AIRPORT SURFACE TRAFFIC SCHEDULING WITH CONSIDERATION OF DE-CING OPERATIONS

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Abstract

In this paper, airport departure scheduling problem in the situation of aircraft de-icing operations required was studied. Estimated de-icing time of each aircraft and de-icing pad assignment for remote pads de-icing operation were integrated into the runway scheduling problem for calculation of Target Take-Off Time (TTOT). The entire departure scheduling problem which includes runway scheduling and de-icing operation scheduling was formulated as Mixed Integer Linear Programming (MILP). The suggested MILP model was tested using the actual operation data of de-icing days in Incheon International Airport. The test results show that the departure scheduling using suggested MILP-model is efficient to reduce summation of taxi-out times including de-icing times of departure aircraft, and the time aircraft takes to takeoff after de-icing, which should not excess the holdover time for de-icing/anti-icing fluid.

1 Introduction

In winter snow weather conditions, aircraft must be inspected for de-icing services before takeoff. For an aircraft deemed necessary for de-icing, the de-icing service is carried out with all passengers boarded and ready for departure. Depending on the airport, the de-icing service may be provided at the remote de-icing pad after the aircraft pushed back and moved to a specific location, or at the stand after aircraft's off-block but before engine startup, or inside ramp area not moving out to the taxiways[1]. In any case, the de-icing service delays the departure of the aircraft and increases the complexity of airport surface traffic and the controllers' workload. Also, since the deiced aircraft is given a restriction condition to takeoff within a certain time according to the holdover time limit[2], de-icing operation should be considered in the airport surface movement scheduling of Departure Manager (DMAN), where Target Take-Off Time (TTOT) and Target Startup Approval Time (TSAT) of aircraft are determined.

In this study, airport surface movement scheduling with consideration of de-icing services at remote de-icing pads was studied for tactical and/or strategic scheduling capabilities of airport surface traffic management at Incheon International Airport (IATA code: ICN) in South Korea. The runway scheduling problem of previous study [3] was improved by integrating assignment problem of de-icing pad to aircraft. Estimated de-icing time and taxi-out time increase due to visiting de-icing pad were also incorporated to deal with the departure scheduling in a situation where de-icing and non-de-icing departure aircraft are mixed.

This paper is organized as follows. Aircraft surface movement procedure from gate to runway including de-icing operation in ICN is described in Section 2. A MILP-based optimization model for departures scheduling is presented in Section 3, and the test results of the suggested model are discussed in Section 4. The concluding remarks and future plan are briefly given in Section 5.

2 Aircraft De-icing Operations at ICN

2.1 Airport-CDM of ICN

ICN has started to implement Airport Collaborative Decision Making (A-CDM) to support comprehensive decision making based on accurate forecasting and sharing important milestones with all stakeholders in airport operation. The implementation of A-CDM in ICN is divided into 3 phases. Phase 1 started from Dec. 2017 and aims to share basic time information with partners via electronic systems and stabilize the system operation. Phase 2 is planned to be implemented through 2020-2024. Provision of enhanced TTOT/TSAT, and enlargement of the A-CDM scope to cover de-icing operation are planned to be the main improvement during Phase 2. The goal of Phase 3 will be materialized after Phase 2, but for now, it aims to improve overall automation performance mainly based on artificial intelligence [4]. In current phase, Phase 1, Korea Aerospace Research Institute (KARI) has developed and been testing DMAN prototype, which can calculate and suggest enhanced TTOT/TSAT to the ramp/tower controllers, and the scheduling functionalities of the DMAN prototype will be improved to cover de-icing operations.

