Modeling Deicing Operations in Departure Scheduling using Fast Time Simulation

Zhifan Zhu
KBRWylie/SGT
Moffett Field, California, U.S.A.
zhifan.zhu@nasa.gov

Vaishali Hosagrahara
KBRWylie/SGT
Moffett Field, California, U.S.A.
vaishali.a.hosagrahara@nasa.gov

Yoon Jung
NASA Ames Research Center
Moffett Field, California, U.S.A.
yoon.c.jung@nasa.gov

Hanbong Lee
NASA Ames Research Center
Moffett Field, California, U.S.A.
hanbong.lee@nasa.gov

Yeonju Eun
Korea Aerospace Research Institute
Daejeon, Republic of Korea
yjeun@kari.re.kr

Daekeun Jeon
Korea Aerospace Research Institute
Daejeon, Republic of Korea
bigroot@kari.re.kr

Abstract— In winter snow conditions, aircraft need inspection for deicing service before takeoff. Deicing service is a procedure to remove frost, ice, slush, or snow from aircraft for safe operation. Deicing operations vary by airport in many ways. Some airports have designated deicing zones, whereas some use a closed runway or terminal area to perform the procedure. Nonetheless, deicing operations add extra workloads to controllers, and cause increased taxi traffic on the ground. NASA and Korea Aerospace Research Institute (KARI) have been collaborating to model deicing operations at Incheon International Airport (ICN). This paper describes the deicing model and the study of deicing operations in departure scheduling using fast time simulations. The deicing model uses a heuristic algorithm for deicing zone assignment. In the fast time simulations, the model uses probability distributions derived from actual operation data to model deicing request and deicing zone time. It is envisioned that such a deicing model can be useful in airport surface scheduling to provide decision support and improve traffic management performance in winter snow operations.

Keywords— aircraft deicing, surface operation, modeling and simulation

I. INTRODUCTION

At airports under winter snow or freezing temperature with precipitation conditions, aircraft must be inspected for deicing service, and, if requested as the result of inspection, be deiced before takeoff. Deicing service is a procedure to remove frost, ice, slush, or snow from aircraft for safe operation [1][2]. An anti-icing procedure often follows to provide protection against the formation of snow, frost, or ice accumulation on the aircraft surface. A winter season at airports in the northern hemisphere can last a few months when deicing services are needed. It is estimated by the US Environmental Protection Agency (EPA) [3], based on the snowfall and aircraft operations criteria, that in the US there

are over 200 primary commercial airports that have potentially significant deicing operations. Deicing aircraft at airports has a big impact on the surface traffic and ultimately, air transportation business. It requires careful planning, implementation and management to reduce extra delays and flight interruptions. For example, the aircraft deicing operation plans at Dallas Fort Worth International Airport (DFW) and Charlotte Douglas International Airport (CLT) consist of detailed rules, procedures, deicing locations and clearly defined roles and responsibilities [4][5].

Depending on the airport infrastructure and space availability, deicing services can be conducted at centralized locations in the ramp or the airport movement area, or at the areas near terminal gates. In the latter case, deicing may occur before pushback or before taxiing after pushback. Centralized deicing, which typically takes place in a remote area away from terminals, has the environmental benefit of being able to collect a high percentage of the sprayed deicing fluid for recycling, and reduce glycol contamination risk. Operationally, it helps reduce the aircraft and service vehicle traffic congestion in the gate area, resulting in better gate access for arrivals. It also allows aircraft to be deiced closer to the departure runway before takeoff, which helps cut down the odds of the anti-ice agent exceeding its Hold Over Time (HOT) [6]. One primary concern for centralized deicing, however, is that it may create a bottleneck at deicing facilities, resulting in delays. Careful planning and construction of the deicing zones are, therefore, a common practice to reduce traffic hindrance. In addition, well scheduled deicing operations in connection to departure takeoffs can improve the overall airport performance under snow conditions. The SESAR's De-icing Management Tool [7] under the SESAR Technological Solution portfolio defines itself as a system capable of improving the predictability of aircraft deicing operations at European

airports with A-CDM deployment. The solution envisions deicing operations as a part of normal operations rather than adverse conditions in the winter period. The conceptual tool has two key functions: an accurate estimate of the deicing operations duration and a calculation of deicing sequences to optimize the deicing resources.

The recent development and field test of various strategies and algorithms in airport traffic management decision support tools conducted by NASA have demonstrated advanced capabilities for airport surface operations [8][9]. Although the new capabilities bring various operational benefits in airport operations, they are primarily designed for the operations under normal weather conditions. Winter operations with deicing services remain a challenge. Controllers require extra effort in assigning deicing services and resources to aircraft that request deicing, and mentally account for deicing operations in departure schedules. Deicing operations add extra uncertainty to the aircraft and directly impact the performance of the decision-making process. The work described in [10] studied the deicing operations at four northern US airports (ORD, MSP, DTW and BOS). It suggested three approaches to estimating departure taxi out times in the event of deicing operations: 1) use a constant deicing time plus a buffer for deicing time uncertainty, 2) attempt to model the deicing time to improve the estimates, and 3) only estimate the taxi time from deicing pad to runway. A recent work [11] considered the deicing operations in a Mixed Integer Linear Programming (MILP) based departure runway scheduler, where the deicing zone assignment was modeled as a decision variable in the optimization formulation. The deicing duration inside the zone was estimated using the average deicing time for each aircraft (size) category. The results showed that an optimal solution could be obtained for both takeoff and deicing queue sequences maximizing the runway throughput.

In this paper, we present the work jointly performed by NASA and KARI to model the deicing operations at Incheon International Airport (ICN) and integrate the model into an airport departure scheduler using fast time simulation. The purpose of the research and the contribution of the paper is to help understand deicing operations in airport traffic movement, evaluate deicing service resource management strategy, and eventually incorporate deicing operation support in airport decision support tools. The rest of the paper is organized as follows. Section II introduces the deicing operations at ICN. Section III describes the development of the deicing model and its integration with a departure runway scheduler. Section IV shows the simulation setup and validation. Section V presents the results and analysis based on the Monte Carlo simulation runs using the deicing model with three different zone assignment settings. The comparison with the actual deicing operations is also provided. The paper concludes in Section VI with the summary and future work.

