

DEICING DECISION SUPPORT TOOL

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Abstract

With today's highly coupled flight schedules, any disturbance to the schedule of a flight could have unforeseen impact on the downstream connecting flights. Thus, it is crucial to be able to minimize the effects of the various potential disturbances. Deicing is one such disturbance. During the winter months, deicing procedures associated with snowstorms can cause unexpected delays in the flight schedules. Due to the nonlinear nature of the total time associated with the deicing process (which we call the "total system time," and includes time of waiting and deicing), it is difficult to predict accurately when an aircraft will complete the deicing process. It is difficult, therefore, to predict how the deicing process will influence the subsequent chain of events. In this paper, a queuing model for the deicing process was developed to assist dispatchers to have a more accurate prediction of the completion time for deicing. Moreover, the two major deicing pads at Detroit Metropolitan Wayne County Airport (DTW) were modeled. Through Monte Carlo simulation, estimates of the total system time for the two deicing pads were derived, along with the corresponding 95% confidence intervals. The simulation results were compared to the historical data in the Dynamic Runway Occupancy Measurement System (DROMS), which contains DTW surface surveillance and other aviation related data since October 2002. A decision support tool (DST) was developed, displaying the time estimates. With this deicing DST, airline dispatchers or air traffic controllers can send the next outbound flight to the deicing pad with the least amount of total system time, and, therefore, reduce potential disturbances associated with deicing.

Introduction

With today's hub-and-spoke system, the flight schedules at hub airports, e.g., Detroit Metropolitan Wayne County Airport (DTW), are highly coupled

to facilitate the passengers connecting at those airports, as well as the crew and aircraft transfers. Any delays to the schedules of those flights could have unforeseen impact on the downstream connecting flights [1]. Moreover, delays could induce wasted passenger time, additional air carrier operating cost, and added environmental impact [2]. Delays associated with the taxi-out portion of a flight accounts for the majority of the total delay (measured in minutes) [3], and represent the most significant part of the total cost of delay. Thus, it would be beneficial to both passengers and airlines to minimize the amount of taxi-out delay. At airports that are exposed to colder climate, the deicing process is a potential cause of taxi-out delay.

DTW is a hub airport for Northwest Airlines (NWA). Due to the geographical location of DTW, deicing is one cause of the delays during the wintry months. During those days, deicing procedures may become a prerequisite part of all flights during the taxi-out process. The deicing process removes any containment on the wings for the safety of all on board. The amount of time for an aircraft to go through the deicing process, including the time in queue and in the deicing procedure, is known as the "total system time"; this time exhibits non-linear behavior and may seem unpredictable. The nonlinearity of the total system time is induced by the constraints during the deicing process. A queuing model can model the constraints in the deicing process and, hence, is able to simulate and predict the nonlinear behavior of the total system time. The predicted total system time can provide a glimpse of the potential delay, and give dispatchers an opportunity to correct or compensate for it before the delay takes place.

This paper describes a queuing model that was constructed to replicate the deicing process at the two major deicing pads at DTW. A deicing decision support tool (DST) was developed based on the queuing model and results from the deicing DST are shown.

Model and Tool Development

DTW is one of NWA's hubs. Approximately 70% of flights in and out of DTW are operated by NWA. In 2002, the new McNamara terminal was inaugurated at the southern part of DTW, which is used exclusively by NWA. Beside the new

terminal, there are two new deicing pads next to the southern end of the two pairs of parallel runways (Figure 1). These deicing pads are staffed and operated by NWA. The modeling of these two deicing pads is the focus of this paper.