2.2 ICN Airport Configuration

In this study, de-icing is defined as removal of frost, ice or snow piled up or formed on aircraft surface for the purpose of the safety of a departure flight. In ICN, de-icing is performed at a designated place equipped with de-icing equipment [4]. Fig. 1 depicts airport surface configuration of ICN in 2017. Currently, there is a new passenger terminal, which opened and has been in operation since Jan. 2018. Because of this new terminal, the passenger terminal ramp area was expanded and a new de-icing zone was added in the middle of the passenger terminal area. Since the actual operation data which were used in this study are the data of the winter season in 2015-2016, the surface configuration model in Fig. 1 was used in modeling of aircraft surface movement. The expanded ramp area and the additional deicing zone have basically same types with the original ones, so the surface movement modeling suggested in this study can be easily expanded to cover them. More detail description of ICN airport configuration is presented in [3], while only those that are related to de-icing operation are dealt with in this paper. As shown in Fig. 1, there are 6 de-icing zones located close to each runway line-up area. This configuration is useful in de-frosting operation days, when relatively very small number of aircraft require de-frosting and time duration for the de-frosting is also very shorter than time duration of de-icing. However, during deicing operation days when many aircraft request de-icing at the same time, it is highly unlikely that all departure aircraft will be able to get de-icing at the de-icing zone located next to the departure runway. This is because the deicing zone is not wide enough to accommodate many aircraft and deicing equipment at the same time. Since taxi-out time varies greatly depending on the relative positions among the aircraft gate/stand, assigned de-icing zone, and the runway, the assignment of the de-icing zone is also an important decision for smooth traffic on the airport surface.

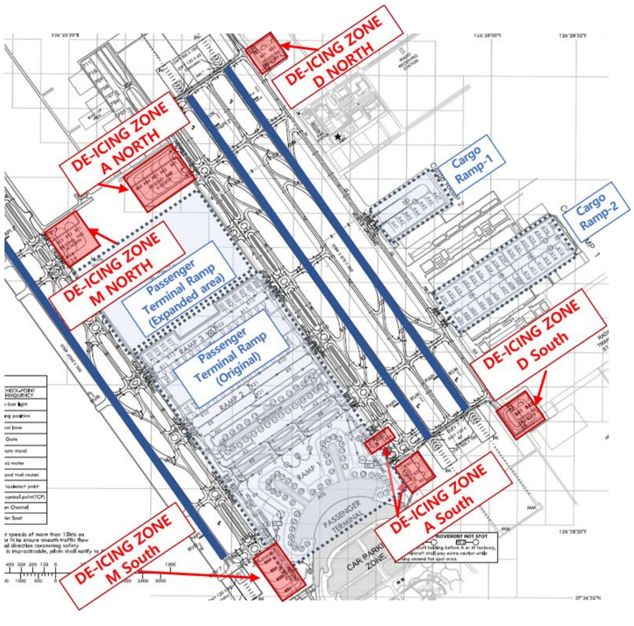

Fig. 1 Airport Surface Configuration of ICN

2.3 Current Procedure for De-icing Operation in ICN

Each de-icing zone has multiple de-icing pads as shown in Fig. 2. Therefore, in the de-icing operation procedure of ICN shown in Fig. 3, a departure aircraft requiring de-icing service is assigned to one of the six de-icing zones by the De-icing Position (DP, a sub-part of ramp control positions) first. After push-back, as the aircraft approaches to the de-icing zone and pilot requests for entering the zone, Pad Control (also a sub-part of ramp control positions) assigns de-icing pad inside the zone.

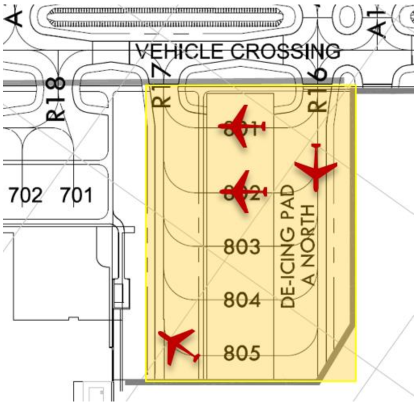

Fig. 2 De-icing Pads inside of De-icing Zone A North

Including assignment of a de-icing zone and pad, decision of off-block time of aircraft and the deicing zone entrance sequences are all determined by the ramp controllers manually. As the limited support of Phase 1 A-CDM system for de-icing operation, estimated de-icing pad-in time and pad-out time are automatically generated and provided to the controllers only after a de-icing zone is assigned and push-back is approved.

