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Airspace Design and Arrival/Departure Planning For Brussels National Airport

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Abstract

At airports without any plans to add new runways, it is imperative to best utilize the existing airport capacity in order to meet continued growth in traffic demand. One approach to maximize the use of airspace and airport is through efficient traffic planning in real time. This paper presents the development of a simulation prototype for Brussels National Airport to project demand in sectors or at fixes for advance traffic planning and load balancing, and to help sequence and schedule arrivals/departures to maximize runway utilization. Functions and algorithm in three phases of development are discussed. The paper also highlights the type of information the simulation generates for projected demand and aircraft situations in various sectors and over different fixes in the Belgium airspace, and provides illustrations of corresponding displays. The future traffic demand can be displayed at a specific future clock time or for selected time intervals as considered appropriate for making traffic flow decisions.

Introduction

Basic Area Navigation (B-RNAV) equipment recently became mandatory on the entire Air Traffic Service (ATS) route network in the European Civil Aviation Conference (ECAC) area. An increasing number of aircraft are equipped with Flight Management Systems (FMS) and Global Positioning System (GPS)-based navigation (possibly to be augmented by wide and local area augmentation systems). In 1990, when the ECAC Ministers agreed on the RNAV requirement for en route, they also charged ATS providers to take advantage of RNAV capability in the Terminal Maneuvering Area (TMA) where beneficial. Additional operations should be considered to permit aircraft to fly efficiently, maximize use of scarce airport/airspace resources and minimize environmental impacts.

There is little possibility to expand existing or add new runways to many of Europe's most congested airports. Yet with the continued growth in traffic demand the authorities will need to enhance the arrival/departure capacity at the most congested airports. In addition, it remains critical to reduce the environmental/ noise impact on the surrounding communities. The need for TMA procedures has resulted in substantial developments by EUROCONTROL and its Member States to define common standards for RNAV procedure design and common operational concepts to allow a uniform application of RNAV. Although there is no plan for the immediate, mandatory use of such procedures, RNAV systems capable of meeting the requirements for TMA operations might become mandatory in the next decade. For this to occur, use of RNAV in the TMA must be shown to be cost-beneficial.

This paper presents the development of a simulation prototype model for Brussels National Airport (EBBR) to: 1) determine in real time projected demand in sectors and at the fixes to permit traffic load balancing; 2) provide an assessment of airport/airspace use after the fact; and 3) assess airspace/routes redesign and airport capacity enhancement procedures.

Simulation Prototype Development

The MITRE Corporation's Center for Advanced Aviation System Development (CAASD) has developed a concept of Terminal Routes Using

Speed-control Techniques (TRUST). Consistent with current procedures, the concept is based on defining the shortest paths to the runways that aircraft using FMS/RNAV could navigate without any guidance from the Air Traffic Control (ATC) system, thereby minimizing the flying time variations caused by vectoring. Precise landing times and order are established based on aircraft pairwise wake vortex separations. For shared runways, departure slots are provided to maximize runway throughput. Speed control, as opposed to path control, is used to mitigate the deviations caused by wind uncertainties, navigation accuracy, and air/ground communication delays to efficiently maintain desired separation between aircraft. Terminal area flying times, landing/departure sequence, time separations between aircraft pairs, landing/departure times, and delays needed to meet desired scheduled times are computed.

Based on this concept, a simulation prototype is being developed for Brussels National Airport (EBBR). The development process involves three phases. In Phase I, the simulation will use prerecorded data for current operations to establish baseline performance. To study the impact of alternative airspace route redesign, or use of routes through military or restricted airspace, in Phase II, the simulation will provide a comparative assessment with the baseline through a set of metrics relating benefits/penalties to the users and operators. In Phase III, the simulation could be used to plan traffic flows in real time for arrivals and departures, and to balance traffic loads at runways, entry fixes or in sectors. The following paragraphs provide details for simulation use in each phase.

Phase I: Performance Assessment and Demand Projection Capability

In this phase, the simulation is developed to be used as a proof of concept of the efficacy of utilizing CANAC (Belgium flight plan and radar data processing system) provided data for strategic real time traffic planning in the Belgian airspace. The prototype is developed in the JAVA language on a Windows 95 platform for developmental efficiency, portability and ease of modification. It is currently designed to utilize prerecorded data. However in the future, the simulation could use real time connection to the CANAC system for traffic load balancing.

Data Input

To simulate the Belgian airspace traffic, actual data from the CANAC system were used. These data consisted of two hours of recorded radar tracks and flight plan messages sent to or received by the CANAC system. Both files were in a human readable form (ASCII text messages) and needed to be parsed into a form processable by the computer. The flight plan message comprised over 210 megabytes of data. Much of the data was redundant for projecting traffic demand, and was reduced to approximately 5 megabytes of significant information. This consisted of 614 flights with an average of 10 flight plan updates per flight.