II. DEICING OPEATIONS AT ICN

A. Deicing Facilities

Fig. 1 shows the ICN airport layout [12][13]. The airport has three physical parallel runways. In the north flow operation, which is the prevailing flow configuration, departure aircraft take off from 33L and 34 and arrivals land on 33L, 33R and 34. In the south flow situation, departure aircraft use 15R and 16, and arrivals land on 15L, 15R and 16. The Passenger Terminal and Concourse are located in the south. As of 2018, a new passenger terminal, Terminal 2 was opened for operation in the Expanded area.
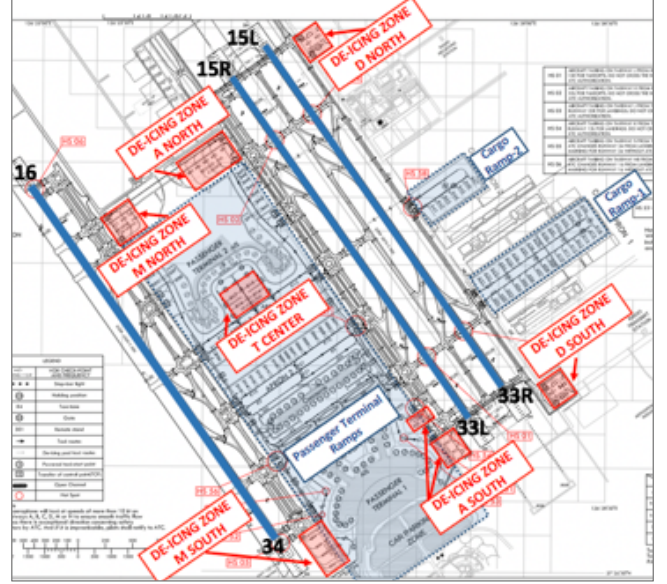

Fig. 1 ICN Airport Layout

At ICN, aircraft are deiced inside the designated deicing zones in the ramp area. There are total of seven deicing zones as of 2019. The latest addition, T Center, was constructed recently near Terminal 2 and was put in operation in January 2018.

Each deicing zone has several deicing pads where aircraft park for deicing. Each pad can accommodate a specific aircraft (wingspan) category according to ICAO Aerodrome Reference Code [14]. TABLE I lists the number of pads for each aircraft category at each zone. For example, A South zone has two pads that can support deicing for Category B aircraft, three for E and two for F, respectively. A pad that can service a larger aircraft category can also service smaller ones, but the reverse is not true.

2

TABLE I. Deicing Zones and Pads

Category	B	C	D	E	F
A South	2			3	2
A North	10			4	1
M South			2	3	1
M North				2	1
D South	4			1	1
D North	4			1	1
T Center		4		4	

B. Deicing Operators

Aircraft are deiced by the certified deicing service providers, or deicing operators. Some of them are airline affiliates, and some independent. Before each winter season starts, the deicing operators sign service contracts with airlines to provide deicing services. A deicing operator can only perform deicing services for the airlines with whom it has a service contract. In addition, Incheon International Airport Corporation (IIAC), who manages the airport operations, assigns specific deicing zone(s) to the deicing operators to use for deicing services. These service and facility contract restrictions often constrain controllers from using all available deicing resources. This is regarded as a major source of inefficiency in deicing resource allocation.

C. Deicing Operations Sequence

On a deicing day at ICN, departure aircraft will be inspected for deicing. The inspection is done at the gate/stand area before an aircraft is ready for pushback. For an aircraft that needs deicing, the operation sequence follows the steps listed below:

- Pilot contacts Deicing Position (DP) at ramp control for deicing request
- DP assigns a deicing zone to the aircraft
- Pilot calls when ready and obtains pushback clearance
- Aircraft leaves gate and taxies to the assigned zone
- Aircraft arrives at the zone and gets the pad assignment from DP
- Aircraft taxies to the pad, and deicing commences
- Pilot contacts Incheon Delivery of ATC for pre-departure clearance during deicing
- Aircraft leaves deicing zone after completion of deicing and taxies to departure runway to take off

The main decision for the DP is the deicing zone assignment. It involves mental calculation to balance the zone workload, taking into consideration various operational constraints such as airline contract, aircraft type, departure runway assignment, terminal and gate location.

During the deicing operation, the pilot contacts Incheon Delivery, a position usually at the ATC Traffic Management Unit (TMU), to get an ATC pre-departure clearance. This is to ensure that the aircraft will depart, after deicing, in time to meet the anti-ice fluid's HOT requirement.

D. Operation Data Analysis

D.1 Deicing Days

The deicing operation data in the 2015-2016 winter season was analyzed for deicing model development. The season was three months long from Dec 2015 to Feb 2016. The average number of daily departures of the three months was about 450 flights. Fig. 2 shows the numbers of aircraft deiced for the top ten deicing days of the season. The busiest day occurred on Dec 3, 2015 when a total of 190 deicing operations were recorded. They accounted for about 40% of total departures on that day.
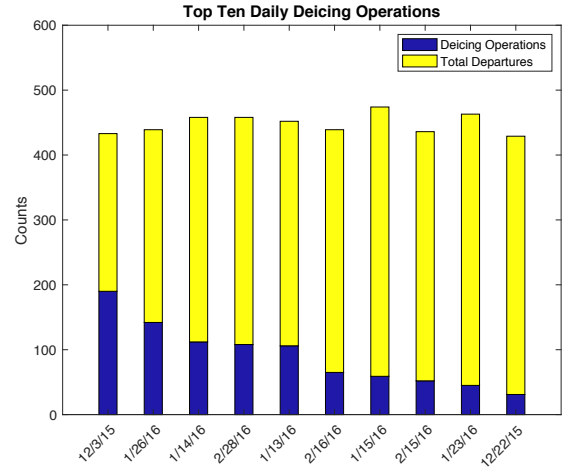

