Project Report
ATC-304

Potential Benefits of Reducing Wake Vortex Related Aircraft Spacing at the Dallas/ Fort Worth International Airport

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16. Abstract

Measurements and modeling of wake vortices reveal that the Federal Aviation Administration's (FAA) minimum separation requirements for departing aircraft are often overly conservative. If the separation times following heavy aircraft can be safely reduced, considerable savings will be realized. The Dallas/Fort Worth International Airport (DFW) experiences departure delays daily. Banks of departing aircraft often create a significant queue at the end of the runway, with aircraft waiting between 10-20 minutes to depart. Additional delays occur during weather recovery operations after the terminal airspace has been impacted by thunderstorms.

The report produces projected delay and cost benefits of implementing reduced wake spacing for departing aircraft at DFW. The benefits are calculated by simulating aircraft departures during both clear weather and weather recovery operations, using current and possible reduced spacings. The difference in delay values using different separation standards is used to calculate a cost savings to the airlines. The benefits for a single day are extended to a yearly approximation based on the estimated number of days that the separation criteria could be safely reduced.

Departure information from February 19, 2001 is analyzed for clear weather operations. The simulation reveals a savings of $4.7 million/yr when the separation criteria is reduced from the current practice of 110 seconds to 90 seconds. A further reduction in the separation criteria to 60 seconds pushes the maximum savings to almost $10 million/yr.

The daily savings for a weather recovery operation is $19,600 for weather impacts between 15-60 minutes and a reduction in spacing from the current 110 seconds to 90 seconds. The average increases to $36,200 when the spacing is reduced to 60 seconds. Significant thunderstorm events impacted the DFW terminal airspace 59 times during 2001, leading to projected yearly savings of greater than $2.1 million for a 60-second separation criteria following heavies.

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1. INTRODUCTION

This report illustrates the potential benefits of reducing wake related spacings between departing aircraft at the Dallas/Fort Worth International Airport (DFW). A small decrease in these requirements will result in a considerable amount of savings in both normal and weather recovery operations.

1.1 BACKGROUND

Currently, FAA requirements specify a minimum amount of time or distance between departing aircraft on the same runway. The type of the "lead" aircraft determines the spacing between departures. Table 1 shows that if the lead aircraft is of type "heavy" (weight greater than 300,000 lbs.), the specified delay time is either four or five miles or two minutes depending on the type of the follower. The delay time after a "large" aircraft (weight between 41,000 lbs and 300,000 lbs.) is one minute or 3 miles, independent of the size of the follower.

TABLE 1

Separation matrix that shows the wake vortex separation criteria between departing aircraft.

Follow/Lead	Heavy	Large
Heavy	2.0 min / 4 miles	1.0 min / 3 miles
Large	2.0 min / 5 miles*	1.0 min / 3 miles

At present, controllers at DFW typically utilize the mileage separation instead of separation by time. The primary reason is that mile markers are conveniently located on the radar displays situated in the control tower near the controller positions. However, a simulation of departure delay based on varying the mileage separation standard is difficult due to differences in aircraft flight speeds. We therefore determined the time separations that currently arise from the use of the distance standard, and then simulate delay based on reducing this time separation.

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* Separation for a large aircraft following a Boeing 757 is two minutes or four miles.

Our observations indicate that the time difference between departures that arise from the current mileage separation is in reasonable agreement with the FAA specified time separation criteria. The average time after a large departure at DFW ranged between 55-65 seconds and between 110-130 seconds following a heavy. Separations greater than 120 seconds following a heavy include values that were inflated due to arriving aircraft taxing across the departure runway, thus, delaying subsequent departures. The lower values in the range exclude the inflated separations and represent spacing that can be expected if a system, such as perimeter taxiways, were to eliminate the need for runway crossings. In this report, the benefits of reduced spacing are based on the 110 second (1.8 min) separations observed at DFW.

Table 2 lists the aircraft currently in use that qualify as heavy on departures. The percentage of aircraft that fall into the heavy category continues to increase in conjunction with increasing passenger loads. At DFW between 16-17% of the nearly 1100 daily departures[1] during the study period are categorized as heavy aircraft.

TABLE 2

Aircraft considered "heavy" on departure.

Boeing 747	Boeing 767
Boeing 777	Boeing 757*
McDonnell Douglas DC10	McDonnell Douglas MD11
Airbus A300	Airbus A310
Airbus A330	Airbus A340
Lockheed L1011	

Measurements of wake vortices reveal that under many environmental conditions the minimum separation criteria after heavy departures can be reduced without compromising safety [1]. Observations and modeling reveal that atmospheric turbulence can induce wake vortices to interact with themselves and decay quickly once a background threshold has been exceeded [2] [3]. A climatology of turbulence at DFW indicates that vortex demise times will be ≤ 60 seconds 80% of the time for most aircraft types. The percentage increases to 95% when the time is increased to 90 seconds [4]. If the separation criteria

[1]A Boeing 757 is less than 300,000 lbs but is treated much like a heavy in FAA separation standards. In this study Boeing 757's are included in the heavy class to simplify the analysis.

can be reduced when environmental conditions produce adequate atmospheric turbulence, significant time and cost savings can be expected [5].

There are two separate situations in which a reduction in wake related spacings could provide significant cost savings. The first occurs during "normal" VFR operations. Airline schedules at DFW are built around "banks" of aircraft that arrive or depart at the same time. During a departure "bank", a large queue of departing aircraft can form on the taxiways near the runway. The queue may persist for over an hour during a large departure push, with individual aircraft waiting between 10-20 minutes for takeoff. A reduction in the separation criteria behind heavy aircraft would considerably reduce the amount of time waiting in the queue, saving time and money.

A second situation, weather recovery, results from the direct impacts of weather to the airport or the Terminal Radar Approach Control (TRACON) airspace. Weather impacts can create a significant backlog of departing aircraft as miles in trail (MIT) restrictions increase and departures are suspended due to weather in the vicinity of the airport. Weather recovery begins when the weather no longer is disrupting departure.