When a flight plan is received by the CANAC system, it uses the route and estimated departure time to compute estimated times along the flight path at fixes or reporting points. The system, upon receipt of information, may modify these estimates by recomputing the estimated times along the flight path. The events that may trigger this may be updated flight plans, departure messages, coordination messages, or periodically when the system detects that the aircraft’s flight track has crossed near or on the reporting points.

Simulation Technique

The simulation inputs the processed flight plan data and creates a flight object, which is defined as an identified flight based on its aircraft identification (ACID). Attached to this flight object were each flight plan estimated positions computed for that flight by the CANAC system. These are stored in time order based upon the time of the CANAC message to which they were attached. Data from the radar track files were read and stored separately based also upon the ACID of the aircraft. They are correlated with the flight object by means of their ACID.

The simulation utilizes a clock that advances the time at either a real time rate or in a fast forward mode. As time advances, the simulation determines where the aircraft is, based on interpolation of the aircraft time, position, and altitude as recorded in the aircraft track data.

Since the flight plan estimates produced by CANAC are updated over time, this process is simulated by choosing the flight plan estimate whose time of creation is nearest to the simulation time, but not later than that time. The times, positions and altitudes in the flight plan estimates are used in a similar fashion to the actual track data to produce estimated future positions by interpolation or extrapolation at desired times when they are not at a reporting point.

Phase II: Development of Airspace/Route Redesign and Evaluation Capability

In order to study the impact of any proposed airspace or route redesign, or availability of restricted military airspace usable at selected or at all times so that the aircraft could be rerouted, the simulation will be upgraded to permit "what if" type analyses to show pros and cons of the changes in procedures or airspace use. This would help users to easily create an operational environment with restructured routes as well as future traffic demand, and compare the performance with the current baseline operations. The simulation would permit determination of benefits/penalties of the proposed changes that will be quantified in terms of a set of metrics: viz., runway throughput, airborne delays, controller workload in terms of number of clearances required to separate aircraft, and inter-aircraft separations on the final approaches as well as at all merge points. The quantification of benefits, or lack thereof, with "what if" evaluations will help Belgocontrol in making decisions how to maximize the use of airspace/airport resources. The upgraded simulation will include:

a) realistic system error models and a flight profile generator to calibrate them with pre-recorded data for baselining current operations in a simulation

b) algorithms to generate traffic scenarios using new routes, runway assignment criteria, arrival/departure interactions with the en route system

c) a set of performance measures to assess airlines/controller/capacity benefits.

Phase III: Development of Arrival/Departure Traffic Flow Planning Tool

Real time planning of arrivals and departures (especially when the traffic enters the Belgian Flight Information Region [FIR] ad hoc) would help maximize airport throughput and permit the aircraft to take the unavoidable delays (needed for separating traffic) most efficiently at higher altitudes. The objective in this phase is to increase the number of operations at the airport without compromising safety. This tool will help efficiently sequence and schedule arriving aircraft as soon as they enter the Belgian FIR to the desired runways according to the established runway assignment and separation rules, and will determine the required delays to be absorbed most efficiently. The tool will automatically allocate slots for known departures to keep the runways full, as well as allow the traffic planner to insert departure slots when the queue builds up, thereby appropriately filling or adjusting arrival gaps. The following functions and algorithms are being developed.

Functions and Algorithms

RNAV Route Design

The FMS aircraft can navigate over predefined paths, and accurately meet times over fixes if the speed profiles are known. In the simulation, a flexible route structure is designed by a set of waypoints and associating the required speeds and altitudes to each flight segment, based on current ATC practices. The routes are designed with adequate separation at the route merges for conflict-free planning. To permit aircraft to land at the earliest times, the highest permissible speeds over each flight segment are assumed for flight planning.

Sequencing and Scheduling

In order to establish landing times, it is necessary to define a strategy to set up the sequence or order of landing. Currently, the operational procedures are based on sequencing aircraft using a First Come First Served (FCFS) approach to the runway. However, other sequencing priorities could be considered based on runway throughput maximization. For example, sequencing most heavier aircraft on a certain runway would require reduced separations between successive heavy aircraft thereby minimizing fuel for overall operations rather than considering savings for aircraft on an individual basis. Once the sequencing approach is selected or defined, the next step is to determine the landing time of the first aircraft in sequence using its minimum flying time to the desired runway. Successive aircraft are then scheduled at times based on whichever is later, of either their minimum times to fly, or by adding the desired time separations (derived from the required distance separations) to the schedule of the aircraft ahead. When gaps exist between the arrivals, departures are scheduled to fill in the available slots with appropriate separations. If departures have been waiting for a long time in the queue, then certain arrivals could be pushed back to land later to allow a few aircraft to depart.