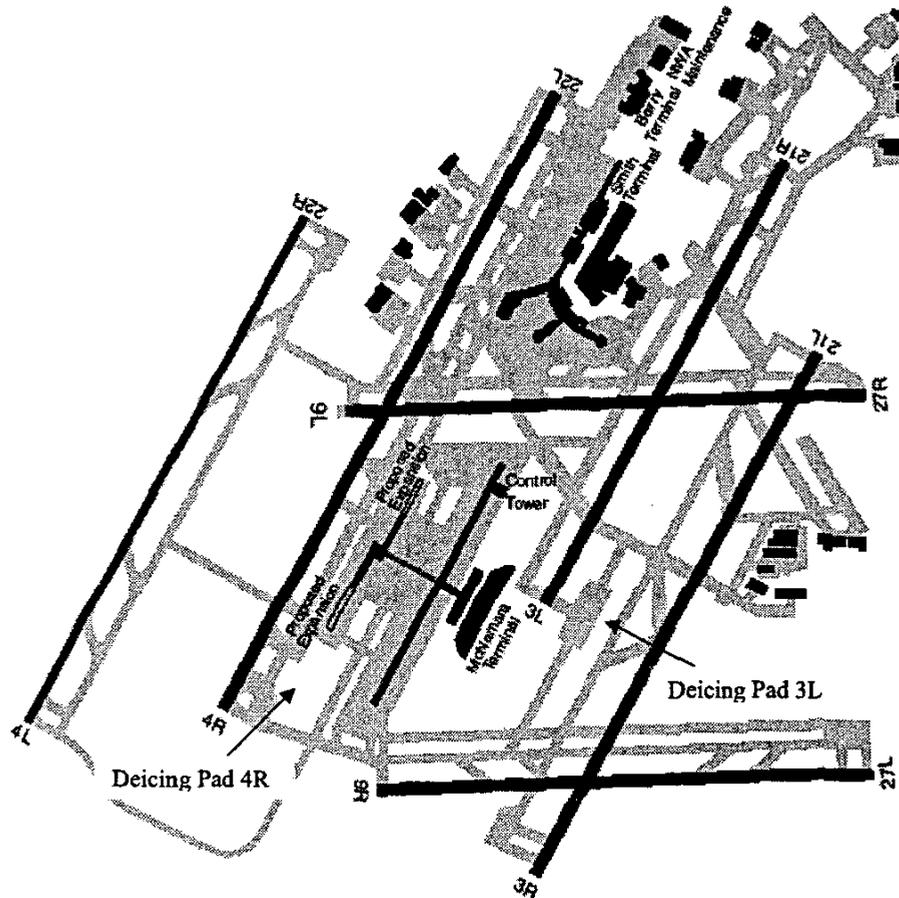


Figure 1. Diagram of DTW Airport

Deicing Queuing Model

The deicing process often involves four elements, which are represented schematically in Figure 2. Once an aircraft arrives at the deicing area, it often has to wait in queue before a deicing station in the deicing pad is available. There is only one queue at each deicing pad for the six deicing stations. The queue has a first-come/first serve policy. If a deicing station is available, the first

aircraft in the queue needs to satisfy the station's size constraint, i.e., the aircraft must fit into the open deicing station. The process of checking the size constraint is denoted as "control" in Figure 2. If the sizing constraint is satisfied, the leading aircraft in the queue taxis into the open deicing station, i.e., the third element of the deicing process. Next, the aircraft is deiced at the deicing station before it taxis out of the deicing station.

