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PROACTIVE FLIGHT SCHEDULE EVALUATION AT DELTA AIR LINES

Bruce Schumacher

Delta Air Lines
Dept. 487
1775 Aviation Blvd.
Atlanta, GA 30320-6001, U.S.A.

ABSTRACT

Delta Air Lines is the first and only airline to carry over 100 million passengers in a year, carrying over 105,000,000 passengers in 1998. To provide service to this number of passengers, Delta operates a "hub and spoke" flight system. In the hub and spoke system, certain key airports, or hubs, are designated as the origination point of a large number of flights, thereby allowing a passenger departing from a hub airport almost unlimited flexibility in terms of direct flight destinations. A change in the operation of the runways in one of Delta's hub airports was planned, and Delta management wanted to determine the effect on the dependable operation of the current and future flight schedules.

Flight schedule dependability can be defined as the reliable, consistent, and timely operation of a published flight schedule. For several reasons, schedule dependability is absolutely critical to the successful operation of an airline. The airline industry is extremely competitive, and schedule dependability is an important benchmark that differentiates competing airlines in the eyes of many customers. Also, schedule dependability is critical to the profitability of an airline because of the high cost of an unreliable operation. These costs include repositioning aircraft, accommodating inconvenienced passengers, and adjusting pilot and flight attendant schedules.

The purpose of this paper is to present two simulation models used to evaluate proposed flight schedules and to quantify the effect of changes in conditions at a major hub airport on the proposed schedule.

1 INTRODUCTION

The Delta Air Lines operation at Atlanta Hartsfield International Airport (ATL) is the largest single airline hub operation in the world. Delta operates over 640 flights per day from the four East-West runways at ATL. In addition to Delta, 27 other carriers operate approximately 520 flights per day. Because of the importance of ATL to Delta's daily operations, any change in conditions at the airport could significantly affect the operation of the entire Delta system. While developing a new flight schedule, Delta was informed of a plan to temporarily close a runway at ATL for construction and allow temporary flight operations on an adjacent taxiway during the construction period. Delta wanted to analyze the impact of the proposed runway closure on various flight schedules under consideration.

2 PROBLEM DEFINITION

As shown in Figure 1, ATL utilizes four runways; 27L and 26R are used for landing to the West, and runways 27R and 26L are used for takeoffs to the West. Likewise, runways 08L and 09R and 08R and 09L are used for eastbound landings and takeoffs, respectively, as weather conditions dictate. A planned closure of runway 27L/09R for construction could have a significant effect on the performance of flights out of ATL.

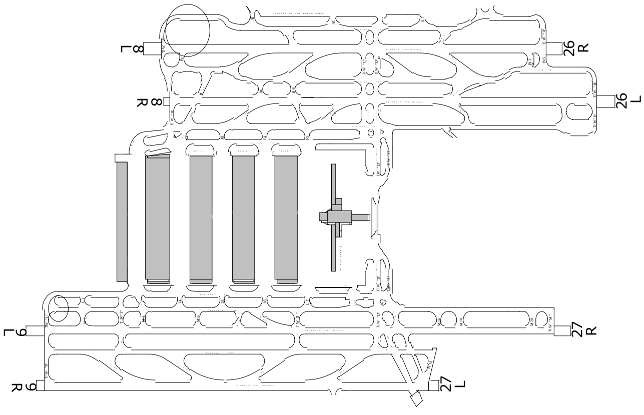

Figure 1: Atlanta Hartsfield International Airport

Prior to publication of a new flight schedule operating during the planned construction period, Delta decided to use simulation to study the effects of the proposed runway closure. The purpose of the modeling effort was to determine the expected change in on-time performance due to the runway closure and to identify the specific flights that would likely be significantly delayed due to the closure.

To answer these questions, two models were built using ARENA by Systems Modeling Corporation. The first model, built to simulate a system flight schedule, evaluated a proposed flight schedule as it operated in all Delta destinations worldwide. The model “flew” the schedule with random sources of lateness in order to replicate the actual operation of the Delta system. Statistics were collected such as average aircraft arrival departure on time percentage, aircraft arrivals per hour, and aircraft utilization by fleet type.

A second model used the flight schedule model as an “engine” and included very detailed logic used only for ATL, with less detailed logic to describe all other stations. The purpose of this model was to show the effect of a proposed runway closure at ATL on the system flight schedule. While all Delta stations were modeled in the runway configuration model, all stations other than Atlanta were modeled generically.