Fig. 2 Top Ten Daily Deicing Operations at ICN

D.2 Deicing Zone Assignments

The deicing operations were found in all six zones. TABLE II shows the deicing zone usage percentages. The A South and M South zones were the two most used ones. They were the natural choices for departure aircraft from the passenger terminal gates because their locations are close to the departure runways 33L and 34. A total of 66% of the deicing operations were assigned to them. The A North and M North zones had a total of 27% combined usage. They accounted mostly for the departures to the runways 15R and 16 for the same reason of being close to the departure runways. Despite the obvious advantage of using south zones for north flow departures and north zones for south flow, there were occasions where other zones were chosen due to other reasons such as a service contract constraint and traffic conditions.

TABLE III summarizes the percentages of zone usages and departure runways combinations. 70% of deicing operations (56% plus 14%) took place at zones that are close to departure runways. The other 30% (18% plus 12%) used the zones that were further away from the departure runways.

TABLE II. Zone Usage in 2015-2016 Winter Season

Zone	A South	M South	A North	M North	D South	D North
Usage	38%	28%	22%	5%	6%	1%

TABLE III. Zone Usage and Departure Runways

	Runway 33L, 34	Runway 15R,16
South Zones	56%	18%
North Zones	12%	14%

D.3 Deicing Zone Time

The deicing zone time was measured as the total time that an aircraft stays in a deicing zone. It includes the taxi time inside the zone, deicing time on the pad, engine shut down and spool up time, and waiting time. Fig. 3 depicts the histogram of the zone time from the data records. Some outliers due to the data inaccuracy, such as the spike around the zero, are evident. The purple line represents the normal distribution fit after filtering out the data points equal to zero or greater than 60 minutes. The overall mean and standard deviation of deicing zone time for all aircraft after the filtering was 23.7 and 11.0 minutes, respectively. But larger aircraft in categories E and F took more time inside the zone, as shown in the table. At ICN, the majority of aircraft are of category C, such as A320 and B737, and category E like B787.
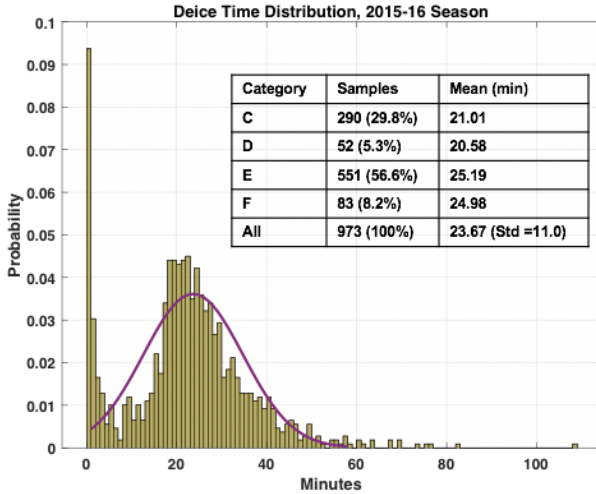

Deice Time Distribution, 2015-16 Season

Category	Samples	Mean (min)
C	290 (29.8%)	21.01
D	52 (5.3%)	20.58
E	551 (56.6%)	25.19
F	83 (8.2%)	24.98
All	973 (100%)	23.67 (Std =11.0)

Fig. 3 Zone Time Distribution

III. DEICING MODEL AND DEPARTURE SCHEDULER

The deicing model for ICN has been developed according to the current day deicing procedure and operation data analysis. It models three deicing related decision processes:

- Pilot's request for deicing operation (for simulation only)
- deicing zone assignment, and

- the length of time that the aircraft will stay inside the zone for deicing

The model is integrated with a departure scheduler. The scheduler calculates the runway takeoff sequence for the aircraft ready for or taxiing to departure. Using the target takeoff times, it then computes the target taxi clearance times for aircraft within a deicing zone to exiting the deicing zone after completion of deicing. The scheduler also issues target pushback times from the gate for both aircraft requesting deicing bound for the deicing zone, and aircraft not requesting deicing bound for the runway.

Fig. 4 shows the data flow between the deicing model, the departure scheduler, and the simulator. The flight data from the simulator consist of call sign, aircraft type, assigned gate and runway, aircraft position, aircraft status (ready at gate, taxi, inside zone, etc.). The deicing data are the deicing model output, including zone assignment and deicing time. The scheduler uses the flight data and deicing data to calculate the schedules. The simulator uses the scheduler output data to taxi aircraft from gates to deicing zones and runways.

When a departure aircraft is ready for pushback at the gate, the deicing model first decides if the pilot requests deicing or not, and if so, assigns a deicing zone to the aircraft. The scheduler schedules the pushback time for the aircraft to taxi to the assigned zone. Once the aircraft is inside the zone, the deicing model produces the amount of time that the aircraft will stay in the zone for deicing. At the completion of the deicing, the simulator notifies the scheduler to schedule the aircraft for takeoff. When a departure aircraft is ready for pushback at the gate, if the deicing model decides that the pilot does not request deicing, the scheduler schedules the aircraft for takeoff and provides the target pushback time for the aircraft to taxi from gate to runway.
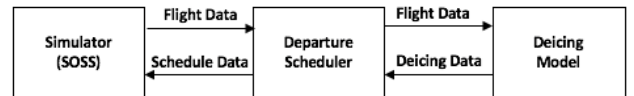

Fig. 4 Data Flow among Deicing Model, Departure Scheduler and Simulator

A. Deicing Model Details

A.1 Deicing Request

The deicing request is modeled using a normalized uniform distribution. The model samples the distribution and compares the returned value to a deicing request rate parameter to set the deicing request. The deicing request rate is defined as the percentage of departure aircraft that need deicing. For example, a request rate of 40% corresponds to 40% of total departure aircraft requesting deicing. If the sampling result is smaller than 0.4, the aircraft requests deicing, otherwise no deicing is needed. So, the chance of an aircraft requesting deicing operation is 40% in this example.