This study quantifies the potential benefit of reducing in wake related spacings by determining the total number of delay minutes spent by aircraft in the departure queue for various separation criteria. The reduction in the amount of time between departures decreases the total number of delay minutes. The difference between total delay minutes for two separate scenarios, the current observed time spacing and some reduced time rule, represents the potential delay reduction. The delay for each separation criteria is computed by simulating the departure operations at DFW.

DFW operations for departures are examined in the first section. Section two describes the simulation used to model the departure operations along with results from both normal and weather recovery simulations. The final section contains a summary and conclusions.

2. DFW OPERATIONS

In order to accurately simulate the DFW departure operations, a detailed understanding of the way departing aircraft are taxied and sequenced is needed. DFW is an ideal airport for this type of simulation because the procedure for assigning the departure sequence is fairly standardized and consistent during the majority of situations.

The DFW airport is comprised of a total of seven runways, two sets of closely spaced parallel runways, a set of diagonal runways, and a fifth north-south runway located on the east side of the airport. The predominant and preferred configuration of the airport is to have departing and arriving aircraft in a south flow. Figure 1 depicts the south flow configuration at DFW. The airport operates in a south flow the majority of time because a south wind is the prevalent wind direction for most of the year and the noise abatement procedures are less restrictive. Also, since the majority of arrivals enter the TRACON from the north, a south flow configuration gives them a shorter path to the runway.

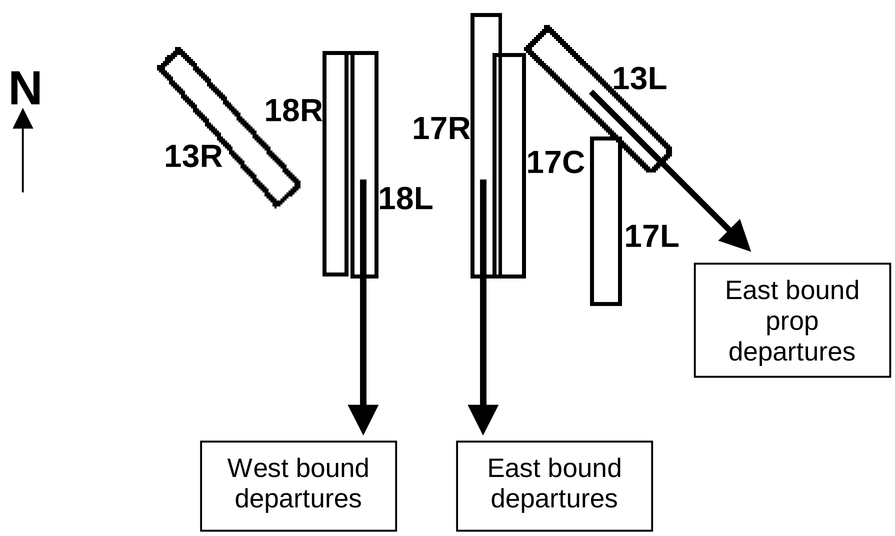

Figure 1. DFW runways and typical departure routes in a south flow configuration.

Figure 1 also shows that only three runways are used for departures during normal operations. However, only runways 18L and 17R are used for jet departures. Runway 13L is only used for commuter prop departures due to noise restrictions that prohibit any jet traffic.

Four separate steps determine the final sequence of departing air traffic. Each step will be discussed in detail below.

1. Assigning a departure runway to the aircraft.
2. Sequencing aircraft on the runway taxiways.
3. Positioning aircraft at the runway holding pad.
4. Clearing an aircraft for departure.

2.1 RUNWAY ASSIGNMENT

The DFW airport consists of four separate semi-circular shaped terminals bisected by a north-south expressway (Figure 2). Three of the terminals (A, C, E) are located on the east side of the airport, while Terminal B is located on the west side. In many ways DFW operates as two separate airports. Each side has its own Air Traffic Control Tower and can independently operate simultaneous arrivals and departures. The majority of time departures are assigned a runway based on the direction of their destination airport and the location of the terminal where the departure originates.

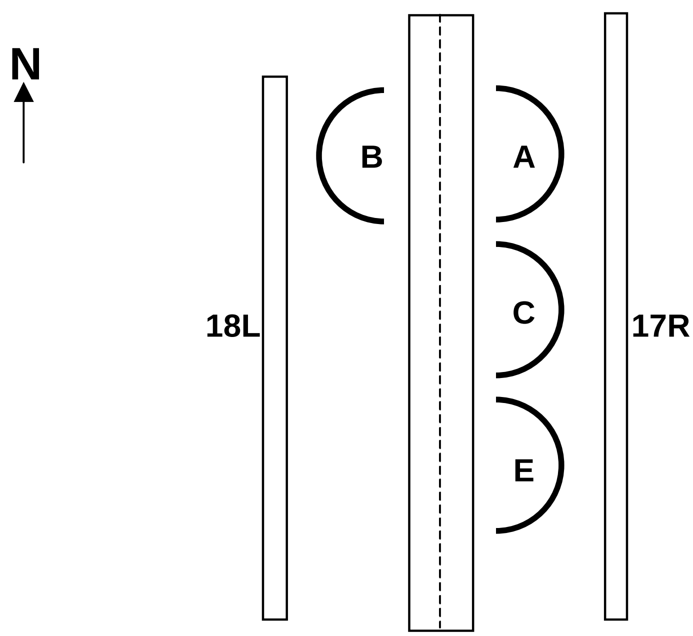

Figure 2. DFW terminal locations.

The direction of the destination airport determines which TRACON departure gate the aircraft will cross. Figure 3 shows the departure gates of the DFW TRACON boundary. There are four departure gates on each side of the TRACON boundary while arrivals cross into the TRACON through the cornerposts. Destination airports to the west are assigned one of the four westbound departure gates (AMA, TCC, LBB, ABI), while destinations north, east, and south of DFW are routed out their respective sides of the TRACON as well. All eastbound jets are assigned 17R as their departure runway, while west bounder aircraft depart off of 18L. The east and west assignments are irrespective of the time of day and are employed in almost all situations. The exception to this assignment occurs only during times of very light traffic. The variability of departure runway assignments occurs with the north and southbound aircraft. DFW has many departure "pushes" (1 or more banks of departing aircraft) scheduled during a day (Figure 4). If a north or southbound aircraft is scheduled to depart during a push, it is assigned a runway on the side of the airport that is the least busy. If the scheduled departure is not during a push it departs from the side of the airport that the departure terminal is located.