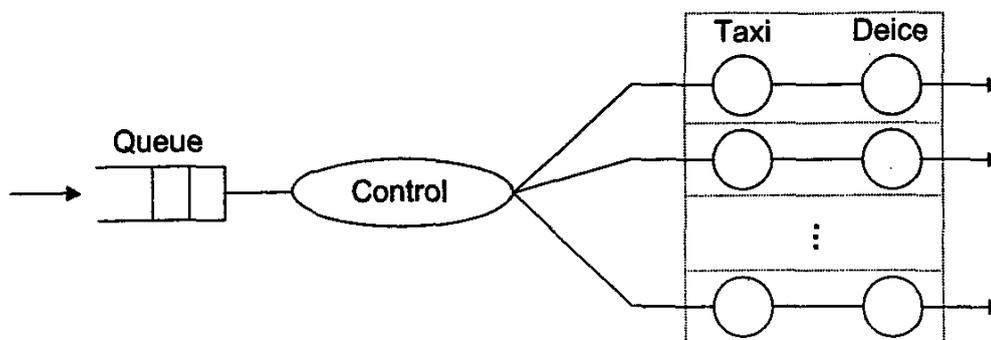


Figure 2. Deicing Queuing Model

The taxi time and deicing time, i.e., the amount of time to taxi into the deicing position and the amount of time to be deiced, respectively, are drawn from probabilistic distributions. The taxi time is sampled from a Gaussian distribution with a mean of 1 minute and a standard deviation of 10 seconds. There are two types of distributions used for the deicing time. The deicing time is distributed according to a Gaussian distribution if the aircraft is coming from the queue. The mean of the distribution varies according to the type of aircraft and type of snow, as listed in Table 1¹. The standard deviation of deicing time is half a minute for all aircraft types and all snow types. For aircraft already in the deicing stations when the simulation is commenced, an exponential distribution is used with the same mean as in the Gaussian distribution for the corresponding aircraft and type of snow.² The deicing parameters are given by the NWA dispatch center and the snow classification of type A through type E is also obtained from NWA [4]. A brief description of the snow types are listed in Table 2.

There are two deicing pads that are modeled in this paper, i.e., one next to runway 4R and another next to runway 3L (Figure 3 and Figure 4, respectively). The size restrictions of these deicing stations of each pad are listed in Table 3 and are inputted into the deicing queuing model. The queuing model for the deicing pads was written in MATLAB; this model predicts the total system time for the last aircraft in the queue, i.e., the total amount of time for that aircraft to wait in queue, to taxi into the deicing station, and to be deiced.

¹ The list of aircraft types operated by NWA is obtained from [5].

² Exponential distribution is used to preserve the memoryless property since the amount of time elapsed in the deicing station is not given for aircraft already in the deicing stations. For more information on the memoryless property, please consult [6]. The queuing model can also sample deicing time for aircraft already in the deicing stations using Gaussian distribution if the amount of time elapsed in the deicing station is given.

Table 1. Deicing and Taxiing Parameters (in Minutes)

| | | Mean Time | | | | | S.D. |
|--------------|-----------|-----------|----|----|----|----|----------|
| Type of Snow | | A | B | C | D | E | All Snow |
| Deice | B747 | 18 | 23 | 30 | 40 | 60 | 0.5 |
| | A330/DC10 | 13 | 18 | 23 | 34 | 45 | |
| | B757 | 8 | 11 | 16 | 20 | 45 | |
| | A319/A320 | 7 | 9 | 14 | 19 | 45 | |
| | DC9 | 3 | 5 | 12 | 15 | 45 | |
| | RJs | 3 | 5 | 12 | 15 | 45 | |
| Taxi | All AC | 1 | | | | | 1/6 |

Table 2. Description of Type of Snow

| | |
|---|---|
| A | Frost, freezing fog or mist, light dry snow less than or equal to ¼"/HR, visibility ½ mile or greater |
| B | Rime ice, light wet snow less than or equal to ¼"/HR, visibility greater than or equal to ½ mile, moderate dry snow ¼ to ¾"/HR visibility greater than ¼ mile |
| C | Moderate wet snow greater than ¾"/HR visibility greater than ¼ mile, heavy dry snow greater than ¾"/HR, visibility less than or equal to ¼ mile |
| D | Heavy wet snow greater than ¾"/HR, visibility less than ¼ mile, light freezing drizzle, visibility less than ½ mile |
| E | Freezing rain: light, moderate, or heavy |