A.2 Zone Assignment

The zone assignment is heuristic in nature. The algorithm considers the gate/stand location, runway, aircraft category, and zone traffic load conditions. It attempts to minimize the taxi distance from zone to runway and the waiting time in a deicing zone queue. It uses a pre-configured priority zone list for each gate area and runway combination. For instance, an aircraft from a Terminal 1 gate to Runway 33L has the zone list in the order of A South followed by A North. The deicing model will assign the aircraft to the zone in the front of the list if the zone's traffic load condition is under a preset threshold. A zone's traffic load condition is aircraft category dependent. This is because the deicing pads in a zone have different aircraft category support capabilities. For example, the A South zone has only two pads that can accommodate category F aircraft. For an aircraft of a given category, the zone's load condition is defined as the ratio of the number of aircraft in the same category currently assigned to the zone to the number of pads which can support the category or larger. For example, if the A South zone has three category F aircraft assigned to its two category F pads, then the zone load condition is 1.5 for a category F aircraft. If the preset threshold is larger than the zone load condition, the algorithm allows additional aircraft to be assigned to this zone. Otherwise, the next zone in the list will be considered. If all the zones in the priority list can no longer take a new assignment, the aircraft will be held at gate until the zone traffic is reduced. With this heuristic, the larger the threshold, the larger the zone queue size. On the other hand, the smaller the threshold, the smaller the zone queue size, and more likely an aircraft will be held at the gate in heavy deicing demand.

The deicing operator contract constraints are not modeled in this study.

A.3 Deicing Time

When an aircraft enters its assigned deicing zone, the model produces a time duration for the aircraft to stay in the zone. This is achieved by sampling the normal time distribution based on the actual deicing data analysis described in the previous section. The model takes aircraft category as input to account for the deicing time impact by aircraft size. This is done by using the unique mean deicing time by category. After the given time duration, the aircraft will be scheduled for takeoff by the scheduler.

B. Departure Scheduler

The departure scheduler uses a first come/ready, first served algorithm with a set of priority groups. It produces three schedule times to the simulator in this study, as follows:

- Target off block time from gate to deicing zone for a departure requesting deicing
- Target off zone time from deicing zone to runway for a departure after deicing

- Target off block time from gate to runway for a departure not requesting deicing

The scheduler calculates the target takeoff times for the departures along with the arrival landing times subject to the runway capacity constraints. The algorithm groups the aircraft in the following priorities in descending order to schedule the runway use times:

1. Arrivals
2. Departures taxiing to runway
3. Departures ready in deicing zone after deicing
4. Departures ready at gate to runway

Departures not ready at gate or deicing zone are not considered in runway scheduling. Within each of the groups, the first come/ready, first served rule applies. For two aircraft taxiing to the same runway, the earliest times of arrival at runway based on unimpeded taxi times are used to decide which one gets scheduled first. If two aircraft at gates are ready for the same runway, their ready times will determine the order of consideration.

The gate pushback time to runway and the taxi clearance time from deicing zone to runway are calculated backwards from their target takeoff times, respectively. In this study, the target gate pushback time of a departure to the deicing zone is the earliest time that a zone is assigned, i.e., the scheduler clears a deicing aircraft at the gate once the aircraft has a zone assignment.

IV. SIMULATION SETUP AND VALIDATION

A. Simulation Setup

NASA's Surface Operation Simulator and Scheduler (SOSS) [15] fast time simulator was used in the simulations. The traffic scenario was created based on the actual flight record on Dec 3, 2015 between 0800 to 1300 local hours. It was in the north flow configuration. Runway 33L was a departure only runway, 34 was an arrival-departure mix-use runway, and 33R an arrival only runway. The flight ready times of departures in the scenario were set as the actual gate pushback times of the operations. The arrival landing times matched the actual operations, too.

B. System Validation

Before the simulations, the system was validated using the full day flight data on Dec 3, 2015. In this validation traffic data, Runways 33L and 34 were used for both arrivals and departures, and runway 33R was for arrivals only. In the validation run, aircraft followed the operation data in the records, including gate, runway, departure off block time, deicing zone assignment, and time spent inside the zone. Then, the results of the validation run were compared against the actual data. Adjustments to the simulator configuration parameters, such as engine spool-up time and taxi speed, were made until the validation was subjectively satisfied. The major validation metrics are shown in the following.

B.1 Taxi Out Time

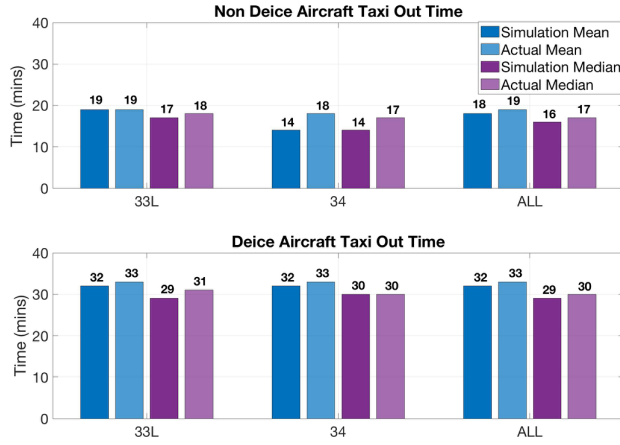Fig. 5 is the comparison of mean and median values of the taxi out times.

Fig. 5 Taxi Out Times

The taxi out time was measured from actual gate out time to wheels-off time. The deicing zone time was included in the taxi out time for deicing aircraft. The comparison indicates an overall good match of the simulation to the operation, except for the simulated non-deice aircraft to runway 34 taxiing a bit faster than operation (top middle plot).

