Extended Abstract:

Operational Characteristics Identification and Simulation Model Verification for Incheon International Airport

Yeonju Eun[1], Daekeun Jeon[2]
Korea Aerospace Research Institute, Daejeon, South Korea

Hanbong Lee[3]
University of California, Santa Cruz, NASA Ames Research Center, Moffett Field, CA, 94035, U.S.A

Zhifan Zhu[4]
Stinger Ghaffarian Technologies Inc., NASA Ames Research Center, Moffett Field, CA, 94035, U.S.A

Yoon C. Jung[5]
NASA Ames Research Center, Moffett Field, CA, 94035, U.S.A

and

Myeongsook Jeong[6], Hyounkyong Kim[7], Eunmi Oh[8], Sungkwon Hong[9], and Junwon Lee[10]
Korea Aerospace Research Institute, Daejeon, South Korea

I. Introduction

Incheon International Airport (ICN) is one of the hub airports in East Asia. Airport operations at ICN have been growing more than 5% per year in the past five years. According to the current airport expansion plan, a new passenger terminal will be added and the current cargo ramp will be expanded in 2018. This expansion project will bring 77 new stands without adding a new runway to the airport. Due to such continuous growth in airport operations and future expansion of the ramps, it will be highly likely that airport surface traffic will experience more congestion, and therefore, suffer from efficiency degradation.

There is a growing awareness in aviation research community of need for strategic and tactical surface scheduling capabilities for efficient airport surface operations. Specific to ICN airport operations, a need for A-CDM (Airport - Collaborative Decision Making[6]) or S-CDM(Surface - Collaborative Decision Making[7]), and controller decision support tools for efficient air traffic management has arisen since several years ago. In the United States, there has been independent research efforts made by academia, industry, and government research organizations to enhance efficiency and predictability of surface operations at busy airports.[8-10] Among these research activities, the Spot and Runway Departure Advisor (SARDA) developed and tested by National Aeronautics and Space Administration (NASA) is a decision support tool to provide tactical advisories to the controllers for efficient surface operations. The effectiveness of SARDA concept, was successfully verified through the human-in-the-loop

[1,7] Senior Researcher, CNS/ATM Team, Korea Aerospace Research Institute, 169-84 Gwahak-ro, Yuseong-gu, Daejeon 305-806, South Korea.
[2] Principal Researcher, CNS/ATM Team, Korea Aerospace Research Institute, 169-84 Gwahak-ro, Yuseong-gu, Daejeon 305-806, South Korea.
[3] Assistant Research Scientist, UARC, Mail Stop 210-8, Moffett Field, CA 94035, hanbong.lee@nasa.gov.
[4] Senior Software Engineer, Stinger Ghaffarian Technologies, Mail stop 210-8 Bldg N210, P O Box 1, Moffett Field, CA 94035-0001.
[5] Aerospace Engineer, Aerospace High-Density Operations Research Branch, Mail Stop 20-6, NASA Ames Research Center, Moffett Field, CA 94035, AIAA Senior Member.
[6, 8-10] Researcher, CNS/ATM Team, Korea Aerospace Research Institute, 169-84 Gwahak-ro, Yuseong-gu, Daejeon 305-806, South Korea.

(HITL) simulations for both spot release and runway operations advisories for ATC Tower controllers of Dallas/Fort Worth International Airport (DFW) in 2010 and 2012[2], and gate pushback advisories for the ramp controller of Charlotte/Douglas International Airport (CLT) in 2014.[3] The SARDA concept for tactical surface scheduling is further enhanced and is being integrated into NASA's Airspace Technology Demonstration – 2 (ATD-2) project for technology demonstration of Integrated Arrival/Departure/Surface (ADS) operations at CLT.[11]

This study is a part of the international research collaboration between KAIA (Korea Agency for Infrastructure Technology Advancement)/KARI (Korea Aerospace Research Institute) and NASA, which is being conducted to validate the effectiveness of SARDA concept as a controller decision support tool for departure and surface management of ICN.