Estimation of Time Separations

The existing procedures define the requirements for distance separation on the final approach between aircraft pairs depending upon the weights of lead/trail aircraft that have to be maintained for safety. For sequencing and scheduling of aircraft, a precise computation of corresponding landing time intervals is important. If runway occupancy time is not a constraint, then the landing time interval depends upon the desired distance separation between an aircraft pair, the along-track wind estimate over the final approach, airspeed profiles of the aircraft pair on the final approach, and the length of the segment on the final approach where the minimum separation occurs. For example, in the case of a fast aircraft following a slow aircraft, the minimum distance separation occurs when the slow aircraft reaches the runway threshold. But when a slow aircraft follows a faster aircraft, the minimum distance separation exists as soon as the slow aircraft turns onto the final approach behind the faster aircraft. The case of equal speed aircraft is a subset of either of these two situations.

The field use of this tool will require a data feed from CANAC to input flight plan information as soon as such information becomes available. An information link will help acquire information on departures. The output information on arrival/departure sequences and schedules could be made available at the planning position on an auxiliary display. The delay information for specific aircraft could be used by a planning position to inform the respective controllers to take the needed actions to achieve the required times at selected fixes, or could be electronically forwarded, if such an interface could be developed. MITRE/CAASD could help provide algorithm and auxiliary information display development, but Belgocontrol may chose to use a development contractor for upgrading information display to the controllers.

Preliminary Results and Displays

This section presents the features of simulation capability developed in Phase I. Prerecorded flight plan data for two hours is used to generate the future traffic situation displays and traffic demand in different segments of airspace and at predefined fixes. Based on the information in the flight plan on future positions and corresponding time estimates, the simulation generates the display of future positions in the entire Belgian FIR, as well as for each sector at a clock time selected by the user (traffic planner in the real operation) of the simulation. For example, Figure 1 shows the projected position of each aircraft at the future selected time (shown as 17:56:58) set by the time slider shown at the bottom of the figure. The departures are shown in green, arrivals in red and overflights in the white color. The simulation also allows the user to look at future demand in a specific sector by clicking on the desired sector buttons shown on the right side of the figure. The information could help the traffic planner to move certain aircraft onto different flight paths from one sector to another in order to balance the traffic load among sectors. By clicking on the aircraft ID, the simulation also shows the projected path of the aircraft.

In order for the traffic planner to get the information on projected sector loads quantitatively, Figure 2 shows the Maximum Instantaneous Airborne Count (MIAC) in an interval of 15 minutes (or a user-selected interval) for each sector shown color-coordinated. The “OOC” term in the figure represents airspace outside the Belgian FIR. The user of the simulation can also get information on the estimated Instantaneous Airborne Count (IAC) in each sector by selecting a clock time set by the time slider as shown in Figure 3. Figures

2 and 3 provide specific information for sectors expecting heavy vs. light traffic loads during the time period of interest.

Figure 4 shows the traffic load expected at each fix (within 2 nmi) for a selected time at various flight levels. As shown in the figure, the simulation is limited in displaying three fixes simultaneously at a time. However, the information is available for all fixes defined in the airspace. The simulation also provides information on the number of aircraft expected to cross each fix during a specific time interval.

In the future, if the simulation capability could acquire real time flight plan data, the traffic planner could use the future situation display and sector load information to change the routes of certain flights to balance traffic load in sectors. The simulation would then use the updated flight plan information to project revised sector traffic loads to permit the traffic planner to ascertain that the new sector loads provide the desired load balance among sectors. Similarly, the demand information for individual fixes would help the traffic planner to take early decisions to move certain aircraft from one fix to the other to avoid congestion at a fix or fixes. Advance information on the projected demand at individual fixes, especially for arrivals, would help the traffic planner to assign a different terminal entry fix to some aircraft than originally planned in order to increase airport utilization and reduce overall operational delays.

In order to assess the performance of operations after the fact, the simulation also uses prerecorded track data and can generate the same type of information as shown in Figures 2 to 4. This provides an understanding of the actual and maximum traffic handled in each sector, or over each fix during various time periods. However, beyond the above information, the two most important measures to help determine the potential opportunities for improving airport capacity and reduce delays are: 1) achieved airport throughput, and 2) actual inter-aircraft separations identifying the gaps.