In current procedures of ICN, The DP assigns de-icing zones to the aircraft in the order that the aircraft requested de-icing and push-backed. If the number of aircraft requiring de-icing is large, the aircraft will create a queue at the de-icing zone entrance, since there is no other holding area. This de-icing zone entrance queue causes congestion in ramp areas, especially around some de-icing zones, such as Zone-A-South or Zone-M-South, where the aircraft in the de-icing queue might even block push-backs of other aircraft from the gates. In addition, the Air Traffic Control (ATC) clearance of de-icing aircraft is issued during de-icing, whereas the aircraft de-icing sequence is determined when the pilot requests push-back, a lot earlier than ATC clearance, and the de-icing sequence is determined without considering Traffic Management Initiative (TMI) restrictions. Therefore, the aircraft which finished de-icing may not be able to exit the de-icing zone and should wait ATC clearance delayed due to TMI restrictions.

Especially, due to the close proximity of ICN to the adjoining FIR border, a lot of Minimum Departure Interval (MDI) restrictions are imposed continuously, and the separation values of MDI restrictions may change several times a day[3]. ATC clearance delivery and determination of the takeoff sequence with consideration of de-icing aircraft are also big burdens to the ATC controllers. Moreover, the time from de-icing end to takeoff must be within the holdover time limit decided by the deicing/anti-icing fluid types. Otherwise, the aircraft need to come back to redo the deicing service. In order to overcome these problems, we are trying to determine the de-icing sequence and take-off sequence reflecting TMIs, when the aircraft is still on the gate/stand.

There was another restriction for assignment of de-icing zones until the winter of 2016-2017. There are multiple ground handling service companies which provide de-icing services to the aircraft. These de-icing service companies have de-icing service contracts with airlines, and aircraft could get de-icing service only by the company that has contract with the airline of the aircraft. At the beginning of a winter season, the companies placed their de-icing facilities to the de-icing zones under the coordination of Incheon International Airport Corporation (IIAC), and each de-icing zone might be occupied by several companies but was mainly occupied by one of the major companies. This restriction caused a lot of inefficiencies so has been changed since the winter season of 2017-2018. Currently, all of the de-icing service companies share their de-icing facilities and fluid, and aircraft can get de-icing services at any of the de-icing zones. This change has increased the degree of freedom for de-icing pad assignment and increased the need for efficient assignment.

Using the scheduling model, which will be described in the next Section, the de-icing pad-in sequence and runway take-off sequence are determined simultaneously, and estimated times for de-icing pad in and out times are also determined with consideration of the holdover time limit.