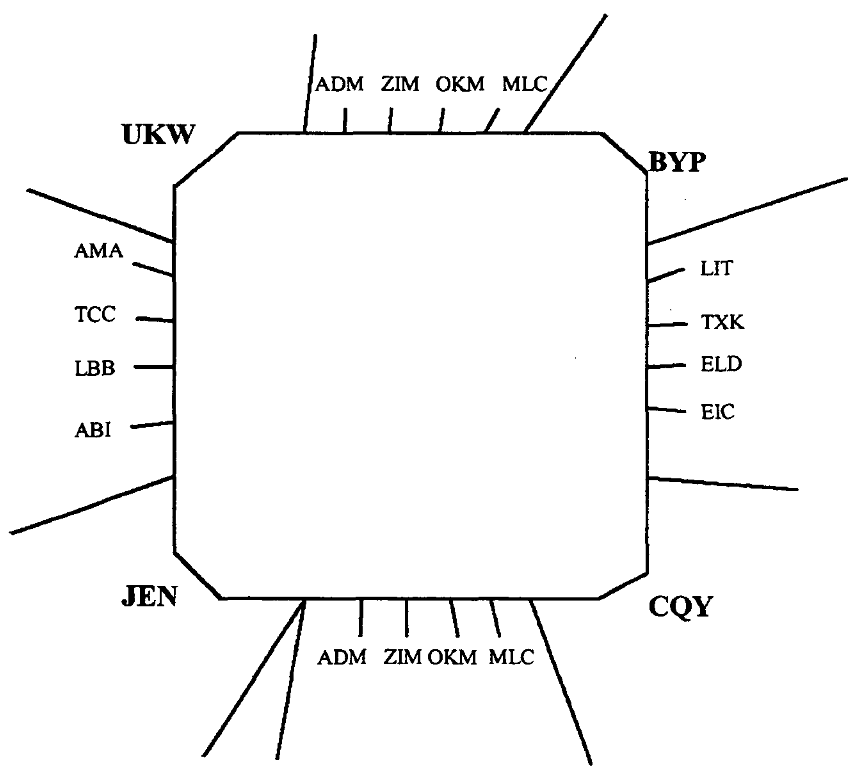

Figure 3. DFW arrival and departure gates. Arrival gates are located at the cornerposts, while the departure gates are located along the sides of the TRACON boundary.

TABLE 3

Example of DFW West side and East side departure pushes.

West side pushes	East side pushes
1110-1155	0740-0830
1600-1640	0920-1010
1920-2020	1110-1200
2240-2300	1430-1500
	1740-1820
	1930-2020
	2100-2145

2.2 SEQUENCE ON TAXIWAYS

Aircraft enter the taxiway from the terminal ramp area on a first-come-first-served basis. Tower controllers contact aircraft on the ramp and assign a taxiway that leads to the waiting pad near the end of the runway.

2.3 HOLDING PAD POSITIONS

The taxiway assignment and the position on the holding pad are based primarily on the departure fix provided to the departing aircraft in the flight plan. Aircraft departing through the same fix will be positioned in a manner that allows consecutive departures to use separate fixes. This is necessitated by the fact that as aircraft leave the TRACON they must maintain at least five miles of separation. As mentioned previously the separation criteria for many planes is as low as one minute (~3 miles). Thus, consecutive departures following the same route would be unnecessarily delayed. Sequencing of the departures on the holding pad allows for maximum capacity during pushes.

2.4 CLEARANCE FOR DEPARTURE

Aircraft are sequenced on the holding pad, and clearance to depart the next aircraft is given once the required wake separation spacing from previous aircraft is achieved.

3. DEPARTURE SIMULATION

The simulation was run on data from the Airline Service Quality Performance reports (ASQP). These reports are compiled monthly by the Department of Transportation (DOT) and include fields for airline ID, flight number, departure airport, destination, pushback time, taxi time, and wheels off time, among others (Figure 5). The data does not include propeller commuter planes or international flights.

When the model executes, it ingests the data for all DFW departures for a specified day. The model then assigns a size class to each aircraft based on the percentage of large and heavy departures for its airline at DFW. The pushback time is then used as the starting point for each flight. The model simulates the runway assignment process by following the DFW operation procedures discussed in the previous section. Detailed runway information from the 19th of February was obtained to verify the accuracy of the runway assignments in the simulation. The model correctly assigned 295 of the 355 (83%) jet departures made on runway 17R. Approximately 60% of the missed assignments were made during non-push times when the accuracy of the assignments is less important to aircraft spacing.

