ADTOS: Arrival Departure Tradeoff Optimization System*

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ABSTRACT
This paper develops a novel automated decision support system, named ADTOS, intended to assist traffic flow management specialists select the most optimal arrival and departure strategies. We have built and maintained a data warehouse using streams of aviation data as part of an internal research and development project at Boeing Advanced Air Traffic Management in Chantilly, VA. ADTOS leverages this data warehouse, making use of Aircraft Situation Display to Industry (ASDI) surveillance, Meteorological Aerodrome Reports (METAR), Terminal Aerodrome Forecast (TAF) data, and runway configurations. The warehouse database architecture and the arrival/departure tradeoff optimization module is presented with a validation case study in which ADTOS is utilized for strategic planning of arrival and departure traffic and airport capacity from 1 hour to 24 hours into the future at Dulles International Airport (IAD).

Categories and Subject Descriptors
H.2.4 [Information Systems]: Database Management—Systems

General Terms
Algorithms, Design, Performance

Keywords
Air traffic management, flow management, data stream management, information extraction, data analytics

1. INTRODUCTION
The current levels of congestion are an indicator of the fact that restricted capacities/constraints in the NAS are unable to meet growing air traffic demand, resulting in costly delays. Although air traffic controllers (ATC) perform traffic flow management using various tools and techniques with all necessary data to alleviate the problem, the outcome may not deliver the most optimal solutions with best performance in an automated fashion, causing additional increase in ATC workload. Many attempts have been made to model and predict likely losses in capacity to allow stakeholders in the NAS to take corrective actions to ameliorate the system delays [18, 16, 8, 10, 17, 12, 13, 14, 15, 11].

ADTOS is a novel system to optimally sequence arrival and departures at airports, introducing a greater degree of automation and decision support for traffic flow management. It is driven by data from an aviation data warehouse [9] continually updated by live data sources.

The rest of this paper is organized as follows: In Section 2, we explain the overall architecture of ADTOS, in Section 3, we introduce data sources and present the database design. Section 4 discusses the arrival/departure tradeoff optimization module. Section 5 presents a case study: arrival/departure tradeoff optimization at Dulles International Airport. The final section contains concluding remarks and suggested future work.

2. ARCHITECTURE
ADTOS is built upon an aviation data repository using IBM’s InfoSphere Warehouse [3], where ASDI [1], METAR [6], and TAF [7] data are stored. Requests coming through a web interface are passed onto an arrival/departure tradeoff optimization module. Per an incoming request, the optimization module connects to the database, retrieves the relevant data, runs the algorithm and responds to the request with the recommended strategy, presenting the results on the web page. Each retrieval action is posed in terms of a corresponding query of the aviation data repository.

Figure 1 is a graphical overview of the system architecture, where components are connected to each other with arrows indicating data flow.

Back end processing is illustrated with green components and comprised of interim and final partitioned databases, an XML shredder, and the arrival/departure tradeoff optimization module. The XML Shredder, comprised of a set
of stored procedures, parses out raw individual ASDI messages and puts their content into separate tables in the interim database. Tables are partitioned by month across the external drives.

The front end module is a web interface powered by IBM’s Cognos Business Intelligence (BI) [2], illustrated with a red component.

Data sources and pre-processing modules are illustrated with blue components. The database is fed using streams of aviation data.

3. DATA SOURCES AND DATABASE DESIGN
This section presents data sources and the database design.

3.1 Data Sources
ADTOS uses three main data sources, ASDI stream, METAR report, and TAF forecasts that are handled separately.

The ASDI data feed is a continuous stream of messages delivered over a TCP/IP network socket from an upstream ASDI vendor. The stream consists of data packets containing Zlib compressed XML documents of ASDI messages with binary headers.

Figure 2 shows the number of ASDI messages processed by hour throughout a single day, June 5, 2013. Note that a total of over 30 million ASDI messages are processed in any single day.

ASDI messages can be flight plan related data, oceanic reports, or host track reports. During the initial stage of the processing, a TCP/IP live ASDI stream is consumed by a message flow where messages are sorted and pushed to related queues based on their message types. This near real-time data consumption is handled by IBM WebSphere Message Broker [4] and MQ [5]. Correlator is in charge of correlating various message types. Its purpose is to tag flight plan and track messages from multiple Air Traffic Control (ATC) centers relating to the same flight with a unique identifier called the (FLIGHT_KEY). Decompressing Zlib files with XML content comes next. The final step in processing is splitting a set of ASDI messages into individual messages.

METAR is an international format for reporting airport weather information. The report is a weather observation near ground level from an airport station containing information such as date, time, wind, visibility, and temperature. A TAF is a concise statement of the expected meteorological conditions at an airport during a specified period (usually 24 to 30 hours). Arrival/departure tradeoff optimization engine makes use of TAFs to best match the arrival/departure capacities given the meteorological conditions at an airport.