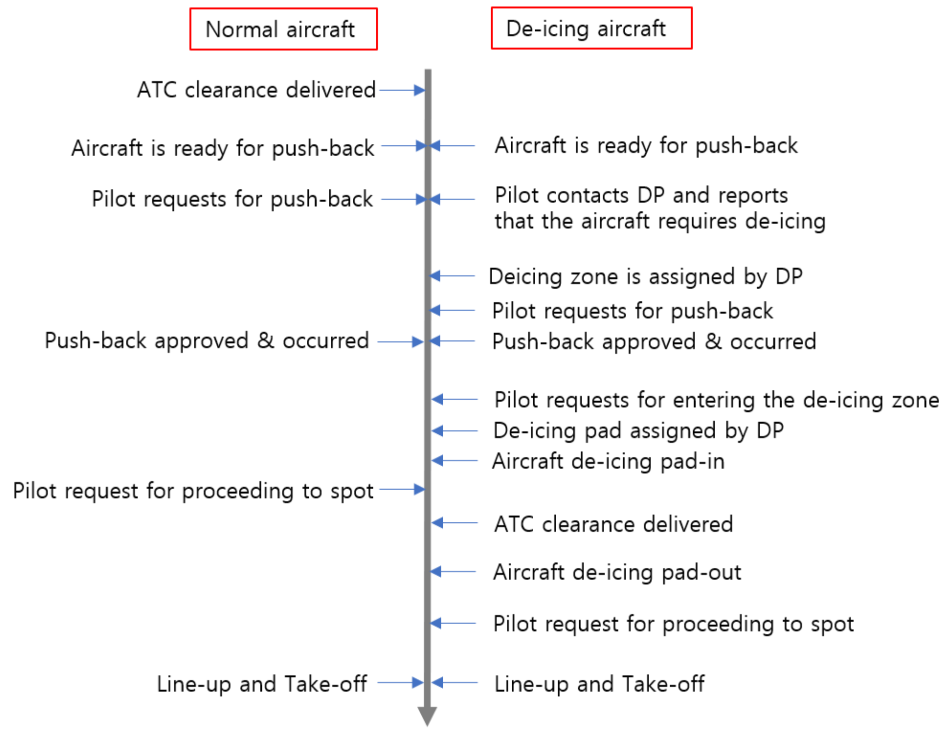

Fig. 3 Important Events during Surface Movement Procedure of Departure Aircraft

3 MILP-based Model for Departure Scheduling with De-icing Operations

In order to accommodate de-icing pad assignment and determination of de-icing pad-in sequence, new decision variables and constraints were integrated into the runway scheduling of the prior study[3]. Therefore, the MILP-based model for runway scheduling in a situation where de-icing and non-de-icing departure aircraft are mixed was formulated as Equations (1)-(15), where Dep denotes the set of departure aircraft. Dep_{ICE} is a subset of Dep and denotes set of departures requiring de-icing services, and Pad denotes the set of de-icing pads. The new decision variables for integration of de-icing operations are the de-icing pad-in time of aircraft i ($\forall i \in Dep_{ICE}$), t_i^P, and de-icing pad assignment variable, b_i^k of pad-k ($k \in Pad$). The de-icing pad assignment variable b_i^k is a binary variable, which will be 1 if aircraft–i is assigned to pad-k, otherwise 0, and should satisfy Equations (3) and (4).

$$\text{minimize} \sum_{i \in Dep} t_i^R - \text{EarliestTTOT}_i \tag{1}$$

$$\text{subject to} \quad t_i^P \geq \text{TOBT}_i + \sum_{k \in Pad} b_i^k \cdot \text{VTT}_i^{G \to k}, \quad \forall i, j \in Dep_{ICE}, \quad i \neq j \tag{2}$$

$$\sum_{k \in Pad} b_i^k = 1, \quad \forall i \in Dep_{ICE} \tag{3}$$

$$b_i^k = \{0, 1\}, \quad \forall i \in Dep_{ICE} \tag{4}$$

$$t_j^P \geq t_i^P + \mathrm{EDIT}_i\left(b_i^k + b_j^k - 1\right) - M\left(1 - z_{ij}^P\right), \ \forall i,j \in Dep_{ICE}, \ \ i \neq j, \forall k \in Pad \quad (5)$$

$$z_{ij}^P + z_{ji}^P = 1, \ \forall i,j \ \in Dep_{ICE}, \ \ i \neq j \quad (6)$$

$$z_{ij}^P = \{0,1\}, \ \ \forall i,j \ \in Dep_{ICE}, \ \ i \neq j \quad (7)$$

$$t_j^R \geq t_i^R + \mathrm{RwySep}_{i,j} - M\left(1 - z_{ij}^R\right), \ \forall i,j \ \in Dep, \ \ i \neq j \quad (8)$$

$$z_{ij}^R + z_{ji}^R = 1, \ \forall i,j \ \in Dep, \ \ i \neq j \quad (9)$$

$$z_{ij}^R = \{0,1\}, \ \forall i,j \ \in Dep, \ \ i \neq j \quad (10)$$

$$\mathrm{EarliestTTOT}_i \leq t_i^R \leq \mathrm{LatestTTOT}_i, \ \forall i \in Dep \quad (11)$$

$$\mathrm{EarliestTTOT}_i = \mathrm{TOBT}_i + \mathrm{VTT}_i^{G\rightarrow R}, \quad \forall i \in (Dep - Dep_{ICE}) \quad (12)$$

$$\mathrm{EarliestTTOT}_i = t_i^P + \mathrm{EDIT}_i + \textstyle\sum_{k \in Pad} b_i^k \cdot \mathrm{VTT}_i^{k\rightarrow R}, \ \forall i \in Dep_{ICE} \quad (13)$$

$$\mathrm{LatestTTOT}_i = \mathrm{EarliestTTOT}_i + \mathrm{MaxDelayT}, \quad \forall i \in (Dep - Dep_{ICE}) \quad (14)$$

$$\mathrm{LatestTTOT}_i = t_i^P + \mathrm{EDIT}_i + \mathrm{MaxHoldOverT}_i, \quad \forall i \in Dep_{ICE} \quad (15)$$