After the runway assignment, the time each aircraft reaches the end of the runway (runway time) is calculated by adding an airline specific taxi time, based on the airline gate to runway distance, to the pushback time. It is assumed that there are no other delays that affect the ability of the aircraft to taxi to the runway. The runway time is the time when an aircraft, barring a queue in front of it, could take off. A takeoff time is then computed for each departure. Starting with the first aircraft of the day, the simulation simply makes each aircraft wait (if necessary) until the required time separation from the lead aircraft is achieved. When aircraft arrive at the runway faster than they can depart, a queue builds and when aircraft arrive less frequently the queue decays. The difference between the runway time and the departure time for each aircraft is the delay for that aircraft. The total delay is the sum of the individual aircraft delay values. The potential benefits of reduced spacings are determined by executing the simulation with different separation matrices and comparing them to the FAA mandated separation criteria used today.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
AA	0001	JFK	LAX	2001	02	02	5	0900	0900	0000	1209	1209	0000	0000	0000	0369	0000	0000	0000	0000	0000	0000	UNKNOW	0000	0000	0000	Y	N
AA	0001	JFK	LAX	2001	02	03	6	0900	0900	0910	1209	1209	1159	0000	0000	0369	0349	0010	-0010	-0020	0932	1155	N370AA	0022	0004	0323	N	N
AA	0001	JFK	LAX	2001	02	04	7	0900	0900	0858	1209	1209	1128	0000	0000	0369	0330	-0002	-0041	-0039	0913	1124	N363AA	0015	0004	0311	N	N
AA	0001	JFK	LAX	2001	02	05	1	0900	0900	0856	1209	1209	1149	0000	0000	0369	0353	-0004	-0020	-0016	0913	1142	N383AA	0017	0007	0329	N	N
AA	0001	JFK	LAX	2001	02	06	2	0900	0900	0904	1209	1209	1210	0000	0000	0369	0366	0004	0001	-0003	0925	1206	N363AA	0021	0004	0341	N	N
AA	0001	JFK	LAX	2001	02	07	3	0900	0900	0857	1209	1209	1224	0000	0000	0369	0387	-0003	0015	0018	0928	1210	N380AA	0031	0014	0342	N	N
AA	0001	JFK	LAX	2001	02	08	4	0900	0900	0904	1209	1209	1157	0000	0000	0369	0353	0004	-0012	-0016	0920	1149	N382AA	0016	0008	0329	N	N
AA	0001	JFK	LAX	2001	02	09	5	0900	0900	0902	1209	1209	1242	0000	0000	0369	0400	0002	0033	0031	0924	1236	N377AA	0022	0006	0372	N	N
AA	0001	JFK	LAX	2001	02	10	6	0900	0900	0859	1209	1209	1218	0000	0000	0369	0379	-0001	0009	0010	0920	1214	N357AA	0021	0004	0354	N	N
AA	0001	JFK	LAX	2001	02	11	7	0900	0900	0907	1209	1209	1221	0000	0000	0369	0374	0007	0012	0005	0929	1211	N359AA	0022	0010	0342	N	N
AA	0001	JFK	LAX	2001	02	12	1	0900	0900	0926	1209	1209	1230	0000	0000	0369	0364	0026	0021	-0005	0942	1218	N383AA	0016	0012	0336	N	N
AA	0001	JFK	LAX	2001	02	13	2	0900	0900	0855	1209	1209	1253	0000	0000	0369	0418	-0005	0044	0049	0924	1251	N363AA	0029	0002	0387	N	N

1. Airline, 2. Flight #, 3. Dep Arpt., 4. Dest, 5. Yr., 6. Mon., 7. Day, 8 Day Of Wk., 9. OAG Dept. Time, 10. CRS Dept. Time, 11. Actual Dept. Time, 12. OAG Arrv. Time, 13. CRS Arrv. Time, 14. Actual Arrv. Time, 15. OAG-CRS Dept. Delay, 16. OAG-CRS Arrv. Delay, 17. CRS Elapsed Time, 18. Actual Elapsed Time, 19. Actual CRS Dept. Delay, 20. Actual CRS Arrv. Delay, 21. Actual CRS Elapsed Time Diff., 22. Wheels Off Time, 23. Wheels On Time, 24. Tall #, 25. Taxi Out Time, 26. Taxi In Time, 27. Airborne Time, 28. Canncellation, 29. Diversion

Figure 4. Sample table of the ASQP data. The definitions of the data in each column are given at the bottom of the figure.

3.1 NORMAL OPERATIONS

The date selected for use in the non-weather simulation was February 19, 2000. On this day a large dome of high pressure was situated in the center part of the country providing clear skies and little precipitation across the nation (Figure 6). The selection of this date means that impacts due to distant weather are minimized.