Figure 5 shows the arrival and departure throughput for dual runway 25L/R operations at Brussels National Airport. Runway 25L is generally used for arrivals due to noise abatement procedures. Figure 6 shows the arrival/departure time separations for Runway 25R. The results show larger than required separations between certain aircraft pairs. In order to enhance airport capacity, the proposed planning function discussed in the next section could help reduce the variations between planned vs. achieved separations, and also provide means to optimize the landing sequence. One of the strategies under consideration for improving the airport throughput (that could be evaluated via simulation) is to land all heavy aircraft on Runway 25R shared with the departures, while all other aircraft land on Runway 25L. In this mode, a smaller separation (4 nmi) will be required among heavy aircraft as compared to the current situation where larger (5 and 6 nmi) separations are planned between aircraft with the mixed equipage.

Arrival/Departure Traffic Flow Planning

Real time planning of arrivals and departures at EBBR, especially when traffic enters the Belgian FIR without dynamic flow controls, can help maximize airport throughput, and impose the unavoidable delays (needed for separating traffic) most efficiently at the higher altitudes. The primary objective is to increase the number of operations at the airport without compromising safety. This model would help efficiently sequence and schedule arriving aircraft, as soon as they enter the Belgian FIR, to the selected runways according to the established runway assignment and separation rules, and determine the required delays to be taken in the en route airspace to eliminate holding in the terminal area. The model automatically allocates slots for known departures to maximize runway use, and will allow the traffic management specialist to insert departure slots reducing departure queues when needed. Table 1 illustrates the interface for displaying the schedule for arrivals and departures.

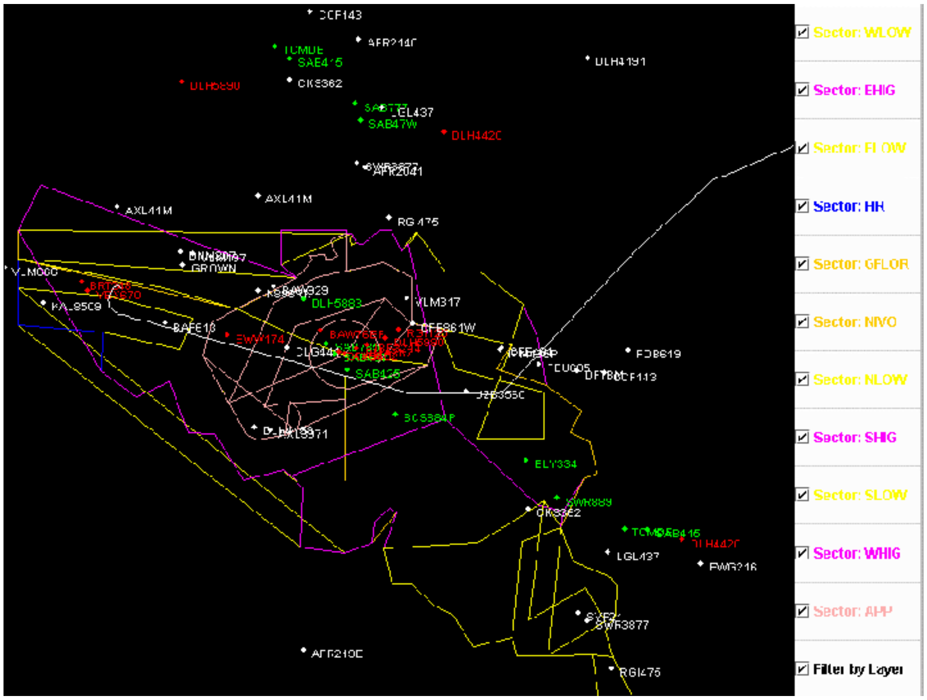
Summary

The traffic demand information and displays being developed in Phase 1 will help mange the traffic flows in order to balance loads in sectors and at fixes, especially for arrivals at terminal area entry points, to maximize the use of airspace/airport resources. In Phases II and III, consistent with operating procedures at EBBR, the simulation would plan traffic based on defined paths to the runways that RNAV equipped aircraft could navigate consistent with the need to better serve FMS/RNAV/GPS aircraft. The objective is to eliminate most verbal direction from the air traffic controllers thereby minimizing flying time variations caused by vectoring and reduce controller/ pilot workload.

Unequipped aircraft (if any) can be guided along the same paths by the controllers. Precise landing times and order take into account wake vortex separations so as to achieve maximum throughput. For shared runways, departure slots are created to maximize runway throughput while balancing arrival-departure demand. The simulation algorithms assume the use of speed rather than path control in the terminal area to mitigate the flight time deviations. The traffic planning process is independent of the need for any inter-FIR traffic flow constraints for the adjacent FIRs.