3 FLIGHT SCHEDULE EVALUATION MODEL

The flight schedule model serves two basic functions. The first use of the model is to evaluate an input flight schedule. In the model, a schedule is flown and evaluated by considering various delays based on historical distributions. Multiple replications of the input schedule generate results describing the overall feasibility and reliability of the schedule. So, before a schedule is published, the model can predict the on time performance of the airline. The second use of the model is as a “what-if“ tool to evaluate alternative schedule scenarios on the overall operation. The alternative scenarios could be as detailed as the modification of a single flight departure or arrival time, or as high level as the evaluation of alternative aircraft types for given routes.

The model starts with all aircraft in an initial position and state as described by an input data file. The start time of the model was selected in order to minimize the number of aircraft in flight at model start.

At the start of the model run, time advances as in-flight aircraft continue towards their destination, based on calculated actual arrival time. At model start, in-flight aircraft are be placed along their route based on the interpolation between scheduled departure and calculated actual arrival times versus current time. The method for calculating actual arrival is discussed below.

Upon arrival to the destination airport, in-flight aircraft proceed to the runway, land, and taxi to the destination gate. Taxi time is determined based on a sample selected from a probability distribution. The distribution was selected based on historical data. The historical data was analyzed using the Input Analyzer tool that is a component of the ARENA simulation software package. This tool performs best-fit analyses on input data and determines the distribution and parameters for the distribution that best fit the input data. Mean taxi time is a function of airport and time of day. Upon reaching the gate, statistics are collected for the completed flight segment, and the aircraft waits for the next calculated actual departure time.

Aircraft at a gate wait for their scheduled departure time. At the scheduled departure time, a value representing departure lateness is sampled from another probability distribution determined from historical data. The actual departure time is the greater of the scheduled departure time and the actual arrival time plus the mean ground time based on departure city and a sample from a historical probability distribution. When the calculated departure time is reached, the aircraft taxis out to the departure runway, again based on a random taxi time, and departs. Once in flight, the actual arrival time is calculated based on the actual departure time, the scheduled flight time for the city pair and aircraft type, and a variability distribution based on the city pair and the time of day.

The flight schedule model was used to evaluate several proposed schedules. The main purpose of these simulations was to determine if a proposed flight schedule would meet the goals of the airline in terms of on time arrival percentage. The final result of the model runs was to predict the performance of a proposed flight schedule.

3.1 Model Assumptions

Several assumptions were made in order to increase the flexibility and ease of use of the model, while maintaining the integrity and accuracy of the results. Some of the major assumptions used in the model are listed below.

Technical Dispatch Rate (TDR). TDR is the ratio of flights completed to flights scheduled. Normally, a very small number of scheduled flights are cancelled every day due to unavailability of aircraft. In the model, a TDR of 100% was assumed because when a flight is cancelled, for whatever reason, the normal rotation of the aircraft is disturbed. To regain the normal operation of the schedule requires very complex decision making that was beyond the scope of the model.

Irregular Operations (IROPS). IROPS occur when a scheduled flight can not be made for reasons of weather, crew availability, or mechanical reasons. IROPS could occur at any time, and demand the instant attention of a staff of highly experienced members of Delta’s Operations Control Center (OCC) to determine the best course of action to remedy the IROPS occurrence. Because IROPS are random events and require human intervention which in effect artificially reset the system, they were not considered in this model.

3.2 Animation

The flight schedule model included a top-down view of the entire Delta system. Aircraft were depicted to indicate their type, and were differentiated between domestic and international flights. An unexpected benefit of this animation was that schedule developers could for the first time see the entire schedule as a whole, and could see the effects of their scheduling decisions.

3.3 Flight Schedule Model Results

The flight schedule evaluation model, once verified, was validated by performing a long, continuous simulation run starting with an empty and idle system. Because there is actually never a time when all Delta airplanes are on the ground, at model start time, any flights scheduled to be enroute are started and accelerate to their proper position along their flight path. A model start time of 0500 Atlanta time was chosen as the model start time to minimize the number of aircraft enroute. Certain high level statistics from the model run were compared to the actual operation of the airline. These statistics included the number of arrivals and departures per hour, aircraft fleet utilization, and counts of flights between certain city pairs. Based on the results of the model run, the proposed schedule was determined to be feasible. Further runs were made to determine the expected on-time performance of the airline with the proposed schedule.