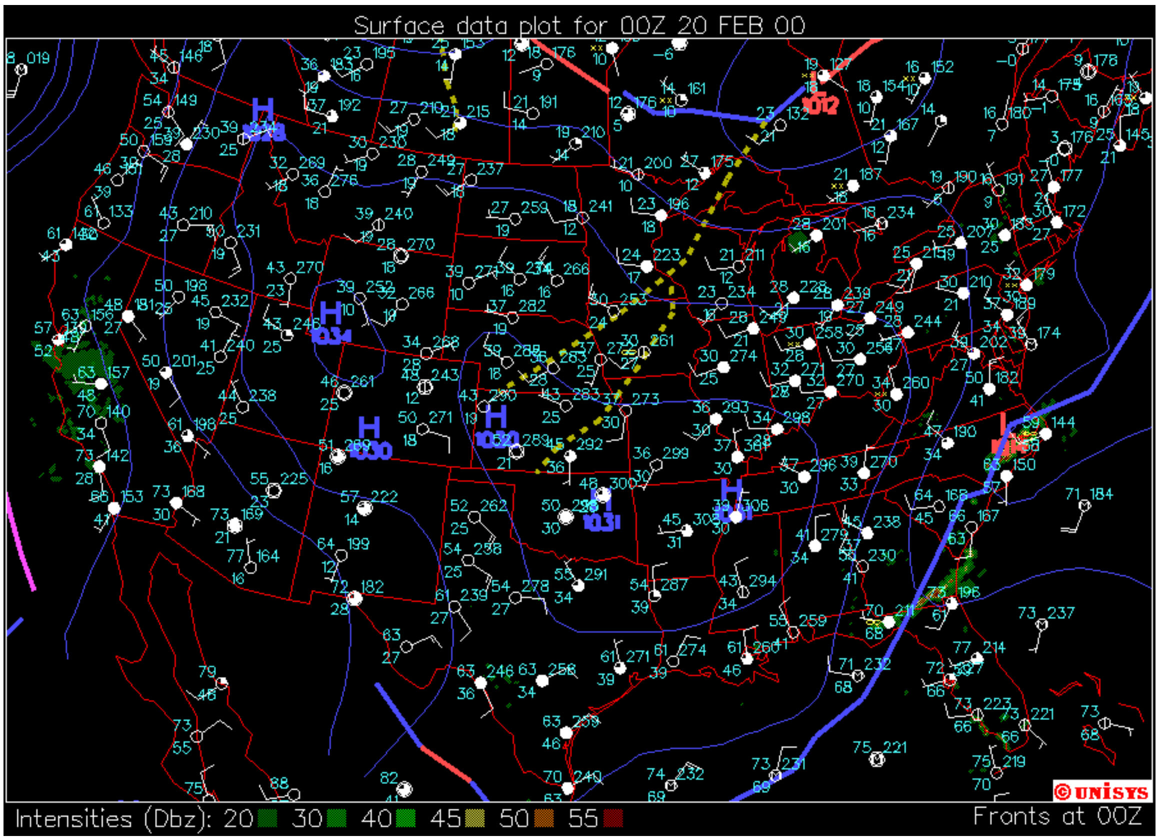

Figure 5. Surface map from 0000 UTC on February 20, 2000. The image shows that very little precipitation was occurring over the nation, due in part to the large area of high pressure near the center of the country.

In order to verify the accuracy of the model, the delay for each aircraft was computed using the wheels off time that is recorded in the ASQP data. The runway for each flight was assigned in the same manner as illustrated above, however, instead of computing the delay based on the estimated runway time, the actual time of the departure was used. If the runway assignment is incorrect, the actual departure time may be later than the estimated runway time, thus producing a negative delay. Therefore, two delay times are calculated, one that included negative delay values and one that did not. Table 3 shows the simulated delays using the estimated and actual departure times for different separation criteria. The wheels off delay values are averaged over the three simulations because there is some variability in the calculated runway time for each aircraft. The wheels off delays are shown only once because the values are independent of the separation criteria selected.

TABLE 4
Simulated total delay values and estimated delays computed using the wheels off times found in the ASQP data. All delays include departure runways 17R and 18L and the values shown are in minutes.

Time after heavy departure	Simulated Total Delay	Estimated Actual Wheels Off Delay	Estimated Actual Non-Negative Wheels Off Delay
1.0	1321	X	X
1.5	1856	X	X
1.8	2328	X	X
2.0	2458	2053	2593

The wheels off delay values are similar to the simulated delays using the 2.0 minute separation criteria. The agreement suggests that the runway assignment logic used by the simulation is realistic.

The simulation was run on data from the 19th using a 1.8 minute separation criteria behind heavy aircraft. The delay in minutes for each aircraft departing on runway 17L is plotted in Figure 7. The plot shows that even during non-weather impacted days, significant delay times can occur due to the lack of departure capacity. The largest delays on the 19th were associated with the departure pushes that occur at scheduled times throughout the day, for example between 1730-1830 CST. The simulation also indicates that several aircraft would have been delayed between 15-20 minutes after reaching the runway.

In order to investigate the potential savings from reducing wake related spacings the simulation was re-run with separation criteria of 1.0 and 1.5 minutes. These values are representative of realistic lower bounds for how soon a large aircraft, under certain environmental conditions, can safely depart after a lead heavy. The total delay for the three separate cases is shown in Figure 8 as well as for a 2 minute separation. As expected, the separation criteria and the total delay are related, with a reduction in the spacing leading to a smaller overall delay.

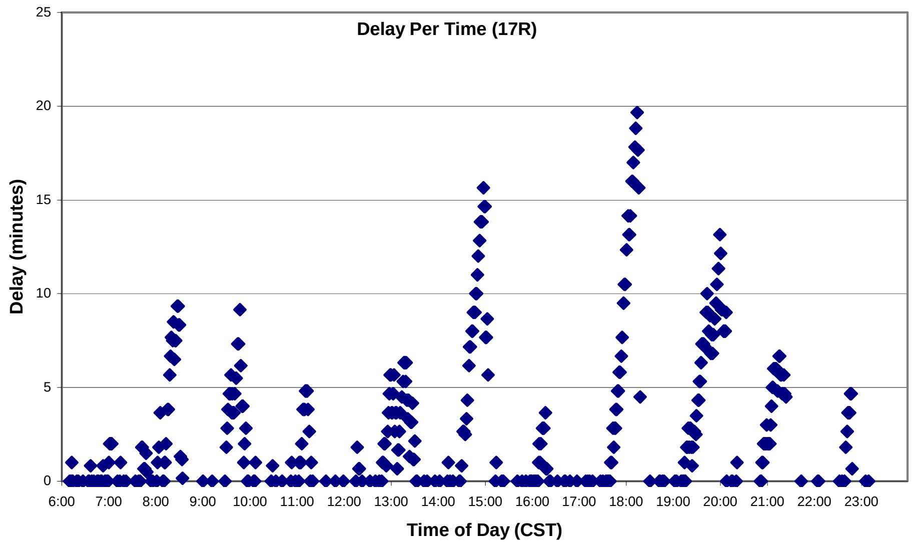

Figure 6. Simulated delay values for each aircraft departing on runway 17R at DFW for February 19, 2000. The values were computed using two minutes of spacing following a heavy departure.

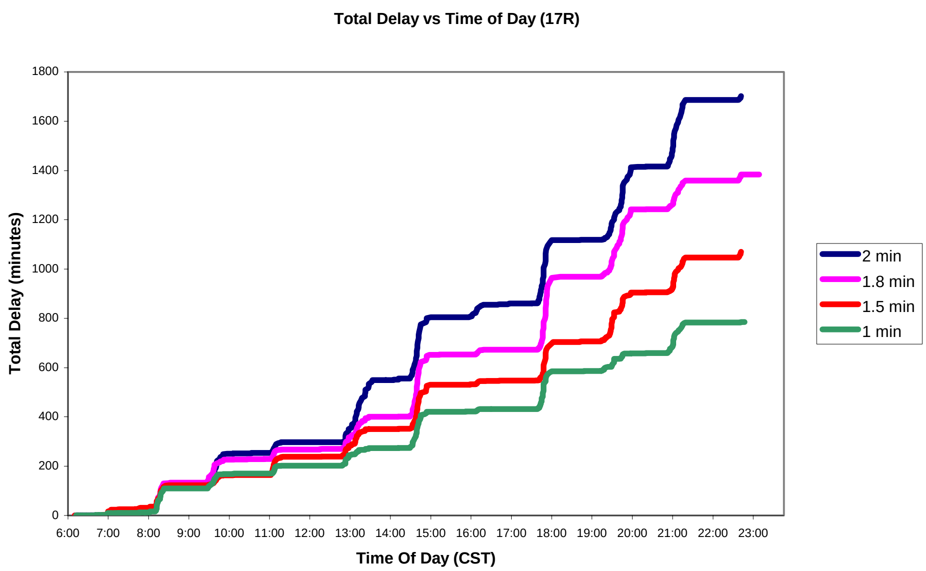

Figure 7. Simulated total delay values for different separation criteria on runway 17R for February 19, 2000.