The cost function is summation of delayed time of take-offs, which is expressed as Equation (1), where $\mathrm{EarliestTTOT}_i$ is the earliest possible take-off time of aircraft-*i*. Equation (2) is the lower limit of de-icing pad-in time of aircraft-*i*, where $\mathrm{VTT}_i^{G\rightarrow k}$ denotes variable taxi time (VTT) from the gate to de-icing pad-*k* of aircraft-*i*. In Equation (5), EDIT_i is Estimated Deicing Time (EDIT) of aircraft-*i*, which is the time difference between de-icing pad-in and out time. In ICN, aircraft engine should be shutdown during de-icing, hence EDIT_i also includes the time duration for engine shutdown before de-icing and startup after de-icing. In (5), z_{ij}^P represents relative order of aircraft in the pad-in sequence regardless of pad assignment. Equation (5) is for time separation between t_i^P and t_j^P of aircraft-*i* and *j* which are assigned to the same de-icing pad. This constraint by Equation (5) has effectiveness only if b_i^k=b_j^k=1, by utilization of sufficiently large constant value, *M*. The other decision variables are TTOT of aircraft-*i*, t_i^R and the binary variable z_{ij}^R, which represents relative order of take-offs between aircraft-*i* and *j*. In Equation (8), $\mathrm{RwySep}_{i,j}$ is the required runway separation between aircraft-*i* and *j*, when aircraft-*i* take-offs before aircraft-*j*. $\mathrm{EarliestTTOT}_i$ and $\mathrm{LatestTTOT}_i$ denote the earliest possible take-off time and latest possible take-off time of aircraft-*i*, respectively. $\mathrm{EarliestTTOT}_i$ and $\mathrm{LatestTTOT}_i$ can be given differently as (12)-(15), depending on whether the aircraft-*i* requires de-icing or not. For the aircraft which does not require de-icing, $\mathrm{EarliestTTOT}_i$ is given as Equation (12), and $\mathrm{LatestTTOT}_i$, is summation of $\mathrm{EarliestTTOT}_i$ and the maximum delay time, MaxDelayT. On the other hand, for the aircraft requiring de-icing, $\mathrm{EarliestTTOT}_i$ is the earliest possible take-off time after de-icing and expressed as Equation (13). The $\mathrm{LatestTTOT}_i$ should be given as the estimated time of de-icing pad-out time and holdover time limit of de-icing aircraft-*i*, $\mathrm{MaxHoldOverT}_i$. For application of TMI restrictions, other constraints in [3] might be incorporated to Equations (1)-(15).

The suggested MILP-based model expressed as Equations (1)-(15) is also applicable to departure scheduling with on-stand deicing operations. In that case, the binary decision variable b_i^k is useful to express assignment of aircraft-*i* to de-icing resource-*k*, such as a de-icing car. EDIT_i of Equation (5) should be changed as $\mathrm{EDIT}_{i,j}$ in order to express that it is a dependent variable on the relative sequence of de-icing services to aircraft-*i* and *j*. Also it should include the required time for deicing resource-k to be prepared for de-icing service to aircraft-*j* after aircraft-*i*.

4 Scheduling Tests

The suggested MILP-based model for departure scheduling with de-icing operation is tested using a scenario which is generated based on the actual traffic data of Dec. 3, 2015. In order to simplify the scheduling problem, TMIs were not considered, and the test scenario was generated using the departures during single runway operation [3], therefore all departures in the test scenario should take-off through RWY 33L, which is located in the middle and heading to the north-direction in Fig. 1. EIDT_i of Equations (5) and (13) is assumed as Table 1, where the time durations were the averaged values of the de-icing aircraft in ICN during 2009-2012 [6]. In Table 2, aircraft class is the element 2 of the ICAO Aerodrome Reference Code[8], which is derived from the most restrictive of either the aircraft wingspan or the aircraft outer main gear wheel span.

Table 1. Time Durations in De-icing Pad (sec)

	Time Duration			
Aircraft Class	Engine Shutdown (A)	De-icing (B)	Engine Startup (C)	EIDT (A+B+C)
A	120	600	180	900
B	120	840	180	1140
C	180	1020	240	1440
D	180	1080	240	1500
E	240	1200	240	1680
F	240	3600	300	4140

RwySep_{ij} of Equation (8) is given as Table 2, and depends on the Wake Turbulence Category (WTC) of the two consecutive departing aircraft-*i* and *j*, where the four WTCs, L (Light), M (Medium), H (Heavy), and SH (Super Heavy), are used.