The overall benefits expected from the use of this simulation are:

- Increased airport capacity
- Reduced noise foot print and avoidance of sensitive areas
- Reduced air/ground communications
- Reduced flying time and fuel savings
- Decreased workload for controllers and pilots



☑ Sector: WLOW
☑ Sector: EHIG
☑ Sector: FLOW
☑ Sector: HH
☑ Sector: GFLOR
☑ Sector: NIVO
☑ Sector: NLOW
☑ Sector: SHIG
☑ Sector: SLOW
☑ Sector: WHIG
☑ Sector: APP
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Figure 1. Future Traffic Situation Display

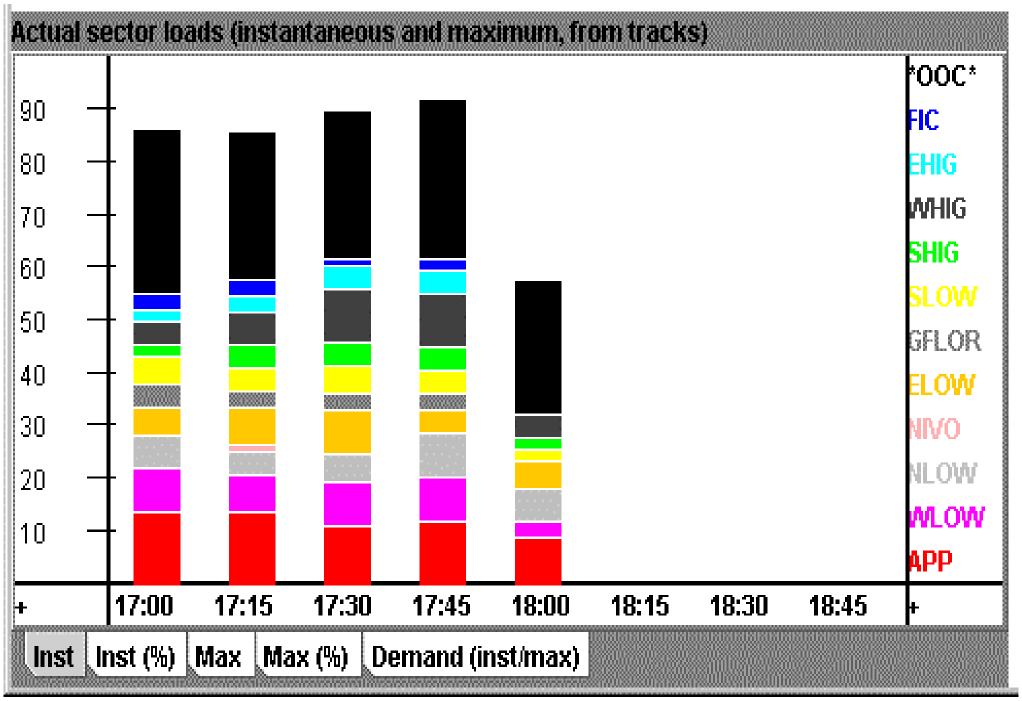


Figure 2. Future Traffic Demand by Sectors

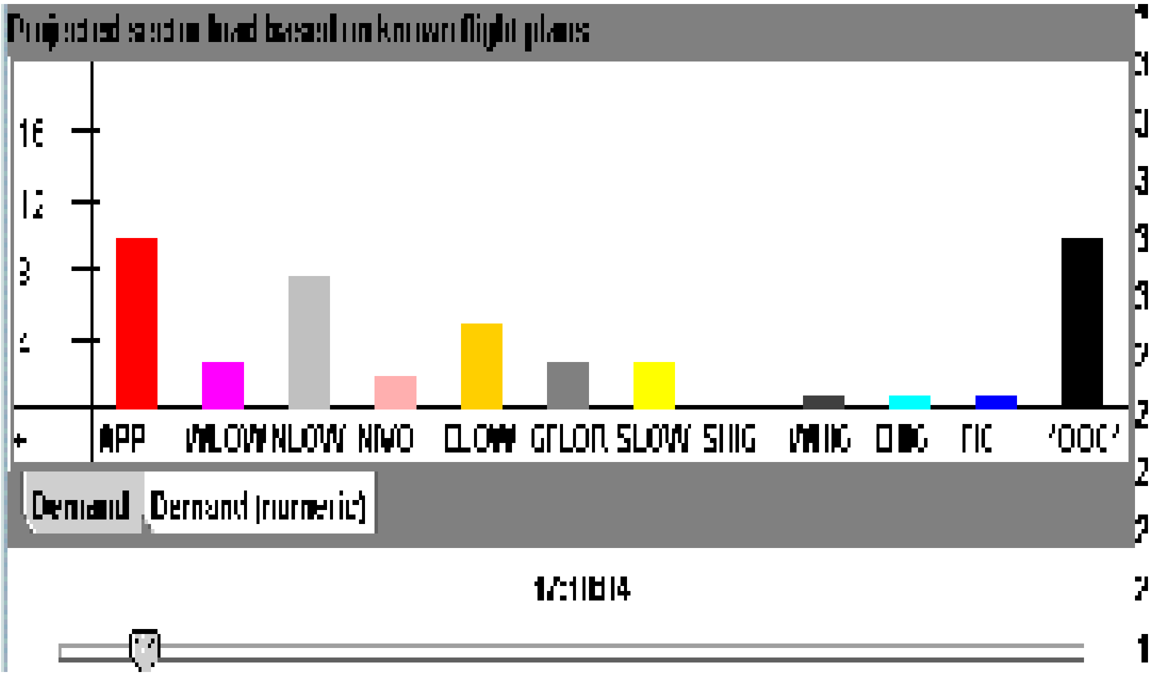
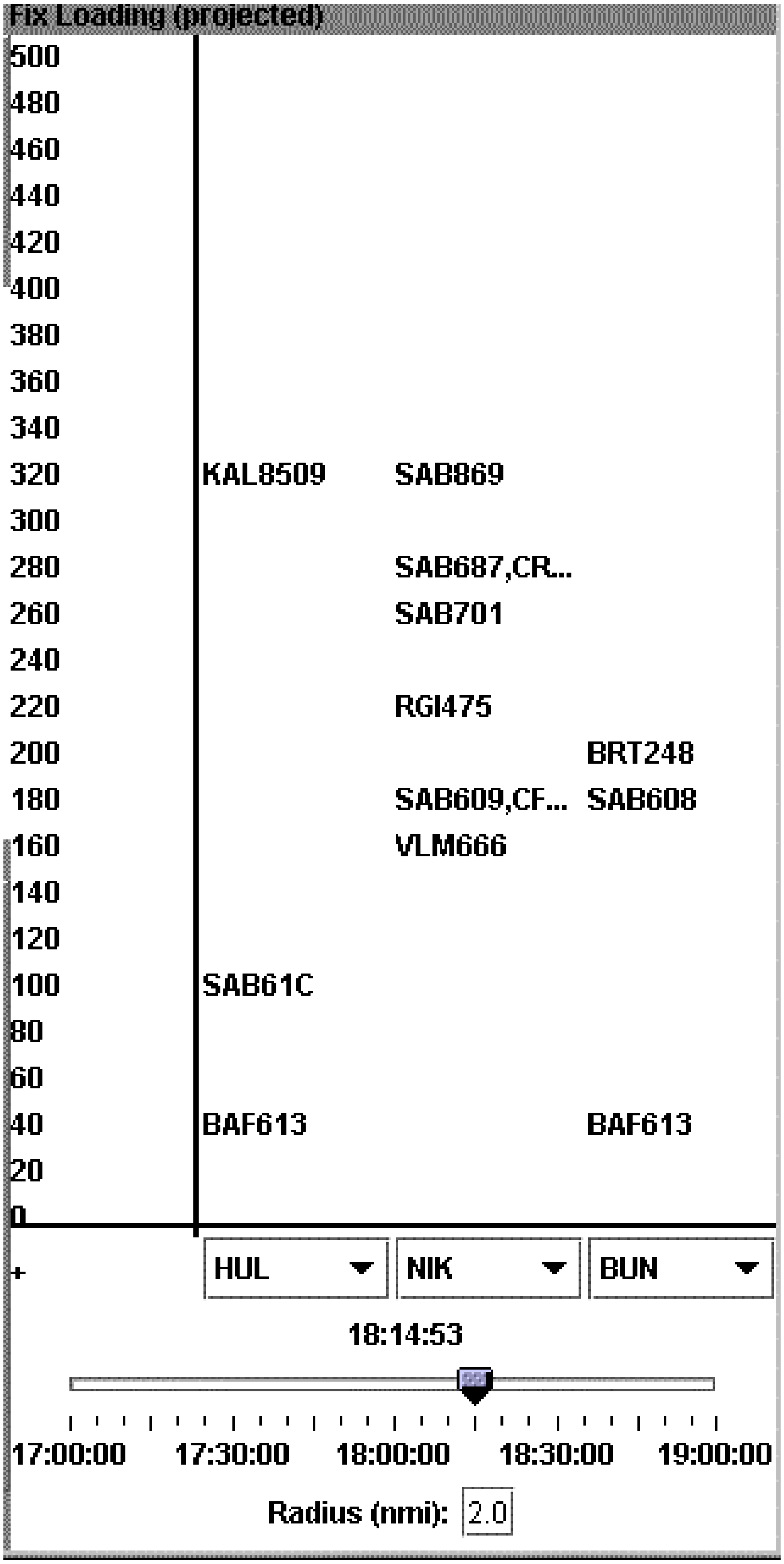