The total number of minutes for each separation criteria is converted to hours and multiplied to the airline Direct Operating Cost (DOC) (this does not count passenger cost or down stream delay costs) in order to obtain the total cost of delay for this day. A DOC value of $2000/hr was used in the calculation.[1] (Figure 9 indicates that a reduction in the spacing criteria of 20 seconds to 1.5 minutes yields $16,000 of cost reduction using the DOC formula. Additional savings are gained if the spacing is reduced to 1.0 minute. A theoretical year of no weather impacts, similar to the 19th, produces a maximum potential yearly savings of just over $4,700,000 using a 1.5 minute spacing and assuming that the separation can be safely reduced 80% of the time. The same calculation using the 1.0 minute separation yields $9,900,000 in savings.

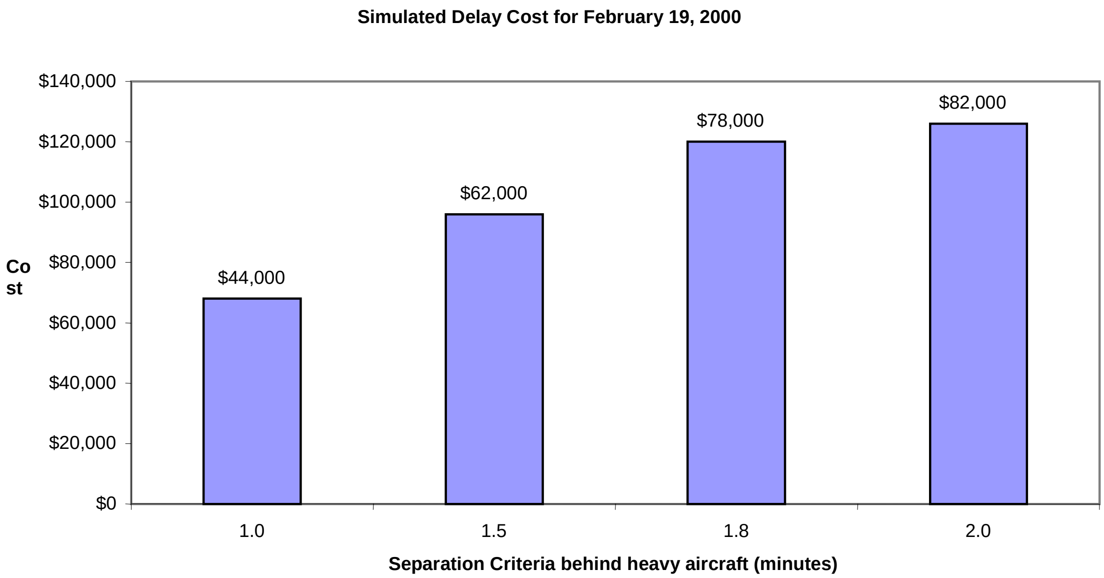

Figure 8. Simulated delay cost at DFW for different separation criteria on February 19, 2000.

3.2 WEATHER RECOVERY

Weather recovery occurs whenever the airport or the TRACON airspace is significantly impacted by thunderstorms. Benefits of reduced separations in a weather recovery event can be difficult to determine with a simulation because the impacts of weather on air traffic differ depending on the location of the weather. If thunderstorms are impacting the TRACON airspace, but not the airport itself, the effects on air

[1] This is the approximate cost as estimated by the Air Transport Association (http://www.airtransport.org/public/industry/display1.asp?nid+1201) and by the Aviation Week (http://www.aviationnow.com/content/publication/awst/20010611/aw90.htm).

traffic may be limited to increased separations between arriving aircraft in en-route airspace, with no impact on departures. However, as the precipitation crosses the airport it may cause a complete cessation of departing aircraft. After impacting the airport, if the thunderstorm activity moves away or decays quickly, normal operations may ensue and the benefits of monitoring wake vortices become more readily apparent. The latter scenario occurred on August 11, 2001 and will be the basis for the weather recovery simulation.

Thunderstorms formed during the early afternoon on the 11th. By 2150 UTC, thunderstorms with microbursts were impacting DFW (Figure 10). The activity moved away from the airport to the south and east and began to decay. Most of the convection had decayed within a few hours and all precipitation had ended by 0130 UTC on the 12th.