This paper presents the preliminary results of the collaboration effort. It includes investigation of the operational environment of ICN, data analysis for identification of the operational characteristics of the airport, construction and verification of airport simulation model using Surface Operations Simulator and Scheduler (SOSS), NASA's fast-time simulation tool.[5]

II. General Information about ICN

The airport configuration of ICN is shown in Figure 1. There are three parallel runways. Runway 15L/33R and 15R/33L are two parallel runways with the distance of 400m between them. 15L/33R is used primarily for arrivals and 15R/33L is primarily for departures. Runway 16/34 is used for both departures and arrivals, and the usage is changed several times a day depending on the departure and arrival traffic demands. All cargo flights take off and land using the runways 15L/33R and 15R/33L, exclusively, not using 16/34. On the other hand, the passenger flights can use all three runways.

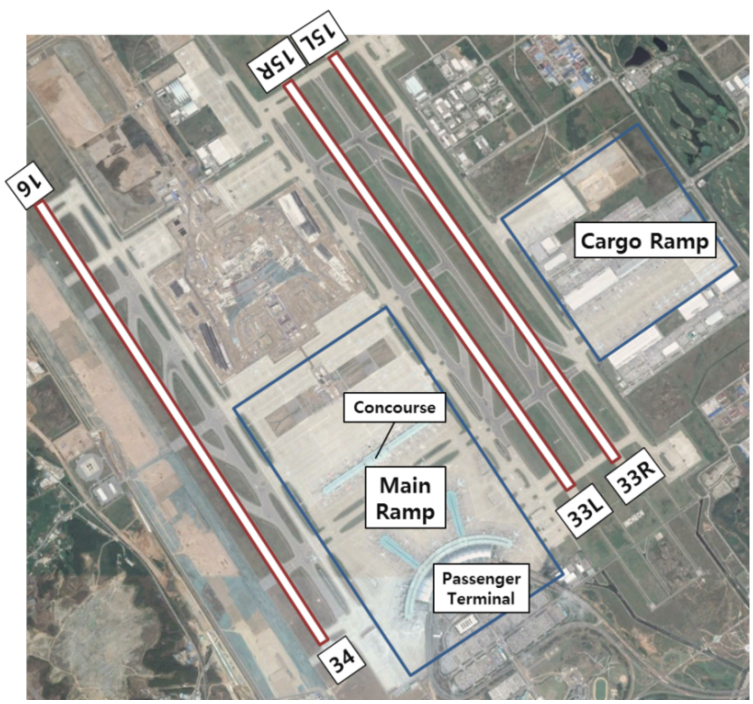

Figure 1. Airport configuration of ICN

The control authorities and the control towers for the movement areas (i.e., taxiways and runway) and the ramp areas (both main and cargo ramp) of ICN are completely separated. The startup and pushback clearances and taxiing guidance services for all aircraft in the ramp areas are provided by the airport authority (i.e., Incheon International Airport Corporation).

ICN is located in the north-east side of Incheon Flight Information Region (FIR), which is bordered by Shanghai FIR of China on its west side, Fukuoka FIR of Japan on its south-east side and Pyongyang FIR of North Korea on its north side, as shown in the Figure 2. Available airspace on north of the airport is very limited due to the flight prohibited areas on the border of North Korea, as well as in-bound and out-bound traffic from/to Pyeongyang FIR are prohibited. The distance to the border of Shanghai FIR is just about 120nm, therefore the Traffic Management Initiatives (TMIs) from Shanghai FIR is a major constraint for scheduling of the departure flights entering into Shanghai FIR from ICN. In the Seoul Terminal Maneuvering Area (TMA), which ICN is located in, another major airport of Korea, Gimpo International Airport (GMP) exists. The route Y71/Y72 in Figure 2, which should be shared between ICN and GMP for the south-bound traffic to Jeju TMA, is the second busiest air route in the world in terms of the movements* and also used by the flights to South-Asia and Oceania (i.e., a region centered on the islands of the tropical Pacific Ocean) from ICN.