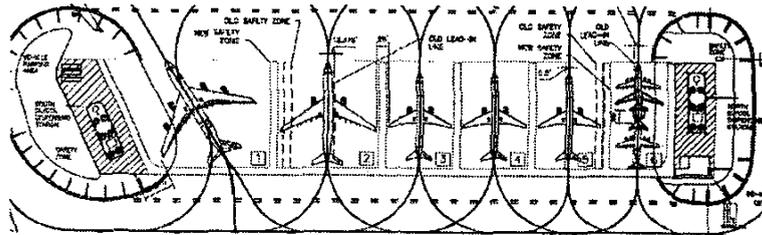


Figure 3. DTW Deicing Pad 4R

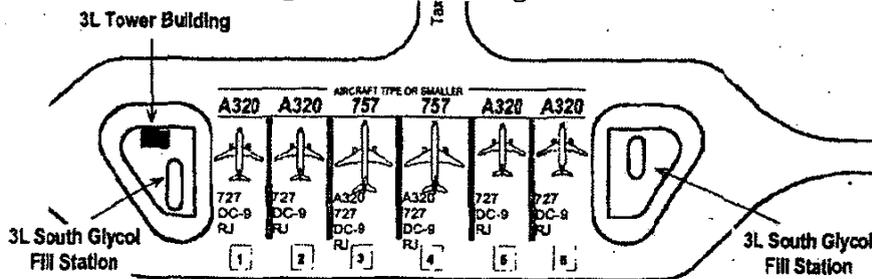


Figure 4. DTW Deicing Pad 3L

Table 3. Maximum Aircraft Size

| | 4R | 3L |
|-----------|------|------|
| Station 1 | B747 | A320 |
| Station 2 | A330 | A320 |
| Station 3 | B757 | B757 |
| Station 4 | B757 | B757 |
| Station 5 | B757 | A320 |
| Station 6 | DC-9 | A320 |

The Dynamic Runway Occupancy Measurement System (DROMS) contains DTW surface surveillance data from the Multistatic Dependent Surveillance (MDS) system (a multilateration system), and other aviation related data since October 2002 [7]. Attempts were made to compare the results from the aforementioned queuing model to the DROMS dataset. Due to the partial deployment of the base-station of the MDS system at DTW and pilots failing to turn on the transponder immediately after pushback, the surveillance data at DTW may not be complete. Therefore, the validation process of the queuing model could not be performed using the DROMS dataset.

Deicing Decision Support Tool

Based on the deicing queuing models built for deicing pads 4R and 3L at DTW, a deicing decision support tool for DTW was created. The goal of the DTW deicing DST is to give dispatcher/controller better estimates of the total system time for an outbound aircraft to go through each of the two deicing pads. Therefore, airline dispatchers or air traffic controllers can send the next outbound flight to the deicing pad with the least amount of total system time. A graphical-user-interface to the deicing DST was built (Figure 5). The user of the DST is asked to enter the type of snow, the type of aircraft for the flights in the deicing pads or in the queues, as well as the outbound aircraft. To facilitate the input process, a pull-down menu was incorporated for entering aircraft types. The outbound aircraft is added to the end of each queue

and 1,000 (the default value) simulation runs of the queuing model are performed. An estimate for the total system time, along with the 95% confidence interval, for the outbound aircraft going through each of the two queues is estimated based on the Monte Carlo simulation and displayed in the DST. The estimate of the total system time, e.g., 37.04 minutes to go through deicing pad 4R, is based on the average system time from the 1,000 simulation runs. The end points of the 95% confidence interval are the 97.5 and 2.5 percentiles of the samples from the Monte Carlo simulation, e.g., 49.8 minutes and 26.85 minutes respectively at deicing pad 4R.³ The sloping line connecting the estimated total system time for the two deicing pads suggest which deicing pad might have a shorter wait time, e.g., deicing pad 4R.

³ In other words, the confidence interval attempts to capture the amount of variability of the next outbound flight, instead of the variability in the estimate of the average. Both the estimated total system time and the 95% confidence interval are shown in the graph and in the text of the DST.