B.2 Runway Throughput

Fig. 6 and Fig. 7 plot the accumulated runway throughput comparisons for 33L and 34, respectively. They are the accumulated counts of wheels-off (departures) and wheels-on (arrivals) in local time. The closeness in the comparison gives reasonable confidence that the system is able to simulate the runway capacity appropriately.
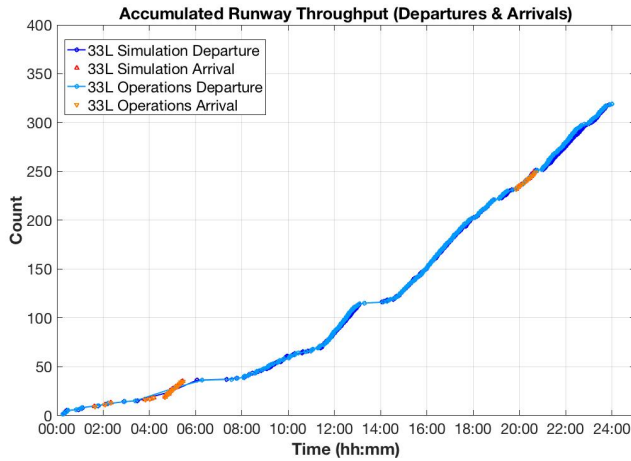
Fig. 6 Accumulated Runway Throughput on 33L
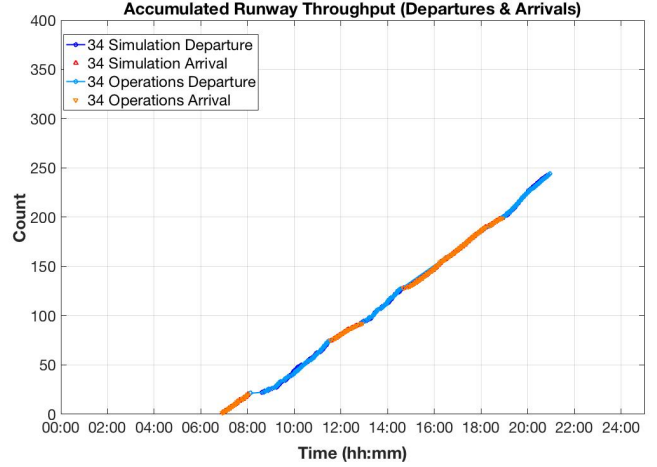
Fig. 7 Accumulated Runway Throughput on 34

B.3 Departure and Deicing Queue Size

Fig. 8 and Fig. 9 show the departure runway queue size and deicing queue size comparisons, respectively. The departure runway queue was measured as the number of departure aircraft that have left the gate and not yet taken off. The deicing queue was measured as the number of deicing aircraft that have left the gate and not yet exited the deicing zone. The results further verify the simulation dynamic behavior against the actual operation.
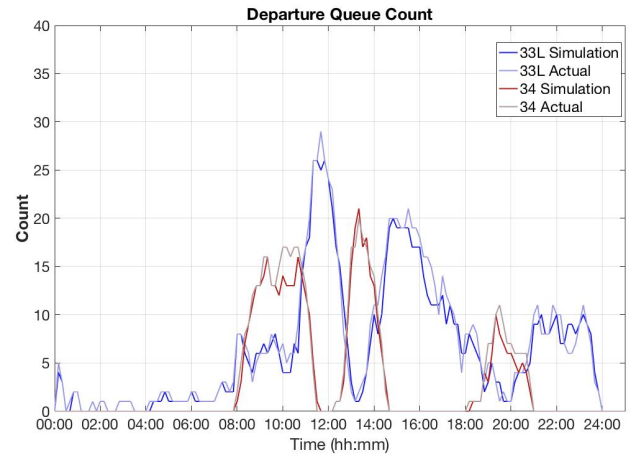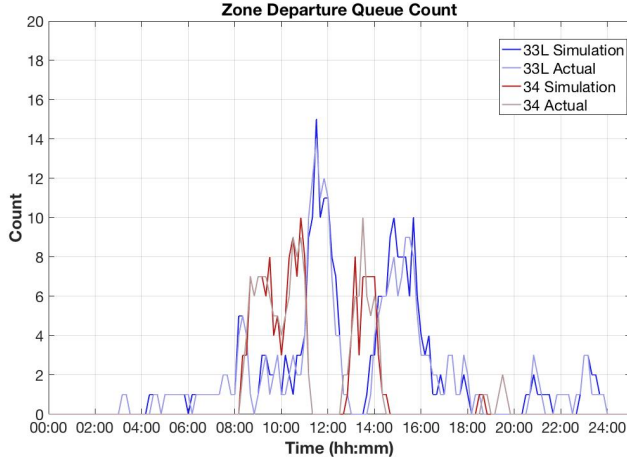

Fig. 8 Departure Queue Count

Fig. 9 Deicing Queue Count

V. RESULTS AND ANALYSIS

The results described in this section were obtained from the three primary sets of 20 Monte Carlo simulation runs that varied by deicing zone load threshold. The perturbation variables of the deicing model included the departure deicing request rate and deicing time. The deicing request rate was set at 40%, matching the actual operation data for the busiest deicing day observed on Dec 3, 2015. The means and standard deviation of the deicing time were also set according to the operation data analysis (Fig. 3). Fig. 10 shows the simulated deicing time distributions in two aircraft wingspan category groups, C or D and E or F. The dominant aircraft categories are C and E shown in percentage in TABLE IV, where the mean deicing times from the simulations are compared to the values in the actual operation. They matched well in all categories.
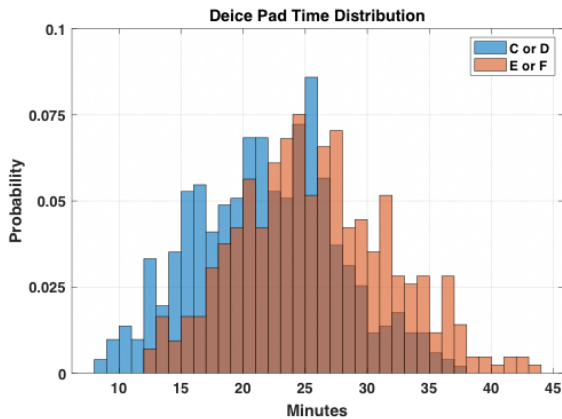

