints or enter multiple holds. This bug is the subject of a multi-year improvement project at TPG. Debugging duties should include watching the simulation to see that aircraft are holding at the designated waypoint and that the right number of aircraft are put into holding in comparison to baseline data.

Debugging Flight Files

In debugging, the true limits of the data in terms of accuracy, data drops, germaneness, and completeness are discovered. Debugging consists of two types of examination: one a statistical and commonsense perusal, the other to ascertain whether the data produce the flights that the analyst intended, in the time and manner intended. TAAM provides a helping hand on the second by providing error messages as flight files are loaded to the simulation project.

For this type of simulation, in which data on flights flown and planned are loaded, TAAM provides a reasonableness check on the data themselves. TAAM delivers warnings when the position reports of aircraft are not within the parameters of the flight performance file. The analyst is alerted to the problem and can then use independent verification to determine whether there is an error in the data or the parameters of the flight performance file should be adjusted. TAAM also creates an alert when there is an unknown destination in the route file; the analyst can then check to see if the waypoint or airport was misspelled, the file used the wrong identifier, or a new waypoint must be added to the file.

TAAM checks the performance of aircraft on STARs and SIDs: Turbo props may be attempting to take STARs designed for jets; clunky jets may be taking a STAR or SID meant for nimbler jets. These errors can be corrected by changing the usage file to assign certain aircraft to certain STARs (the most accurate solution); relaxing the turn or altitude requirements on a STAR (a work-around to undertake with caution); changing the type of aircraft (a work-around that ignores those jets); or, in the case of overrun runways, adjusting the parameters of the aircraft performance file (to be done in delay studies but not in new-runway capacity studies).

TAAM varies the weight characteristics of the aircraft in the simulation; the variance is enough to prohibit B767s from landing on the shorter (outer) runways at Atlanta's Hartsfield and heavy aircraft from landing at National Airport—although in reality such aircraft do so all the time, having been properly weighted. TAAM is not programmed to assume that airlines will adjust the weight of a widebody to land at a short runway. TAAM assumes average weights and performances.

Appendix B

SIMMOD Simulation Model

SIMMOD MODELING METHODOLOGY

SIMMOD *Plus* is a discrete-event simulation model that calculates various aircraft delay and travel time performance measures for airspace and airfield design projects. SIMMOD has been under development since the 1980s. Initially developed as a fuel burn model, it has evolved into a comprehensive planning tool for airport designers, airport managers, air traffic planners, and airline operational analysts. The SIMMOD *Plus* model can be used to evaluate any number of alternative airspace and airfield projects. Modeling can be used to support various airspace and airport studies in the development of cost-benefit analysis, environmental impact statements, environmental reviews, and master plan updates (to name a few). Through the past couple of decades, models of this type have gained acceptance in the aviation industry as an integral part of any type of analytical study.

Although no two SIMMOD studies are exactly alike, there are general characteristics that all have in common. The first step in a SIMMOD study is to have a thorough understanding of the airport environment. This environment includes air traffic control procedures, runway operating procedures, and taxiway movements. To obtain this knowledge of the airport environment, a trip or trips may have to be made to the airport to interview air traffic controllers and airport operations personnel. The input to the simulation model is created through this process. These procedures are transformed from the real-world operation to the simulation model. After the simulation model has been developed, the model is run. As the model is running, it is calculating many aircraft performance measures. These statistics are stored and presented at the end of the run in the form of delay and travel time statistics.

SIMMOD INPUT/OUTPUT FILES

SIMMOD *Plus* has a series of input and output files in text or ASCII format that can be easily manipulated through the use of text editor programs. There are many input and output files from the SIMMOD *Plus* model; in this section, we briefly describe the primary input and output files that are used during a simulation analysis.

Input data for the SIMMOD *Plus* model is contained in separate files that represent different areas of operation, including an airspace file, a ground file, and an events (or schedule) file. We used the city of Chicago's World Gateway Program Airside Simulation Analysis for Chicago O'Hare International Airport Operating Configuration Plan B as the basis for this study. Each input file contains a series of specific data related to the airspace, ground or schedule. Numerous probability distributions are included which represent possibilities that may occur with human interaction between air traffic controllers and pilots. Each file is briefly described below.

Airspace File

The airspace file (also referred to as the SIMU03 file) includes detailed information concerning aircraft movements while in flight. Although there are too many details to list here, examples of information included in this file include, but are not limited to the following: aircraft route information, aircraft separation distributions, aircraft speed distributions, runway coordination information, and on-time arrival and departure distributions. This file was not modified during the study.

Ground File

The ground file (also referred to as the SIMU07 file) includes detailed information concerning aircraft movements on the ground at Chicago O'Hare International Airport. As with the Airspace File, there are many different types of information included in this file. Examples of data contained in this file include taxiway speeds and direction of travel, aircraft gate utilization assumptions, landing and takeoff roll probability distributions, and runway crossing probability distributions. This file was not modified during the analysis.

Events (Schedule) File

The events file (also referred to as the SIMU09 file) includes detailed information concerning scheduled and nonscheduled aircraft activity for a 21-hour time period at Chicago O'Hare International Airport. Examples of information contained in this file include the airline name, aircraft type, arrival time, departure time, and gate assignment. This file was modified, hour by hour, throughout the process.

Report File

Output data from the SIMMOD model is contained primarily in one file (the Report File), although various other files are used during the debugging process. The focus of this report, however, is on the information contained in the Report File. The Report File (also referred to as the SIMU48 file) includes summary output information from the SIMMOD *Plus* model. Information contained in this file include but are not limited to the following: hourly runway use for arrival and de-

parture operations, average travel time by hour for each runway, average delay by hour for each runway, gate utilization statistics by hour for each gate, and flight delay information by 5-minute time periods for arrival and departure operation. We used information from this file in the comparison of the SIMMOD-only versus the SIMMOD-LMINET integration analysis described in Chapter 3.