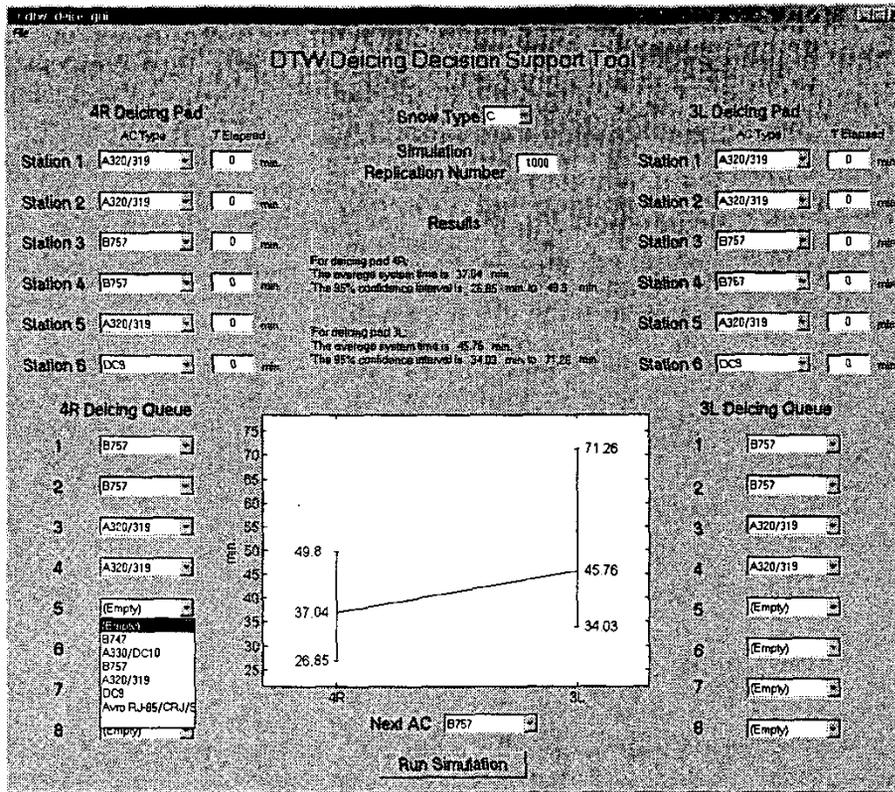


Figure 5. DTW Deicing Decision Support Tool

Results

A number of scenarios were developed in an attempt to validate the deicing DST. We present the results of those scenarios below.

Scenario 1: Effect of Oversize Aircraft

Due to the size constraints of the deicing stations in deicing pads 4R and 3L, the wide-body aircraft, e.g., B747, A330, and DC-10, cannot be deiced in the deicing pad 3L. In this scenario, an outbound A330 was entered with a random stream of aircraft being deiced and in the queues of deicing pads 4R and 3L. Figure 6 shows the estimates for the total system time. Since a numerical value is required for total system time in the plot for the deicing pad 3L, an extreme value of 120 minutes was used. A quick comparison of the plot shows that it would be desirable to send the A330 to 4R deicing pad.

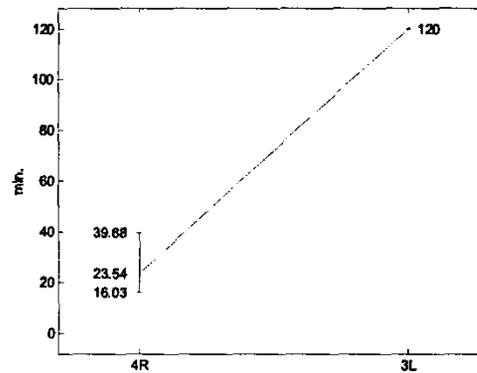


Figure 6. Oversized Aircraft at 3L

Scenario 2: Effect of Snow Event

In this scenario, we tested the effect of the type of snow on the total system time. We set the type of aircraft in the corresponding deicing stations to

be identical for both deicing pads, while satisfying the size constraint, in order to enable equal comparison between deicing at the two pads (A320 in Stations 1, 2, and 5; B757 in Stations 3 and 4; and DC-9 in Station 6). There is no aircraft in queue and the outbound aircraft is an A320. We entered two types of snow events, A and C. The total system times are shown in Figure 7 and Figure 8. As the type of snow changed from a less severe weather pattern (A) to a more severe pattern (C), the corresponding estimate of the total system time also increased due to a lengthier deicing process.