Fig. 10 Simulated Deicing Time Distributions

TABLE IV. Simulated Deicing Time Statistic

Category	C	D	E	F
Simulations	21.7 (51%)	20.7 (4%)	25.7 (42%)	24.0 (3%)
Operation	21.0	20.6	25.2	24.9

Three deicing zone assignment priority lists were configured according to the gate and runway assignments:

- Terminal gates to Runway 33L: [A South, A North],
- Cargo gates to Runway 33L: [D South, D North, A South], and
- All gates to Runway 34: [M South, M North]

Three deicing zone load thresholds, 100%, 150%, and 200%, were used, one for each of the three sets of Monte Carlo runs.

A. Zone Assignments

Fig. 11 shows the percentages of zone assignments from the three simulations of different deicing zone load thresholds. For comparison, the zone usage of the actual operation is also included in the last column. The model used the first-choice zones (A South, D South and M South) for the majority of the deicing requests. In the actual operation, however, the zone assignments appear more spread out. For example, 9% of departures to 33L used M North, which has a long taxi distance to the departure runway. One possible reason was the deicing operator and airline contract constraint, as mentioned earlier.

Among the three simulations, the bigger the zone load threshold, the more aircraft tend to be assigned to the first-choice zones. At the 200% threshold setting, almost all (98% and 100% for 33L and 34, respectively) deicing operations were assigned to the first-choice zones (A South, D South, and M South). At 100% threshold, which represents no overload of the zone capacity, on the other hand, 20% and 15% aircraft were assigned to the second-choice zones for 33L (19% A North and 1% D North) and 34, respectively. It indicates that at 40% deicing request rate and the overall departure traffic demand, the first-choice deicing zone capacity would be able to meet the deicing demand 80% to 85% of times. This assumes that each zone operates at its full capacity in this study.
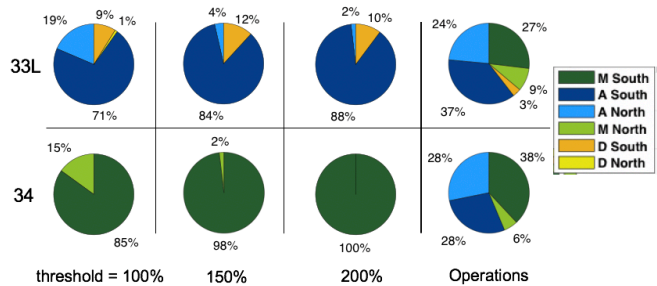

Fig. 11 Zone Assignments

B. Zone Queue Size

Although the first-choice zone in the heuristic model has the shortest taxi distance to the departure runway, overloading it may cause aircraft to incur additional waiting time in the deicing zone when a queue builds up. Fig. 12 and Fig. 13 show the zone queue sizes for 33L and 34,

7

respectively. The zone queue size is defined as the number of aircraft either inside a zone or taxiing toward the zone. It is plotted as the average aircraft count in 10-minute bins along time. The mean and maximum values of the first-choice zone queues for aircraft from the Terminal gates, A South and M South, are also displayed along the bar charts. The simulations show that overloading the first-choice zones increases their queue sizes, as expected. It will be interesting to see the potential aircraft taxi time change as the queue size grows, which will be analyzed later in this section.
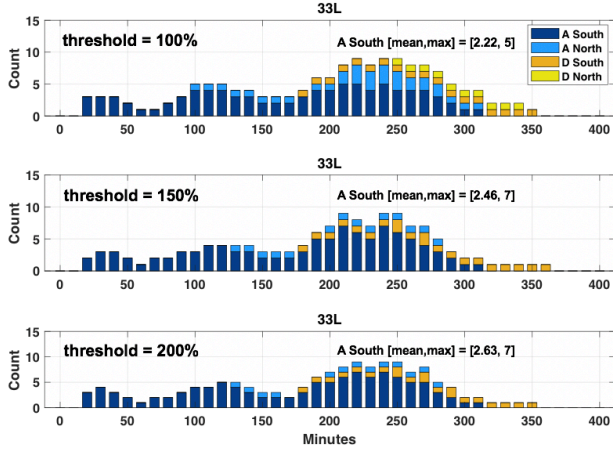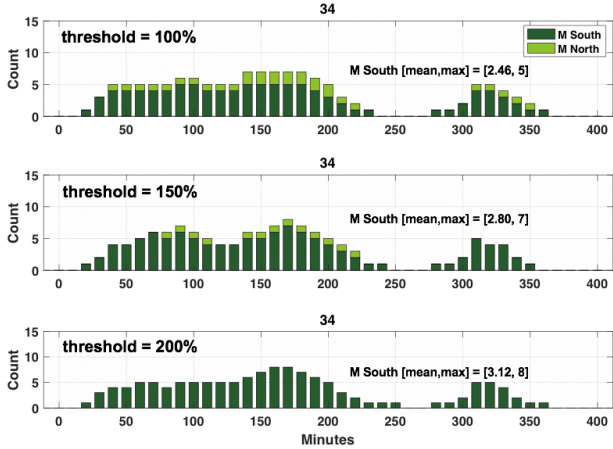

Fig. 12 Zone Queue Size for 33L

Fig. 13 Zone Queue Size for 34

C. Deicing Aircraft Gate Hold

The deicing model holds aircraft at the gate when all the deicing zones in the priority list have reached their loading threshold. To see how it works, two additional simulations were run with the deicing request rates at 30% and 50% without zone overloading, i.e., zone overload threshold of 100%. The data from these two runs were used only for the gate hold analysis.