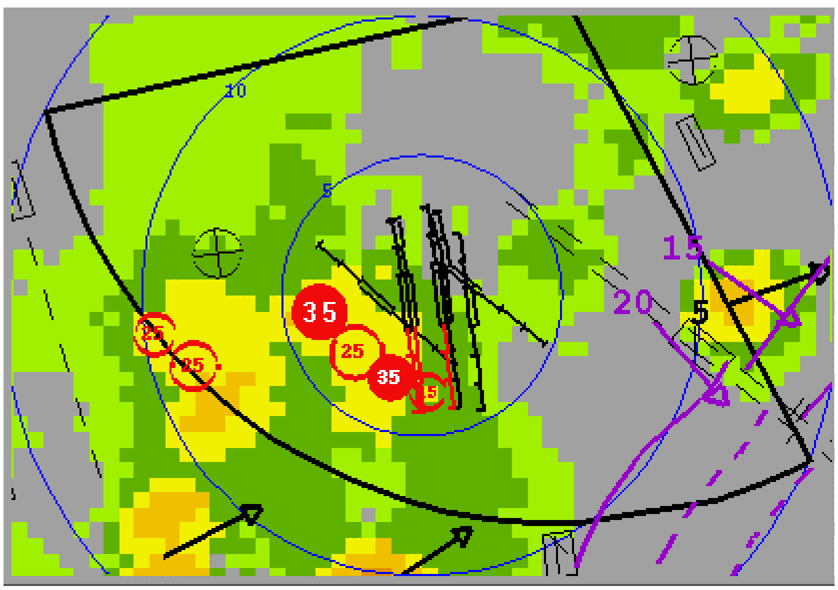

Figure 9. Integrated Terminal Weather System (ITWS) display from August 11, 2001 at 2150 UTC. The precipitation intensity is indicated by the green and yellow colors. Red circles indicate the location of wind shear and microburst (filled) events. The DFW Areas Noted for Attention (ARENA) is drawn in black and red at the center of the image.

The direct impact of the thunderstorms over DFW caused a significant decrease in the number of departures between 2100-2300 UTC (Figure 11). However, because the thunderstorms decayed shortly after crossing the airport, departure rates quickly returned to normal. In order to replicate this type of weather event, the simulation will discontinue departures for selected time periods during the day and then immediately return to normal operations with varying separation criteria.

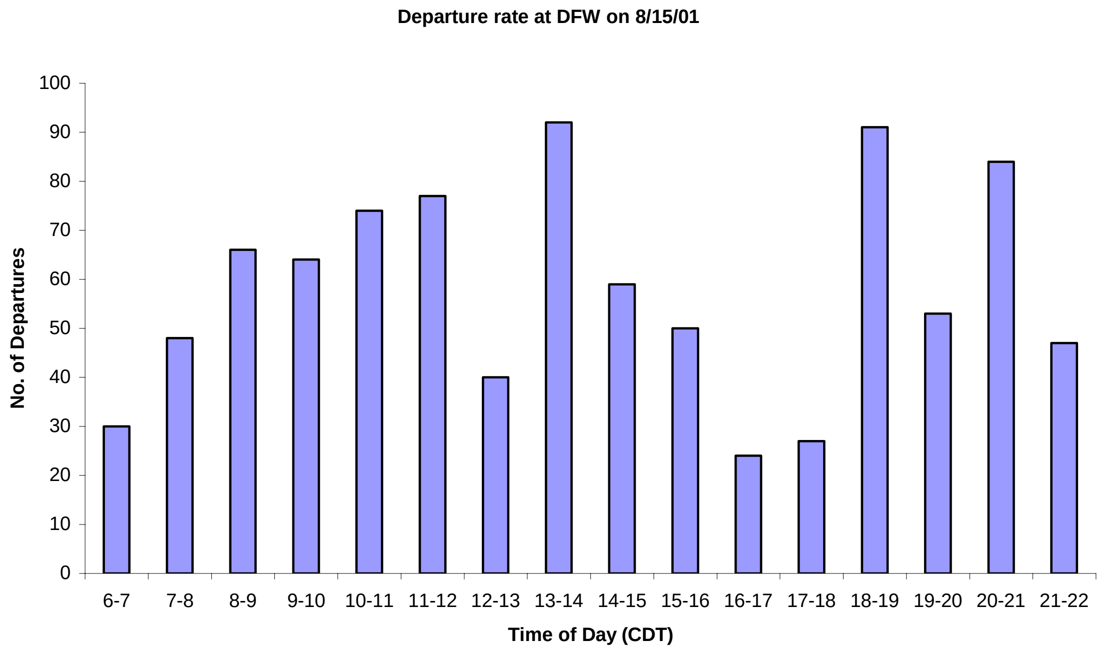

Figure 10. Departure rates at DFW on August 11, 2001. The significant decrease in departures between 1600-1800 was caused by thunderstorms over the airport.

Figure 12 shows the simulated departure delay values for various separation criteria when departures are discontinued for different lengths of time. The departures were discontinued during a departure push in order to represent a "worst case" scenario. Once again, the simulation reveals a significant decrease in the total delay as the spacing criteria is reduced.

The cost savings for a weather recovery day are shown in Figure 13. The values for each of the simulated weather events represent just one day. A review of weather conditions recorded in the ITWS Daily Operations Reports reveals 59 days in 2001 when thunderstorms impacted the DFW airport or TRACON airspace between 0600-2200 CDT. As an example, the yearly weather delay cost savings for a 30 minute discontinuance of departures is $1,200,000 for a 1.5 minute spacing and $2,100,000 for a 1.0 minute spacing.