4 RUNWAY CONFIGURATION MODEL

Following the successful use of the flight schedule model to evaluate a proposed schedule, another model was needed to analyze the effect of changes in runway availability. Specifically, ATL runway 27L was scheduled to be closed for approximately six weeks for construction. Delta needed to know what effect the runway closure would have on the airline in terms of on-time performance and whether or not the flight schedule could be reliably maintained during the construction period. Also, we wanted to identify any flights that would be consistently affected due to the closed runway, so that the scheduled arrival and departure time of those flights could be adjusted in order to minimize the effect of the runway closure on these flights. To answer these questions, the flight schedule model was used as a starting point to analyze ATL in detail while still considering the massive network of flights outside of Atlanta. Two major changes were made to the schedule evaluation model. First, the Atlanta airport was modeled in great detail, while all other Delta stations remained at a very high level. Second, other airlines were modeled arriving into and departing from ATL only in order to accurately consider the true demand on the runways at ATL.

As before, a schedule file was read, and the model “flew” the schedule. The detailed ATL logic was used whenever a flight was bound for ATL. In the case of flights enroute to ATL, the flight would proceed normally to a point representing either one of two assumed initial approach points (IAP) near the ATL airport. The selection of either the North or South IAP was made based upon the origin station of the flight. Certain origin stations were designated to use a specific IAP, and for those origin cities not specifically designated, the North or South IAP was selected based on the lesser number of uses. This logic basically duplicates the logic used by air traffic controllers to attempt to equalize the traffic between two landing runways. Once arriving at an IAP, an aircraft was required to establish a minimum spacing between itself and the preceding aircraft. The minimum spacing, in minutes, was an input to the model depending on the scenario being considered. Because of the random lateness of the departure and in-flight phases of the flight, the actual arrival time of the aircraft at the IAP frequently varied from the scheduled time based on the flight schedule. If two or more aircraft arrived at an IAP with less than the required spacing, the following aircraft were delayed in order to achieve the spacing. This delay represented Air Traffic Control programs such as speed restrictions enroute. Once the required spacing was achieved, the aircraft departed the IAP for the landing runway. All aircraft departed the IAP in the order they arrived, in a first-in-first-out (FIFO) order. A standard approach speed, which translates into the time required from the IAP to touchdown on the runway, was an input to the model. After touchdown, the aircraft taxied to the scheduled arrival gate, the arrival time was captured, the flight segment was terminated, and the aircraft waited until the next scheduled departure time.

4.1 Model Assumptions

In addition to the assumptions listed for the schedule evaluation model, certain assumptions were added to the runway configuration model.

Taxi Times in ATL. For aircraft in ATL, a distribution was randomly sampled to determine the taxi in and taxi out times for the aircraft. Forty eight different distributions were used, based on the hour of day in Atlanta. An important assumption in this logic was that the selected historical probability distribution accounted for any possible delays encountered in the tazi phase of the flight.

Other Airline Traffic. Unlike the Flight Schedule Model, the Runway Configuration Model included Other Airline (OA) flights in and out of ATL, which make up approximately 45% of the total flights at the airport, and significantly affect the availability of the runways. These flights were assumed to be on time for all arrivals and departures. This was assumed because unlike Delta, only the arrival and departure times of OA flights are known, not the complete aircraft rotation of every OA aircraft in and out of ATL. Therefore, there was no logical way to calculate the actual arrival time of OA flights.

4.2 Animation

The runway configuration model included a top-down view of the Atlanta airport and the assumed North and South IAPs. The animation showed the number of aircraft delayed at the North and South IAPs, and the flow of aircraft in and out of ATL.

4.3 Runway Configuration Model Results

The runway configuration model was evaluated as a terminating system of 24 hours in length. Multiple replications of the model were run, with the system and all statistics reset between replications. Two scenarios were evaluated: the status quo scenario included the four existing ATL runways with the standard approach separation of 3 miles, or 1.2 minutes, between arriving aircraft. The alternative scenario modeled the closure of runway 27L, and the use of an adjacent taxiway as an alternate to the runway. However, when the taxiway is used, the approach separation is increased to 5 miles, or 2.0 minutes, between arriving aircraft, assuming an average approach speed of 150 miles per hour. This increased approach separation was due to reduced capabilities in factors such as approach lighting and navigational aids when using the taxiway as a runway. The increased separation was mandated by the FAA. As discussed above, the spacing between arriving aircraft is established at the Initial Approach Point. All other variables and inputs are unchanged between scenarios.