TABLE V shows the results together with the default 40% request rate. The percentage of deicing gate hold is the number of aircraft experiencing gate hold divided by the total

number of deicing aircraft. The mean hold time is the total gate hold time divided by the number of holds. At 30% request rate, there was no gate hold, because of the low demand with respect to the zone capacity. From 40% to 50%, the simulations showed increased gate hold occurrence and time. Not only did the gate hold percentage increase, but the mean hold time also increased. Further research is needed to study the heavy deicing situation in the overall traffic management strategy.

TABLE V. Deice Aircraft Gate Hold

Deicing Request Rate (%)	Percentage of Deicing Gate Hold (%)	Mean Deicing Gate Hold Time (min)
30	0	0
40	2.24	4.89
50	5.78	6.08

D. Deicing Aircraft Taxi Out Time and Predictability

The taxi out time is measured from gate out to wheels-off. It consists of the taxi time from gate to deicing zone, deicing time, and taxi time from deicing zone to wheels-off.

D.1 Mean Taxi Out Times

Fig. 14 shows the mean taxi out times of the deicing aircraft. The bar charts visualize the total taxi out time, gate to zone, and zone to wheels-off times. For comparison, the mean taxi out times of actual operations are also plotted. The three simulations showed significantly shorter taxi times than the actual operations in all three measurements, likely because of the zone assignment differences due to deicing operator and airline contract constraints discussed earlier. Among the simulations, there were no noticeable differences in the gate to zone times. This is probably because of the tradeoff between the longer taxi distance when aircraft were assigned to the second-choice zones, and the extra waiting time in the first-choice deicing zone queue as discussed in the zone queue size analysis (Section V.B). On the other hand, the zone to wheels-off times show visible decrease as the threshold increases from 100% to 200%, corresponding to the increased use of first-choice zones. Note that less zone to wheels-off time is desirable for anti-ice fluid HOT compliance. The overall taxi out times appear to be influenced by the zone to wheels-off times, but the overall taxi out time differences between 150% and 200% thresholds are less noticeable.
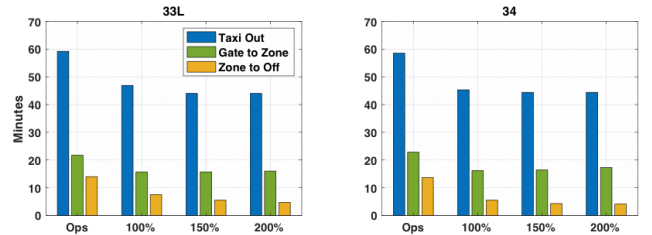

Fig. 14 Mean Taxi Out Times

D.2 Taxi Out Time Predictability

Fig. 15 shows the taxi out time variances in the same three taxi time measurements. The variance is represented by the standard deviation of the taxi time. Less variance leads to better predictability, which in turn, helps the scheduler build robust schedules. The overall taxi out variance is a combination of the variances of the three times, i.e., gate to zone time, deicing time in the zone, and zone to wheels-off time. In the three simulations, the deicing time was modeled with the same statistic. Therefore, the overall taxi out time predictability was a function of the gate to zone and the zone to wheels-off time variances. The results reveal that with increased zone overloading thresholds, the gate to zone time predictability decreased, but the zone to wheels-off predictability improved. The likely reason for the degradation of the gate to zone time predictability is that more aircraft had to wait in the zone queues, which added more uncertainty to the taxi time. On the other hand, more first-choice zone assignments due to the increased zone overload helped the aircraft taxi shorter distances to the departure runways and therefore improved the taxi time predictability. The opposing interests in the deicing zone assignments for taxi time predictability for scheduling aircraft from gate to deicing zone and from zone to runway suggest a tradeoff solution may be considered in further investigation.
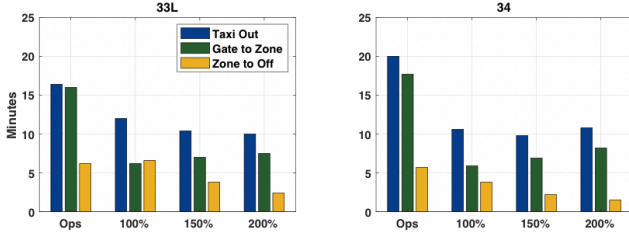
Fig. 15 Taxi Out Time Variances

E. Zone and Runway Throughputs

To analyze the relationship between the deicing zone and runway throughputs, Fig. 16 plots the accumulated zone and departure runway throughputs together. For each departure runway, the zone throughput is the total zone throughputs for the aircraft to the same runway. The results show that the runways are able to catch up with the deicing zone throughputs most of time. In other words, it was the zone operations that dictated the airport departure rate. One notable observation is at 100% threshold on 33L (top left plot) where the runway throughput underran the zone throughput for a time, perhaps due to the longer taxi times after deicing from A North zone. It should be noted, however, that the nominal runway departure rates were used in the simulations. Further study would look into whether a reduced runway operation rate should be imposed during snow weather conditions.
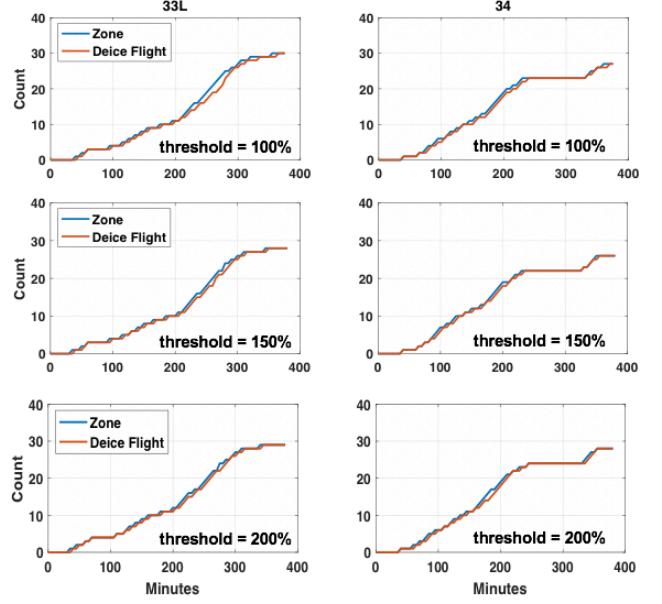
Fig. 16 Zone and Runway Throughputs