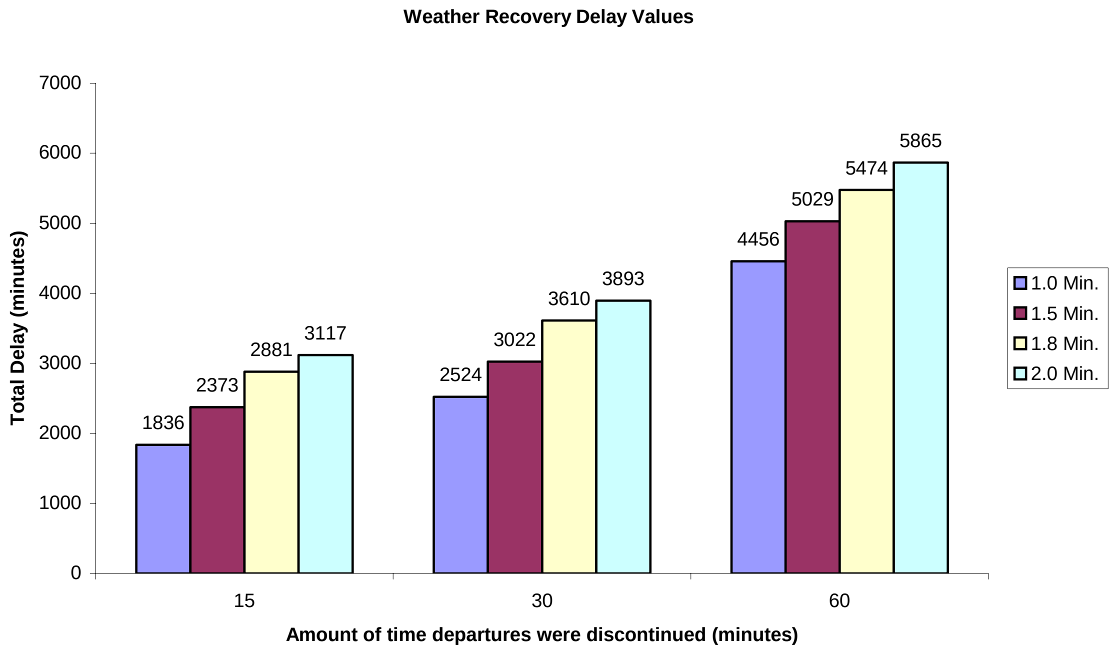

Figure 11. Model generated departure delay values at DFW for varying lengths of discontinued departures. The discontinued departure times simulate weather impacting the airport.

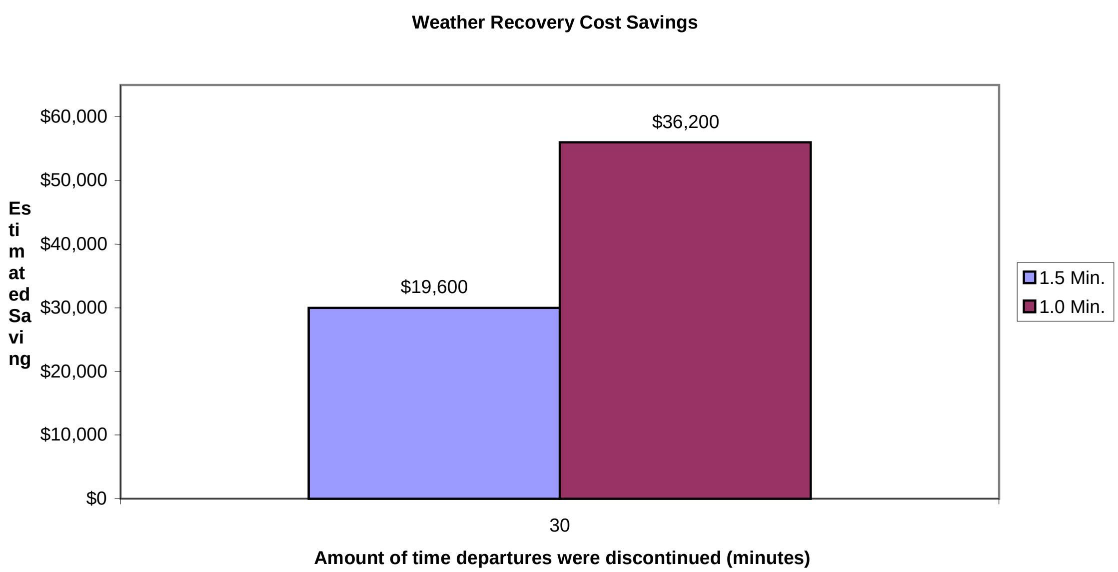

Figure 12. Simulated weather recovery cost savings estimates at DFW for different separations values.

4. GROUND OPERATIONS

A potential dilemma in the calculation of benefits for reduced spacings is the effect that reduced spacing would have on the current procedures used to taxi arrival aircraft from the runways to the terminals. The existing procedure is to taxi arrivals from the outboard runways (e.g. 17C, 17L) to positions that are immediately adjacent to the inboard runway (17R). When time permits, usually after a heavy departure during a departure push, aircraft are allowed to cross the inboard runway and continue taxiing to the gate.

The reduced spacing after heavy aircraft, that yield the benefits outlined in the previous sections, make it increasingly difficult to taxi arriving aircraft to the terminal gate in a prompt manner. A significant increase in the taxi time of arrivals would counteract the benefits achieved by reducing the separation criteria.

DFW has outlined a plan to construct a set of perimeter taxiways that would help alleviate this problem. The new taxiways would allow arriving aircraft to taxi directly to terminal gates without crossing the inboard runway. The increased taxi distance would be offset by the fact that aircraft on the perimeter taxiway would not spend time waiting to cross runways. The plan is still in the initial stages of study and no scheduled implementation date has been set.

5. CONCLUSIONS

Departure procedures at DFW are simulated in an attempt to quantify the benefits of reducing wake related spacings in normal and weather recovery operations. DFW is used for analysis because of the large volume of traffic and well-defined departure procedures that can be more accurately modeled.

Departure information from February 19, 2001, a day with no weather impacts within the US, is analyzed for normal operations. The simulation reveals a DOC savings of $4.7 million when the wake related separation criteria is reduced from 1.8 minutes to 1.5 minutes. A further reduction in the separation criteria to 1.0 minute pushes the savings to almost $10 million.

Weather recovery occurs after weather impacts the airport or TRACON airspace and then decays or moves away and no longer impacts departure operations. A day that illustrates this is August 11, 2001 when thunderstorms with microbursts crossed DFW and completely decayed a few hours later. The simulation modeled weather impacts by ceasing departures for specified time periods that reflected weather impacts to the airport. The average daily savings is $19,600 for impacts between 15-60 minutes and a 1.5 minute spacing. The average increased to $36,200 when the spacing is reduced to 1.0 minute. Significant thunderstorm events impacted the DFW TRACON airspace 59 times during 2001 leading to projected yearly savings of greater than $2.1 million for an average 30 minute discontinuance of departures for each event and 1.0 minute separation criteria following heavies.

If a system can be designed to accurately indicate when the wake related spacing requirements can safely be reduced, the simulation indicates that significant savings can be realized.

GLOSSARY

ASQP	Airline Service Quality Performance
DFW	Dallas/Ft Worth International Airport
DOC	Direct Operating Cost
DOT	Department of Transportation
FAA	Federal Aviation Administration

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