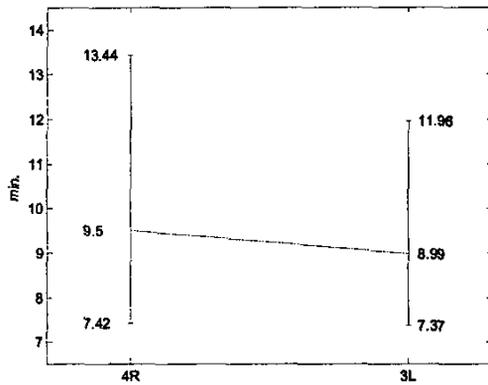


Figure 7. Type A Snow

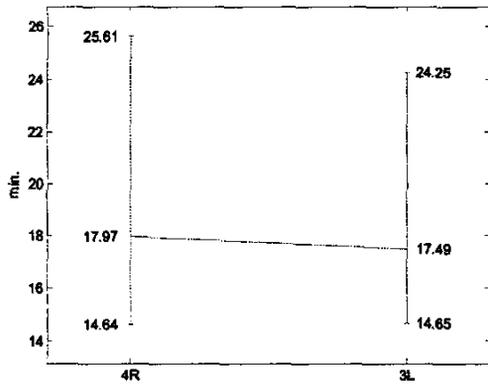


Figure 8. Type C Snow, Outbound A320

In this scenario, it may be advantageous to send the outbound A320 to deicing pad 3L regardless of the type of snow, since the estimated total system times are shorter for deicing pad 3L in both snow types. The slight differences in the estimate of the total system time between deicing

pad 4R and 3L is due to the differences in pad configuration. In 4R, out of the six stations, only Station 1 through 5 can accommodate an A320, whereas all six stations at deicing pad 3L can accommodate an A320. The shortage of one deicing station in deicing pad 4L contributed to the slightly lower total system time.

Scenario 3: Effect of Outbound Aircraft

Scenario 3 tests the effect of different outbound aircraft. We set the type of aircraft in the deicing stations to be identical for both deicing pads, as in Scenario 2. There is no aircraft in queue with type C snow. The outbound aircraft is either an A320 or B757. The result for the A320 is shown in Figure 8 and the result for B757 is shown in Figure 9.

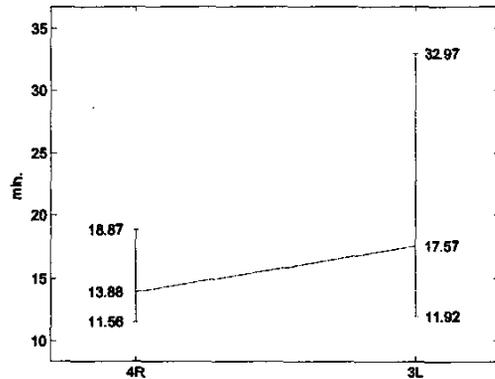


Figure 9. Snow Type C, Outbound B757

No one deicing pad consistently provided the shorter estimated total system time for both outbound aircraft types. In case of an outbound A320, it is better to send it to the deicing pad 3L. On the other hand, an outbound B757 would be more efficient if it is sent to deicing pad 4R. Once again, this is due to the different physical layouts of the deicing pads. Station 1 through 5 of deicing pad 4R can accommodate B757 and only Station 3 and 4 of deicing pad 3L can deice a B757. Therefore, this results in a much shorter estimated total system time for the outbound B757 through deicing pad 4R than deicing pad 3L.