VI. SUMMARY AND FUTURE WORK

This paper described a deicing model developed for winter snow day operations at Incheon International Airport. Integrated with a departure scheduler, the model provided deicing zone assignment to the scheduler and modeled deicing times to the simulator in three Monte Carlo simulations by varying zone load threshold. The model's zone assignment logic uses a heuristic algorithm that considers the zone locations with respect to the gate and runway assignment as well as the zone workload conditions. The model does not reflect the constraints of the airline operator deicing contracts. The simulation traffic scenario was derived from the snow day operations at ICN on Dec 3, 2015.

The simulations showed the better performance, with less taxi out times and smaller taxi out time variance, than the actual operation. Among the three simulations, where different zone load thresholds were tested, the results showed no visible differences in average gate to zone times due to the tradeoff between the longer taxi distance when aircraft were assigned to the second-choice zone, and the extra waiting time in the first-choice zone queue. The average zone to wheels-off times showed a visible decrease as the zone load threshold increased, due to the increased assignments of first-choice zones, which is good for anti-ice fluid HOT compliance. The overall taxi out times were influenced mainly by the zone to wheels-off times. But between 150% and 200% thresholds, the differences of the average zone to wheels-off times were less noticeable.

In addition to the average taxi out times, we also analyzed the taxi out time predictability over three segments: overall taxi out, gate to zone, and zone to wheels-off. The results indicated that in all three simulations the zone to wheels-off

time had the best predictability, whereas the overall taxi out time showed the worst predictability. From the scheduling point of view, it makes sense to schedule deicing aircraft to depart from the zone rather than from the gate. Among the three simulations, when more first-choice zones were assigned, the predictability from gate to zone decreased, which would have a negative impact on scheduling aircraft from gate to zone. On the other hand, the predictability from zone to wheels-off improved, which would be beneficial to scheduling aircraft from zone to departure runway. These observations suggest a possible tradeoff in zone assignment strategy.

Lastly, the deicing zone and runway throughputs were analyzed. The simulations showed that the runway throughputs closely followed zone throughputs. In other words, for deicing aircraft the zone throughput could be the main bottleneck to determine the overall departure throughput.

For future work, the following improvements will be considered: 1) refine the deicing model to model dynamic zone capacity (e.g., deicing truck count), and the fatigue factor of the deicing service operators over time, 2) add zone-airline contract restrictions, and 3) include possible runway operation rate degradation under snow day conditions.

ACKNOWLEDGMENT

REFERENCES

[1] ICAO, "Aircraft Ground De-Icing/Anti-Icing Operations – ICAO Requirements and Guidance, 2016," http://www.icao.int/safety/airnavigation/OPS/Pages/Aircraft-Ground-De-IcingAnti-Icing-Operations.aspx

[2] US FAA, "Advisory Circular: Ground Deicing and Anti-Icing Program, 2004, http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC120-60B.pdf

[3] US EPA, "Preliminary Data Summary Airport Deicing Operations (Revised), 2015, https://www.epa.gov/sites/production/files/2015-06/documents/airport-deicing-pds-2000.pdf

[4] Dallas Fort Worth International Airport, "Aircraft Deice Operations Plan 2018-2019 Winter Weather Season," https://www.dfwairport.com/cs/groups/webcontent/documents/webasset/p2_626762.pdf

[5] Charlotte-Douglas International Airport, "Airport De-icing Plan," 2015-2016,

[6] US FAA, "FAA Holdover Time Guidelines," https://www.faa.gov/other_visit/aviation_industry/airline_operators/airline_safety/media/FAA_2018-19_HoldoverTables.pdf

[7] SESAR, "SESAR solution ID #116 De-icing Management Tool,"https://www.sesarju.eu/sites/default/files/solutions/01_CN_Solution_116_De-icing_Management_Tool.pdf

[8] M. Hayashi *et al.,* "Evaluation of Pushback Decision-Support Tool Concept for Charlotte International Airport Ramp Operations," 11th USA/Europe Air Traffic Management Research and Development Seminar (ATM2015), Lisbon, Portugal, June 2015.

[9] Y. Jung *et al.*, "Field Evaluation of the Baseline Integrated Arrival, Departure, Surface Capabilities at Charlotte Douglas International Airport," 13th USA/Europe Air Traffic Management Research and Development Seminar (ATM2019), Vienna, Austria, June 2019 (unpublished).

[10] Bruce Wilson *et al*., "Improving Runway Queue Management: Modifying SDSS To Accommodate Deicing," IEEE Integrated communications navigation and surveillance conference proceedings, Herndon, VA, USA, pp 16-1 – 16-12, 2011.

[11] Y. Eun *et al.*, "Airport Surface Traffic Scheduling with Consideration of De-Icing Operations," 31st Congress of the International Council of the Aeronautical Sciences, Belo Horizonte, Brazil, September 9-14, 2018.

[12] Incheon International Airport Corporation, "A-CDM Operational Manual," https://www.airport.kr/co_file/ko/file06/A-CDM_Operation_Manual_ENG.pdf.

[13] Y. Eun et al., "Operational Characteristics Identification and Simulation Model Validation for Incheon International Airport," 16th AIAA Aviation Technology, Integration and Operations Conference, Washington, DC, June 2016.

[14] ICAO Aerodrome Reference Code, https://www.skybrary.aero/index.php/ICAO_Aerodrome_Reference_Code

[15] R. D. Windhorst *et al*., "Validation of Simulations of Airport Surface Traffic with the Surface Operations Simulator and Scheduler," AIAA Aviation Technology, Integration and Operations Conference, Los Angeles, CA, August 12-14, 2013.