Figure 3. Instantaneous Airborne Count by Sector



Radius (nmi): 2.0

Figure 4. Instantaneous Traffic Load by Fix of Different Flight Levels

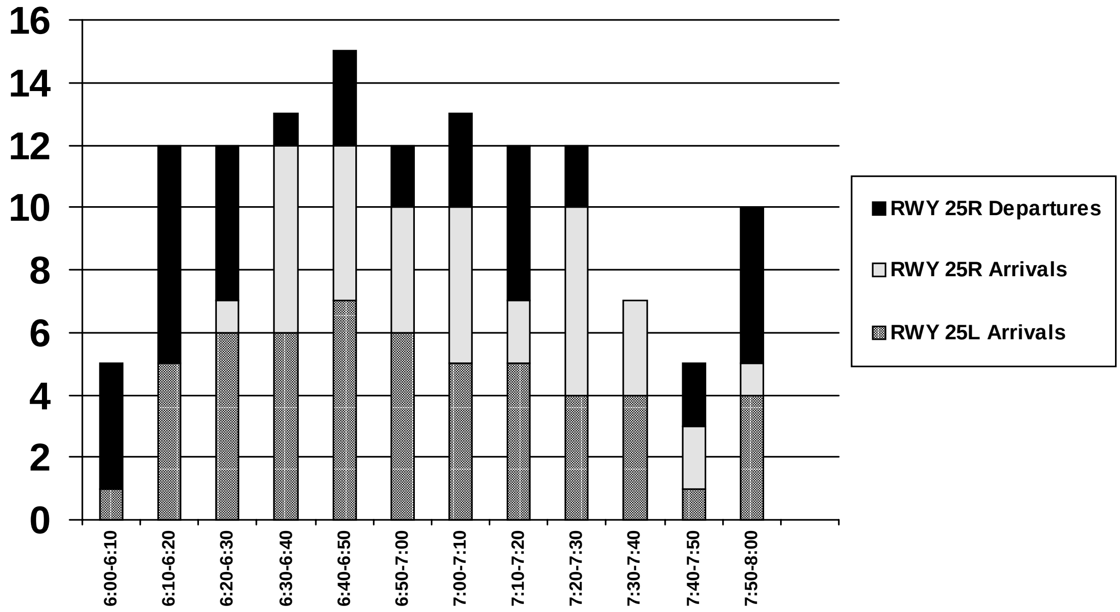


Figure 5. Airport Throughput

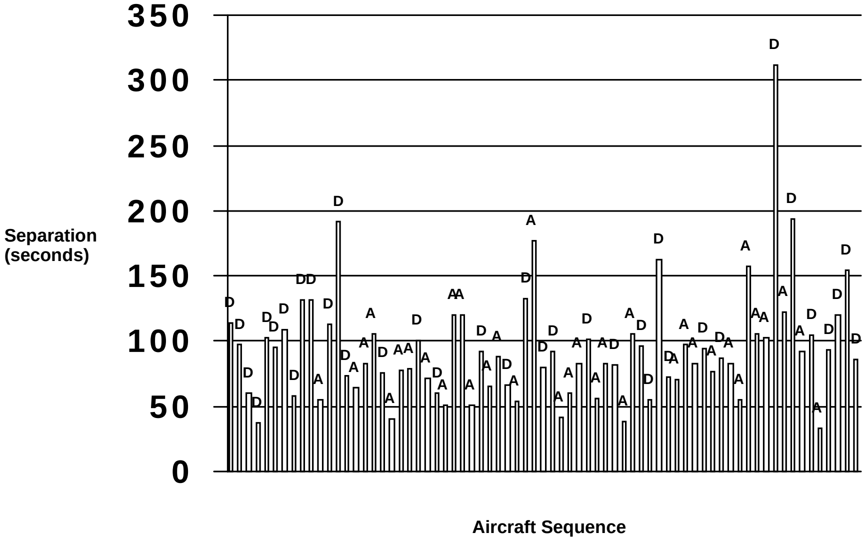
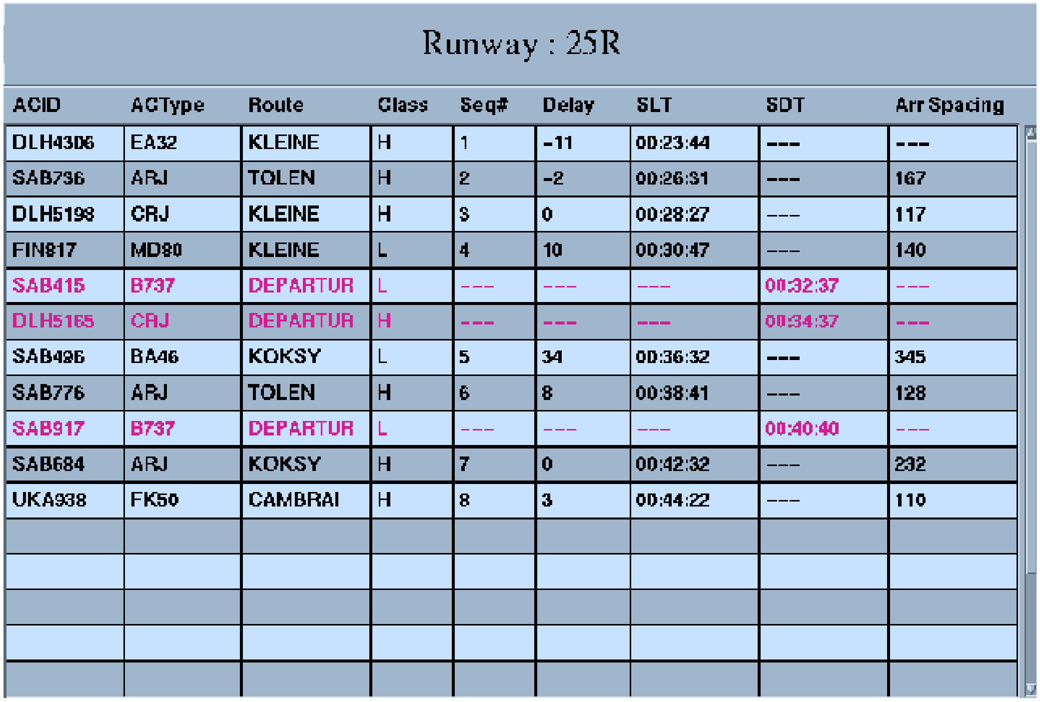


Figure 6. Arrival/Departure time Separations for RWY 25R

Table 1. Sequence and Schedule for Runway 25R



Runway : 25R

ACID	ACType	Route	Class	Seq#	Delay	SLT	SDT	Arr Spacing
DLH4306	EA32	KLEINE	H	1	-11	00:23:44	---	---
SAB736	ARJ	TOLEN	H	2	-2	00:26:31	---	167
DLH5198	CRJ	KLEINE	H	3	0	00:28:27	---	117
FIN817	MD80	KLEINE	L	4	10	00:30:47	---	140
SAB415	B737	DEPARTUR	L	---	---	---	00:32:37	---
DLH5165	CRJ	DEPARTUR	H	---	---	---	00:34:37	---
SAB426	BA46	KOKSY	L	5	34	00:36:32	---	345
SAB776	ARJ	TOLEN	H	6	8	00:38:41	---	128
SAB917	B737	DEPARTUR	L	---	---	---	00:40:40	---
SAB684	ARJ	KOKSY	H	7	0	00:42:32	---	232
UKA938	FK50	CAMBRAI	H	8	3	00:44:22	---	110

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Dr. Mohleji is a Principal Engineer with the Center for Advanced Aviation System Development (CAASD) of the MITRE Corporation. For over 29 years, he has been involved in developing concepts and prototype simulations for air traffic management, navigation, flight guidance, and aviation weather systems. He provided support to the ICAO /FANS Committee to determine cost/benefits for upgrading the air traffic control systems using satellite-based communications, navigation and surveillance technologies in various regions of the world. Currently he is leading an effort to build simulation prototypes to help airport facilities in the U.S. and overseas to redesign terminal routes and airspace for flight management/area navigation system equipped aircraft, and to efficiently manage arrival/departure traffic flows for maximizing runway utilization. Dr. Mohleji has published more than 60 papers and reports on air traffic management concepts to improve flight efficiency.

Dr. Mohleji received a Ph.D. in electrical engineering from the University of Windsor, Ontario, and M.S. in Management Science from the American University in Washington D.C. He is an Associate Fellow of the American Institute of Aeronautics and Astronautics (AIAA). He is an Associate Editor for the Control Engineering Practice Journal (UK) of the International Federation of Automatic Control (IFAC).