The primary result of the model was to evaluate the difference in on-time performance for both ATL and the entire Delta system when the alternative configuration is in use. Figure 2 shows the percentage of ATL arrivals within 14 minutes of scheduled arrival time for the status quo runway scenario and the proposed 3 runway scenario. Figure 3 shows on time performance for the entire Delta network for the status quo and proposed scenarios.

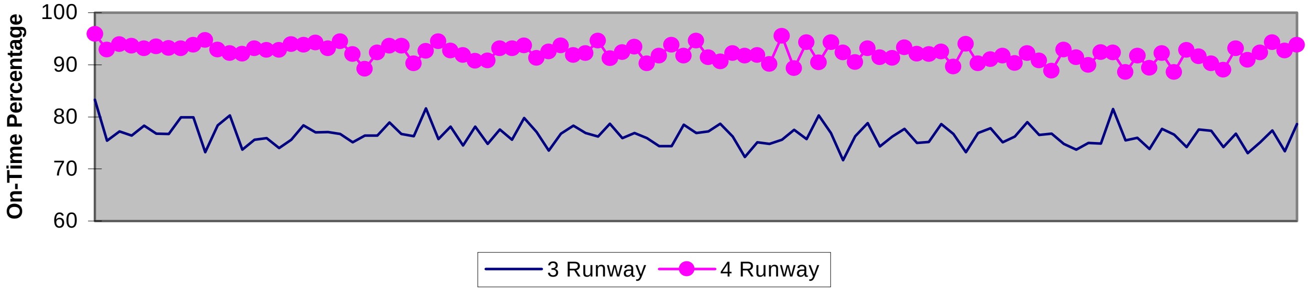

Figure 2: ATL on Time Percentage

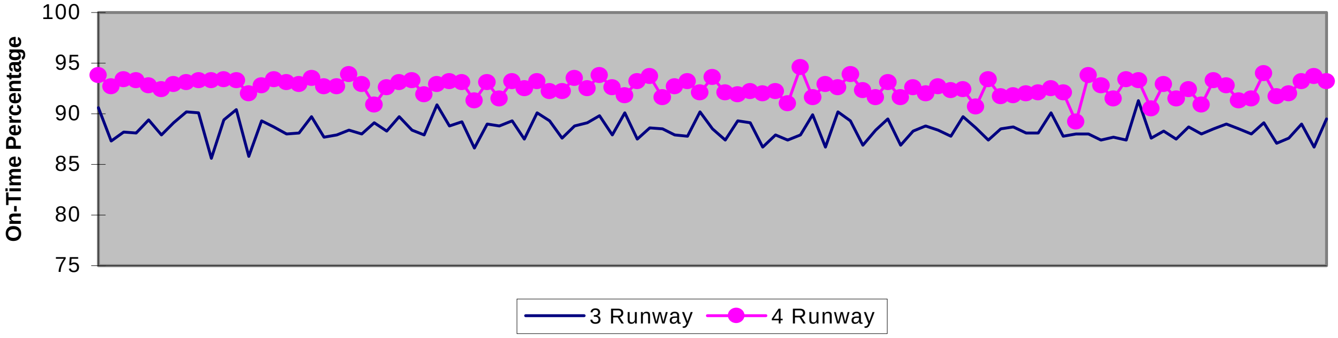

Figure 3: System on Time Percentage

The average on time percentage for ATL dropped from 92.1% to 76.4% in the alternative scenario, a change of -17.1%. Delta system on time percentage drops from 92.4% to 88.4%, a change of -4.3%. Figure 4 shows the results of a t-Test performed to compare the on-time performance of both ATL and the entire system under the two scenarios. The tests assumed unequal sample variances, and Excel was used to perform the tests. The hypothesis was that the mean on-time performance was equal between the 4 runway and 3 runway scenarios. For ATL, the calculated t statistic was -65.08 and the critical value was 1.98. Because -65.08 < 1.98, the null hypothesis is rejected. Therefore, the means are not equal. For the entire Delta system, the calculated t statistic was -33.19 and the critical value was 1.98. Because -33.19 < 1.98, the null hypothesis is rejected. Again, the means are not equal. The results of these tests indicate a statistically significant difference between the 3 runway and the 4 runway scenarios for both ATL and the entire Delta system.