Table 2. Runway separation between departures (sec)

		Trailing aircraft			
		L	M	H	SH
Leading aircraft	L	120	120	120	120
	M	180	120	120	120
	H	180	180	120	120
	SH	180	180	120	120

There are total 21 de-icing pads in ICN. The de-icing pad (stand) numbers inside each de-icing zone are shown in Table 3[7]. The letters shown in 'Stand Availability' column is the same aircraft class of Table 1, the element 2 of ICAO Aerodrome Reference Code. Only 6 of the 21 de-icing pads are available for de-icing of F-class aircraft. The stand availabilities depending on the aircraft classes were also considered in the the test, using the assignment variable b_i^k of the MILP-based model in Section 3.

Table 3. De-icing Zones and Pads of ICN

Deicing Zone	Pad (Stand) Number	Stand Availability
A North	801	A - F
	802, 803 804, 805	A - E
M North	811, 812	A - E
	813	A - F
D North	851	A - E
	852	A - F
A South	821 - 823	A - E
	824, 825	A - F
M South	831	A - F
	832 - 834	A - E
D South	841	A - E
	842	A - F

As optimization results, pad assignment and occupancy time of each aircraft are shown in Fig. 4. Since the operational data used in the test were obtained before Incheon International

Airport introduced the A-CDM, TOBT was not given, and Scheduled Off-Block Time (SOBT) was used instead of TOBT. The result of Fig. 4 shows that most aircraft were assigned to Zone-A-South which is closest zone to the departure runway, RWY 33L. Aircraft 'DEP016' assigned to Zone-D-South is a freighter and Zone-D-South is close enough from the cargo ramp area. Using the suggested MILP-based model in Section 2, since de-icing sequence and take-off sequence are determined simultaneously and de-icing pad-in times are also given as scheduling results, appropriate TSAT of each aircraft can be easily determined based on the de-icing sequence and the estimated taxi-out time from the gate to the de-icing zones.

For comparison with the optimization results shown in Fig. 4, Fig. 5 shows the scheduling results obtained by using actual operation data. Same MILP-based scheduling model as Equations (1)-(15) was used for the scheduling results shown in Fig. 5, however, pad assignment was assumed as same as the actual operation data, and Actual Off-Block Time of actual operation data was used as TOBT of Equation (12). $MaxHoldOverT_i$ of Equation (14) was given as 15 minutes in the optimization of Fig. 4, while it was assumed as 2 hours in scheduling with actual pad assignment of Fig. 5.