3.2 Database Design
ADTOS’ database was designed with Quality of Service (QoS) requirements such as performance, throughput, and high availability in mind so that the vast amount of data streaming and processing can be managed. When an optimization request is received through its web interface, ADTOS is designed to respond with the most up-to-date accurate data available in the database with the best performance. To
address this goal, ADTOS employs a number of tools and techniques including a central DB2 relational database that stores all data received and further refined from processing. ADTOS also employs IBM WebSphere Message Broker and MQ to meet critical QoS requirements.

Figure 3 is an overview of ADTOS’ database schema, showing the tables used for ADTOS’ core data processing.

Tables are color coded: Blue relates to ASDI data, red for METAR, and green for TAF forecasts. Transparent ones are the supporting tables. There is an additional table coded orange indicating that it is populated by running queries against these major three data sources. The orange table is populated overnight, providing custom data for the arrival/departure optimization module. Note that the figure depicts a simplified version of the ADTOS’ database, which currently contains over 100 tables, but these few serve as a useful illustration of the core data and functionality present in ADTOS, as well as the general database design strategy.

Note that (ICAOID) and (Airport) are used interchangeably in the tables. Transparent supporting tables connect to ASDI main tables (blue) using (UUID), whereas ASDI main tables connect to each other using (FLIGHT_KEY). Bold fields in the tables indicate the fact that they are required, whereas others are optional.

The ADTOS’ database schema was designed with potential queries in mind so that the best response performance can be achieved for requests. Therefore, database tables reflect incoming raw messages in XML. The tables are created based on classes generated from schema definitions for the correlated ASDI, METAR and TAF data.

4. ARRIVAL/DEPARTURE TRADEOFF OPTIMIZATION MODULE

Gilbo et al identified the fact that almost all capacity-constrained major airports with certain runway configurations have arrival and departure capacities that appear interconnected. Hence, arrival capacity can be increased at the expense of decreasing departure capacity and vice versa [12]. Therefore, an arrival/departure tradeoff optimization module was implemented for ADTOS that performs the following steps:

- Upon a request received via web interface, the module gathers the input parameters such as date, time interval, weight coefficient, and airport code.
- Based on the input parameters, it connects to the relevant database partition and proceeds as follows:
  - It determines whether the meteorological conditions indicate IFR or VFR at the requested airport given the date/time inputs using TAF data available in the database.
  - Per weather conditions forecasted at the specified airport, the module pulls the relevant arrival and departure capacity values from the database. Note that arrival and departure capacity values are computed based on historical values and updated nightly considering the most up-to-date data.
  - The module retrieves expected arrival and departure demands from the database in the form of 15 minute bins using ASDI flight plan data in the database.
Table 1: Determining IFR and VFR Operational Categories based on ceiling and visibility values

<table>
<thead>
<tr>
<th>Category</th>
<th>Ceiling</th>
<th>Visibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>IFR</td>
<td>&lt;1000ft</td>
<td>&lt;3mi</td>
</tr>
<tr>
<td>VFR</td>
<td>≥1000ft</td>
<td>≥3mi</td>
</tr>
</tbody>
</table>

- Considering weight coefficient provided by the user, the algorithm performs optimization computing the minimum cumulative arrival and departure queues. This way, the demand is best met by the capacity allowing the optimal number of arrivals and departures.

• The final result is presented to the client through a web interface.

The Linear Programming (LP) model of the optimization problem can formally be formulated as

$$\max_{u^*} \sum_{i=1}^{N} (\alpha u_i + (1 - \alpha) v_i), \quad 1 \geq \alpha \geq 0$$

where $\alpha$ is the weight, $u_i$ is the airport arrival capacity at the $i$th time slot, and $v_i$ is the airport departure capacity at the $i$th time slot [12]

5. VALIDATION - A CASE STUDY AT IAD AIRPORT

Arrival and departure delays were identified at IAD from historical data. A time period was then identified in which ADTOS optimally sequenced arrival and departures to minimize the cumulative flight delays. The final results were then validated by comparison with the actual airport performance in the same time period.

IAD is one of the three major airports in the Washington, DC metro area. It has four active runways: three parallel runways 19R, 19C, and 19L, and runway 30. There is a planned runway, 30L that is not currently used. Unlike other major airports such as Atlanta Hartsfield, where each runway is a dedicated single mode runway, IAD runways are multimode i.e. used for both arrivals and departures, making it a good fit for our study.

The case study uses historical data for the time period of June 1-30, 2013 to identify delays and generate arrival/departure capacity curves. Two simplified operational weather categories are used, IFR and VFR. Table 1 shows the rules used for determining these categories.

5.1 Flight Delays at IAD, June 1-30, 2013

In this study, flights arriving or departing 60 seconds or more after the time indicated in the latest filed flight plan including amendment are considered delayed.

To identify delays at IAD, we populated corresponding fields in the Airport Capacity table by retrieving 1-hr counts of arrival and departure delays. Delays were determined by comparing the time in the flight plan with the actual arrival and departure times. Averaging the arrival and departure delays per 1-hr bin for the entire month of June 2013 generated Figure 4.