ATL On Time
t-Test: Paired Two Sample for Means

	3 Runway	*4 Runway*
Mean	76.38	92.135
Variance	6.083838	3.440682
Observations	100	100
Pearson Correlation	0.400423	
Hypothesis	$u_1=u_2$	
df	99	
t Stat	-65.0806	
P(T<=t) one-tail	2.3E-83	
t Critical one-tail	1.660392	
P(T<=t) two-tail	4.61E-83	
t Critical two-tail	1.984217	

System On Time
t-Test: Paired Two Sample for Means

	3 Runway	*4 Runway*
Mean	88.396	92.483
Variance	1.920792	1.62789
Observations	100	100
Pearson Correlation	0.574677	
Hypothesis	$u_1=u_2$	
df	99	
t Stat	-33.1904	
P(T<=t) one-tail	9.42E-56	
t Critical one-tail	1.660392	
P(T<=t) two-tail	1.88E-55	
t Critical two-tail	1.984217	

Figure 4: T-test Results

The second objective of the model was to predict which specific flights would consistently arrive late due to the change in runway configuration in ATL. The simulation model output flight information to an Excel file at the end of each simulation replication. Figure 5 shows a sample of some of the data collected. These data show the observed number of days each flight arrived late under the 3 and 4 runway scenarios over a 100 day simulation period.

Flight No.	Scheduled Arrival	Late Occurrences	
		4 Runway	3 Runway
123	1004	35	85
234	1435	20	75
345	1215	24	65

Figure 5: Sample On Time Data by Flight Number

For example, flight 123 might have been late 35 times in 100 simulated days in the 4 runway configuration, and 85 days out of 100 in the 3 runway scenario. Flight 123 was therefore adversely affected by the runway closure. Each flight that was affected in this way was identified, and the Delta Schedule Development department was notified to attempt to proactively make schedule adjustments in order to improve the on time performance of the identified flight.

5 CONCLUSIONS AND RECOMMENDATIONS

The goals of the models described in this paper were to evaluate the dependability of a proposed flight schedule prior to the implementation of the schedule, to evaluate the effect of a change in runway capacity at a key Delta hub airport on the selected flight schedule, and to specifically identify those flights likely to be adversely affected by the runway closure.

The two simulation models described in this paper met all goals of the project. The model showed that on time performance at the subject airport would decrease by over 17%, and the effects of this lateness would propagate throughout the entire worldwide flight system.

Based on the results of the runway configuration model, we identified all flights that experienced a reduction in on-time arrival percentage in the 3 runway scenario model runs. The identified flights included arrivals into ATL and other Delta stations. We recommended that the proposed flight schedule be re-examined to attempt to improve the on-time performance of these flights by adjusting their scheduled departure and arrival times as necessary. Because the minimum approach separation distance in the 3 runway scenario was mandated by the FAA, we pointed out the sensitivity of on-time performance to this number during certain peak activity times of the day, and recommended that the spacing be minimized whenever possible.

Further analyses that might be performed when time permits would include a look at the effect of the FIFO landing rule. For example, priorities might be assigned to arriving aircraft based on their lateness, their scheduled ground time, or even their passenger load (which was not included in this model). Another analysis might extend the detailed ATL logic to other Delta hubs, such as Cincinnati, Salt Lake City, and New York City-JFK. Further detail might be added to more accurately model an airport by including individual gates as constrained resources, modeling flight crew such as pilots and flight attendants, or even modeling individual passengers moving from city to city in the Delta system.

AUTHOR BIOGRAPHY

BRUCE SCHUMACHER is Manager of the Forecasting and Planning Systems department at Delta Air Lines in Atlanta, GA. Prior to Delta, Bruce worked in the consulting group at Systems Modeling Corporation. There he provided services in model building and training for customers in Asia, Europe, and throughout the United States. Bruce has a Bachelors degree in Industrial Engineering and an MBA. He is a registered Professional Engineer in the State of Pennsylvania.