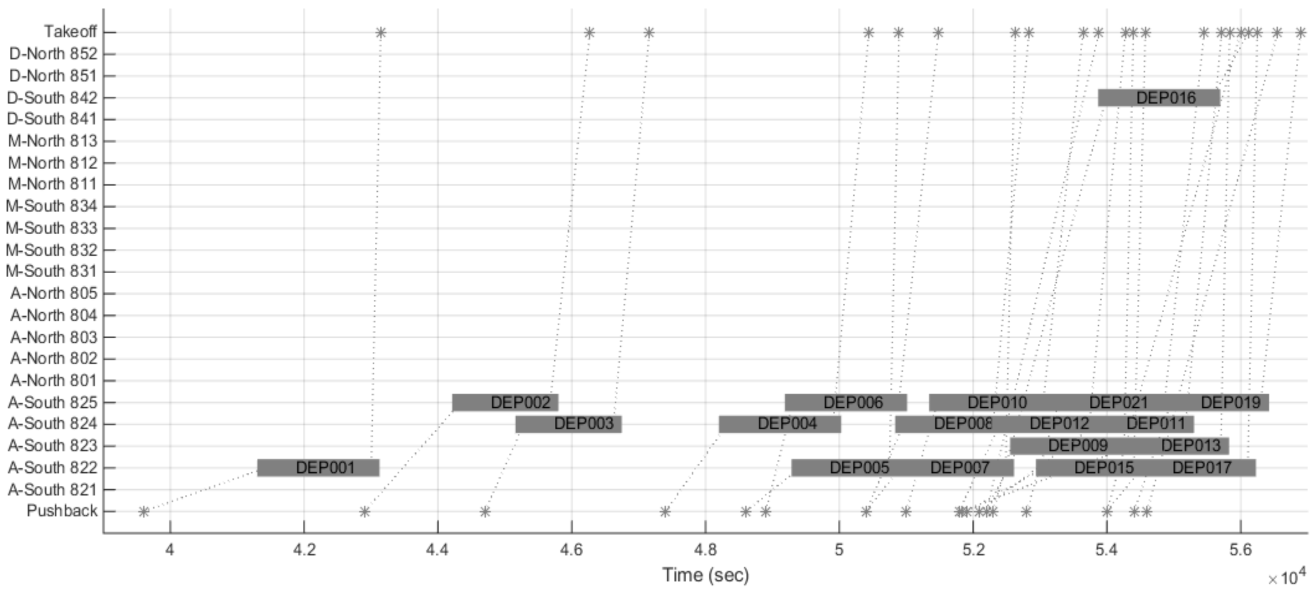

Fig. 4. De-icing Pad Assignment and Occupancy Times of each Aircraft (Optimization Result)

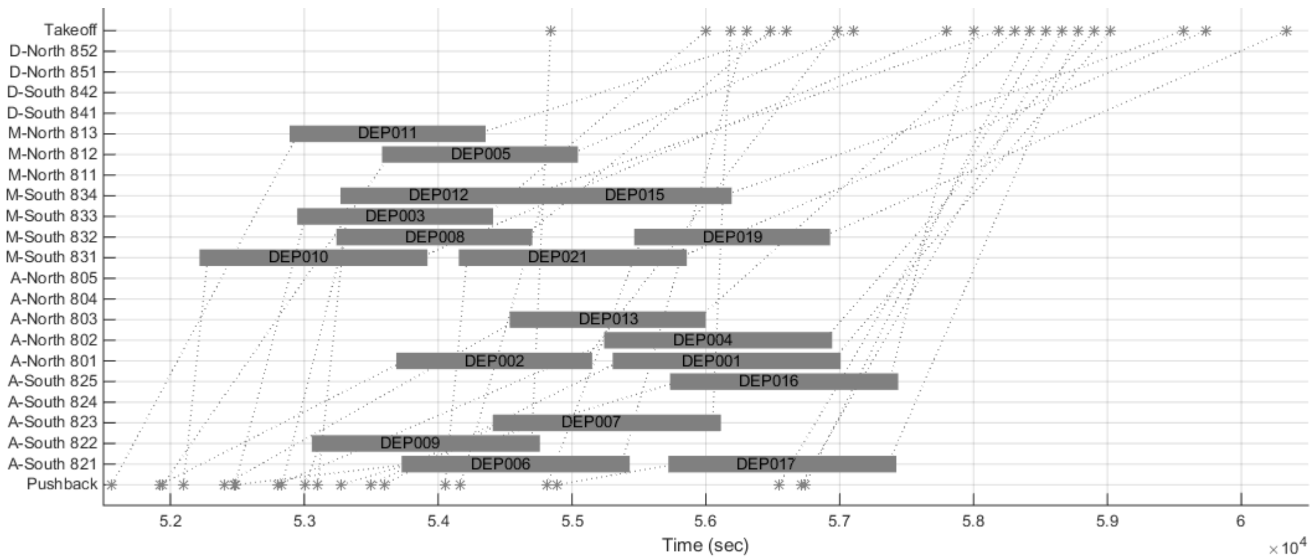

Fig. 5 De-icing Pad Assignment and Occupancy Times of each Aircraft (Actual Assignment Result)

Except the pad assignment, $TOBT_i$, $MaxHoldoverT_i$, and rest of the MILP-model in Equations (1)-(15) were same in the scheduling results shown in Fig. 4 and 5. De-icing pad-in time, t_i^P and $TTOT_i$ are different from the actual operation data. In this way, the various effects of other considerations which should have been taken into account in actual operations were eliminated, and the effect of changes of de-icing pad assignment can be inspected by comparing with Fig. 4. When comparing the pad occupancy times, please note that the x-axis range in Fig. 5. is almost twice as large as the x-axis of Fig. 4. Fig. 5 shows that many aircraft were assigned to several pads far from the departure runway, RWY33L, in actual operation. This is due to the fact that the aircraft had to be assigned by de-icing service contract as mentioned in Section 2. As a result, the aircraft that were assigned to the de-icing zone far from the departure runway took longer time to take-off after exit from the de-icing pad. The estimated time duration for each aircraft to takeoff after exit from de-icing pad is shown in Fig. 6, and the total taxi-out time from gate/stand to runway of each aircraft including EDIT is shown in Fig. 7. In both figures, it is shown that pad-assignment by optimization using the suggested MILP-based model has better taxi-out time performance.