PRACTICAL ISSUES OF RUNNING SIMMOD

Undertaking a SIMMOD analysis can be a very time-consuming and costly process. The SIMMOD model itself is available through the FAA at a small cost. Pre- and post-processing tools that simplify the process somewhat are available from ATAC Corporation; these tools are packaged as *SIMMOD Plus*.

Once the user acquires the software, the user must obtain appropriate hardware that will be able to run the model. The *SIMMOD Plus* model can be run on an IBM-compatible desktop or laptop computer. The following sections list the minimum and recommended IBM Desktop PC-compatible configuration and the recommended laptop configuration.¹

Minimum Desktop Configuration

- ◆ A 90 MHz Pentium processor
- ◆ 32 megabytes of RAM
- ◆ CD-ROM drive (speed not important)
- ◆ A 500 megabyte hard drive (*SIMMOD Plus* with executables and default data files requires approximately 50 megabytes of disk space)
- ◆ A monitor capable of displaying 800 by 600 pixels (*SIMMOD Plus* supports higher resolutions, if available)
- ◆ An average graphics card that has 1 megabyte of RAM and can support 65,000 or more colors.

Recommended Desktop Configuration

- ◆ A 200 MHz Pentium processor
- ◆ 64 megabytes of RAM
- ◆ CD-ROM drive (speed not important)
- ◆ A 1 gigabyte hard drive

¹ These specifications are based on information that is available on ATAC's Web site describing *SIMMOD Plus* (<www.atac.com/plus/hardware.html>).

-
- ◆ A monitor capable of displaying 800 by 600 pixels
 - ◆ A good graphics card that has 4 megabytes of RAM and can support 65,000 or more colors
 - ◆ Windows NT version 4.0 (Windows 95 works well, although Windows NT is more stable).

Recommended Laptop Configuration

- ◆ A 133 MHz Pentium processor
- ◆ 32 megabytes of RAM
- ◆ CD-ROM drive (speed not important)
- ◆ A 1 gigabyte hard drive
- ◆ A monitor capable of displaying 800 by 600 pixels
- ◆ A good graphics card
- ◆ Windows 95 (Windows 95 has several laptop “user-friendly” options that make it a better choice for the laptop than Windows NT).

Once the model has been installed on a desktop or laptop computer, the study can begin. The process can take many months, depending on the number of airport operating configurations to be modeled and how many alternatives will be evaluated. Before any alternative can be evaluated, the SIMMOD model must be calibrated with actual airline performance statistics. This calibration will guarantee that the model is producing results that are representative of actual airline operations. This process may involve meeting with air traffic controllers to get an accurate understanding of the airport environment. The calibration process itself may take 4–6 weeks or longer; the study itself also may take 4–6 months or longer.

DELAY AND TRAVEL TIME COMPARISON

We assembled and compared aircraft performance statistics for each of the SIMMOD-LMINET combinations modeled. These statistics allow for a comparison of airfield and airspace alternatives.

- ◆ *Arrival Airspace (Air) Delay:* Airborne arrival delay including delay caused by congestion outside the ORD TRACON, capacity constraints at ORD, and approach control delay incurred within the ORD TRACON.
- ◆ *Arrival Ground Delay:* Delay incurred between the runway exit and the gate as a result of aircraft traffic congestion and runway crossings.

- ◆ *Arrival Unimpeded Travel Time:* Travel time from touchdown to the gate, based on distance and speed.
- ◆ *Total Arrival Time and Delay:* Time computed as the sum of arrival airspace delay, ground delay, and unimpeded travel time.
- ◆ *Departure Airspace Delay:* Airspace delay incurred as a result of congestion or outbound vectoring while merging onto the assigned departure track and prior to exiting the ORD TRACON airspace .
- ◆ *Departure Ground Delay:* Delay incurred between the time an aircraft is ready to taxi from the gate and the time the aircraft reaches the departure queue. Departure ground delay includes gate push-back delay, delay caused by runway crossings, and delay caused by aircraft traffic congestion.
- ◆ *Departure Queue Delay:* Departure delay incurred in the departure runway queue as a result of separation minima, miles-in-trail restrictions, mixed runway operations, and intersecting or parallel dependent operations, while awaiting departure clearance.
- ◆ *Departure Unimpeded Travel Time:* Travel time from the gate to lift-off, based on distance and speed and route traveled.
- ◆ *Total Departure Time and Delay:* Time computed as the sum of departure airspace delay, ground delay, queue delay, and unimpeded taxi time.

Statistics also were reported for each time and delay category defined above, as follows:

- ◆ *Daily Average Delay and/or Travel Time:* Average delay and/or taxi time (in minutes) incurred by each aircraft operation during the period.
- ◆ *Daily Total Delay and/or Travel Time:* Total delay and/or taxi time (in minutes) incurred during a day, based on the number of operations in the design day flight schedule and the daily average taxi time and/or delay per operation.
- ◆ *Peak Delay Hour:* Hourly average delay and/or taxi time incurred by each operation during the peak delay hour.

Aircraft throughput statistics also were calculated and are defined as follows:

- ◆ *Peak Hour Arrival Throughput:* Largest number of arrival operations occurring during a single hour.
- ◆ *Peak Hour Departure Throughput:* Largest number of departure operations occurring during a single hour.

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- ◆ *Peak Hour Operations Throughput*: Largest number of arrival and departure operations occurring during a single hour.

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