Figure 4 shows that even though average delay count per hour for arrival doesn’t exceed 2, average delay count per hour for departure can be 10 or more. These figures appear to indicate that there is congestion at IAD, and that current mechanisms are insufficient and will not meet the growing air traffic demand; thus, the airport capacity is insufficient and an alternative way of optimization seems to be needed.

5.2 Arrival/Departure Tradeoff Optimization Test Scenario

In this test scenario ADTOS processes a time period in the near future to optimally sequence the arrival and departures in order to minimize cumulative flight delays. The test scenario is executed on Monday, July 1, 2013 at 8:00AM local time, to optimize the flights from one to three hours in the future between 9:00 and 11:00AM local time at IAD.

The execution steps for the scenario are as follows:
• ADTOS uses the latest capacity curves for all runway configurations to determine operational limits.

• ADTOS checks TAF forecasts to identify operational category for the time period of interest.

• Given the category, ADTOS retrieves the relevant capacity table (generated from the capacity curve).

• ADTOS uses flight plan data to determine arrival/departure demands for the time period of interest.

• Provided the capacity and demand tables, ADTOS optimizes the flights.

As ADTOS is driven by data from an aviation data repository that is being continually updated by live data sources, it has the ability to generate and update capacity curves nightly as a batch process. To do this, ADTOS populates the Airport Capacity table that contains 15-min bins for counts of arrivals and departures per airport and the operational weather categories identified as IFR or VFR by simple visibility and ceiling values.

Figure 5 is illustration of IAD airport capacity curve under VFR operational condition and the arrival/departure capacity pairs within the tradeoff area. In the left figure, the coordinates of each point indicate the number of arrivals and departures realized at the airport during the same 15-min interval. The capacity curve is estimated by stretching a piecewise-linear curve over the set of points. To ensure the estimation is robust, ADTOS rejects outliers that can be considered as rare events when the airport operates beyond its operational limits for a short period of time. In the left figure, the red curve indicates the robust estimates and the blue curve the non-robust estimates of the capacity curve [12].

Note that ADTOS used actual historical ASDI and METAR data based on 15-min counts over the period of entire month of June 2013 to generate these capacity curves. ADTOS determines from the weather records that the operational category for the time period of interest is VFR. ADTOS pulls the relevant capacity table indicating the operational limits.

Using operational category for the time period of interest, ADTOS retrieves 15-min counts of arrival and departure demands (9:00AM to 11:00AM EST). Airport demand is determined by using the continually updated flight plan records in the warehouse. Table 2, Column 2 (DEMAND) contains 15-min counts of arrival/departure demands under VFR category for the time period of interest (9:00AM to 11:00AM local time).

The final step in the process is optimizing the arrival/departure sequence. ADTOS finalizes the optimization by keeping all flights served with the cumulative arrival/departure queue of 42. The flow management specialist can further alter the ADTOS' optimization to experiment with alternative sequencing by selecting different arrival/departure variations through the pull down menu as illustrated in Figure 6.

5.3 Validation

In order to validate ADTOS' optimization, we reviewed the actual traffic flow for the time period of interest. Table 2 shows the initial demand, actual traffic flow, and the arrival/departure queue counts in July 1, 2013 between 9:00 and 11:00AM local time.

As shown in Table 2, 59 arrivals were not served, keeping the cumulative queue count at 363.

The case study indicates that ADTOS is able to more optimally sequence arrivals and departures and so minimize the cumulative flight delays, solving the combinatorial optimization problem at the IAD airport. The results ADTOS attained appear to be a significant improvement on the actual arrival and departure traffic flows.

6. CONCLUSION AND FUTURE WORK

ADTOS is a novel automated decision support system to assist in optimally load sharing between arrival and departures at airports, utilizing information from an aviation repository, which is the information base supporting ADTOS. The simple validation exercise used information on arrivals and departure traffic flows at IAD airport. The results indicate that there may be value in the ADTOS approach of prioritizing one flow over another which in this simple approach increased the IAD airport throughput and reduced the traffic delays. Although ADTOS offers a potential capability to assist in reduction of traffic delays, the work so far is experimental and more research is required. The tool currently handles a single airport at a time disregarding other airports in NAS with connecting flights and airspace congestion. In order to better assess delays and offer an optimal solution, NAS will need to be assessed as an entire system. Additionally, a critical data source, airport surface data (ASDE-X) has not yet been included in the data warehouse. Our plan is to utilize ASDE-X in the future to more accurately determine arrival/departure times at airports.

7. REFERENCES


Arrival Departure Tradeoff Optimization System (ADTOS)

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<tr>
<th>TIME (Local)</th>
<th>INITIAL DEMAND</th>
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Total: 282

Figure 6: ADTOS’ optimization.

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Total: 282

Table 2: Actual Traffic Flow