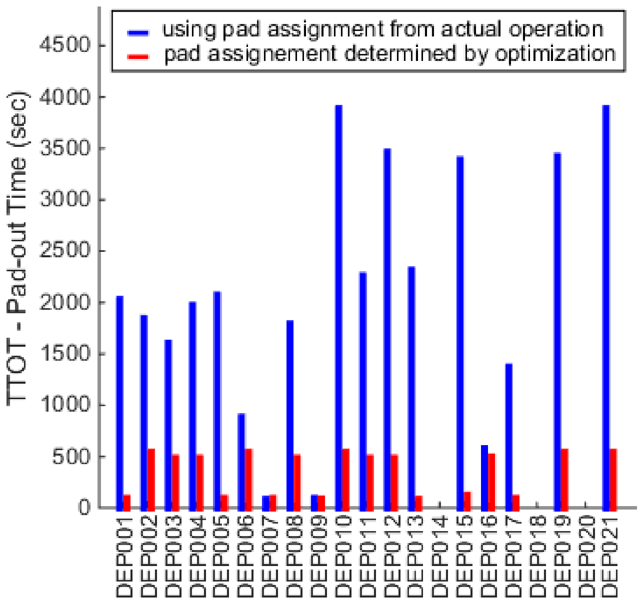

Fig. 6 Expected Time Spent to Take-off after Pad-out

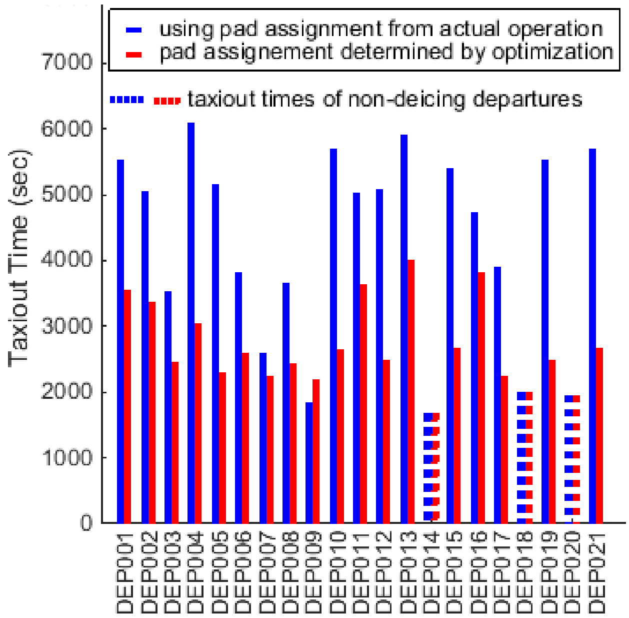

Fig. 7 Expected Taxi-out Time Comparison

5 Conclusion

For the departure scheduling accommodating de-icing operations, a new MILP-based optimization model was studied. As new decision variables, de-icing pad assignment variable and de-icing pad-in time have been added to the runway scheduling model of prior study [3] and new constraints for determination of de-icing sequence were also incorporated. Using the suggested model, de-icing pad-in sequence and take-off sequence can be determined simultaneously under the same constraints. With reference to the de-icing assignment and pad-in sequence, the ramp controllers can easily estimate the appropriate time for pushback of each aircraft, in order to avoid traffic congestions due to de-icing queue in ramp area. On the other hand, the take-off sequence determined under the same conditions with de-icing pad-in sequence, is expected to be useful for issuance of ATC clearance to the departures with TMI restrictions.

As future works, the suggested model will be expanded to cover the new stand/gate of Terminal 2 and the new de-icing zone of ICN, and also will be continuously validated using recent operational data. This work is preliminary study for Phase 2 implementation of A-CDM in ICN. Since the optimization with MILP-based model may require large computation time, a new heuristic algorithm for de-icing pad assignment and determination of de-icing pad-in sequence with take-off sequence will also be studied for practical implementation in ICN based on this study.

Acknowledgement

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