Scenario 4: Effect of Queue Order

In Scenario 4, we tested the effect of the queue order on the estimated total system time. Once again, we set the type of aircraft in the deicing stations to be identical for both deicing pads, as in Scenarios 2 and 3. The snow type is C. The queues for both deicing pads 4R and 3L are also set to be the same. In the first queue, there are two B757s in the first two positions of the queue, followed by two A320s. In the second queue, the order is reversed, i.e., there are two A320s in the front of the queue, followed by two B757s. The outbound aircraft is a B757. The corresponding estimated total system times are shown in Figure 10 for the first queue and in Figure 11 for the second queue.

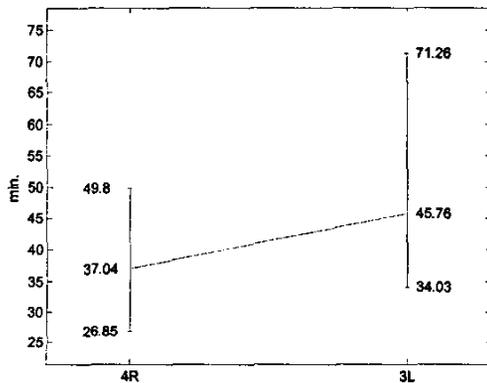


Figure 10. Two B757s in Front of Queue

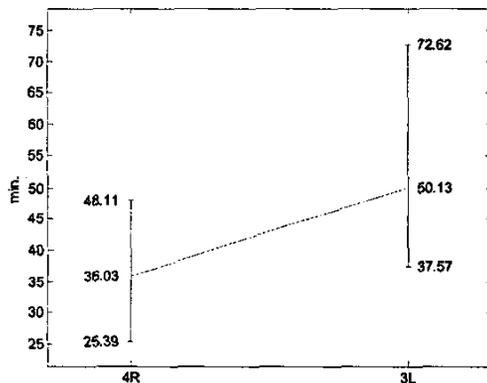


Figure 11. Two B757s in Back of Queue

The two different queue orders would result in similar total system times if the outbound B757 is to go through deicing pad 4R. This is due to the five stations at deicing pad 4R which can

accommodate B757. On the other hand, there is a noticeable difference in the total system times associated with the two queue orders if the outbound B757 is to go through deicing pad 3L. In the first case, the two B757s in the front of the queue would hold up all the aircraft behind it while Station 3 and 4 are not available in deicing station 3L. During the wait, the smaller deicing stations may become free. Once the B757s are able to be deiced, there is a higher chance that the A320s can be deiced, leaving the outbound B757 with a shorter wait. In the second case, there is some probability that either or both of Station 3 and 4 would become free and the A320s in the front of the queue could take either those openings. Therefore, the two B757s in the back of the queue would be held up while holding back the outbound B757, which is added to the end of the queue. Since there are only two B757-capable deicing stations, the two B757s in the back of the queue would take up those stations and hold the outbound B757 at the queue.

Conclusion

In this paper, we described the development of a deicing queuing model and the corresponding deicing decision support tool for DTW. Attempts were made to validate the queuing model based on the DROMS dataset. Based on the results shown in Section 3, the queuing model and the deicing decision support tool seem to give accurate predictions of the shorter total system time. Although the deicing decision support tool could be utilized right now, it would be useful to discuss possible enhancements. A number of enhancements relate to real-time surveillance input to the deicing DST:

- Type of aircraft in deicing station
- Aircraft type in deicing queue
- Type of outbound aircraft

In addition, the deicing DST can provide real-time prediction as well as real-time performance monitoring, e.g., throughput. Another avenue of expansion of the deicing DST is to include the capability of handling multiple outbound aircraft and the optimum deicing sequence assignment, which have shown to be important in Scenario 4.

Acknowledgement

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