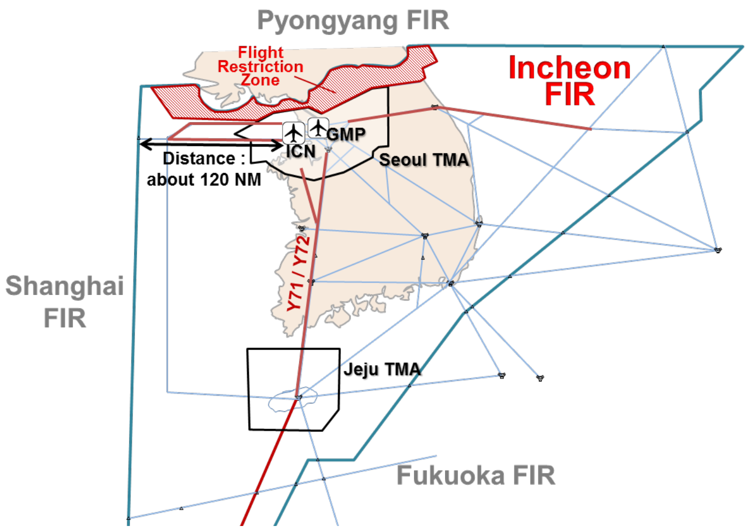

Figure 2. Operational environment of ICN

The total number of departure and arrival flights of ICN was 290,043 in 2014. Since the beginning of airport operations in March 2001, the traffic has continuously increased except for the years of 2007-2008 and 2008-2009 due to global economic crisis in 2008. Especially, the annual increase rate has been higher than 5% for the last five years as shown in Figure 3. If the increase rate of 5% per year continues, the traffic volume is expected to be double by 2030. ICN has an expansion plan of a total of 5 phases, and currently, expansion phase 3 is underway. The phase 3 expansion plan includes construction of a new passenger terminal and cargo ramp expansion, which will result in 56 new stands for passenger flights (currently 109) and 21 new stands for cargo flights (currently 36). These new stands will be newly operable from 2018 (Data source: Incheon International Airport Corporation), although construction of a new runway is not included in this phase 3 expansion plan.

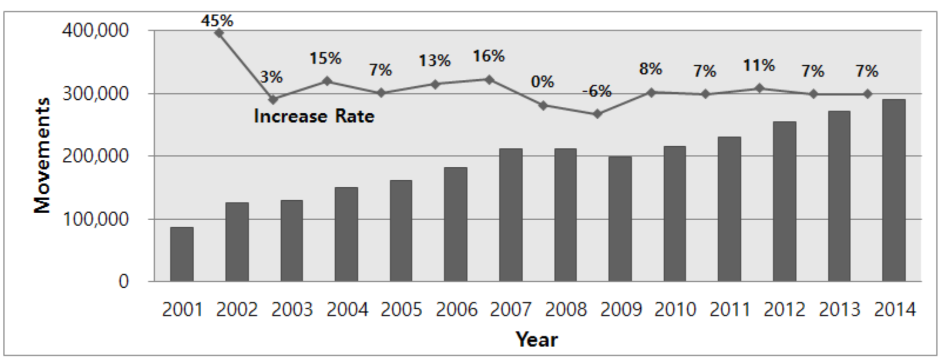

Figure 3. Traffic volume of ICN (Data source: Korea Civil Aviation Development Association)

III. ICN Flight Data Acquisition and Pre-processing

In order to verify the operational considerations and to identify the other characteristics of ICN, data analysis has been conducted. The data were collected for the departure and arrival flights during April 2015, which included Airport Surface Detection Equipment (ASDE) track data, flight plans, operational data from Flight Operations

* source: https://en.wikipedia.org/ wiki/World%27s_busiest_passenger_air_routes#By_aircraft_movements

Information System (FOIS)[12] and Flight Information Management System (FIMS)[13]. The FOIS and FIMS are dedicated systems used for air traffic management in Korea. The FOIS is used for arrival and departure time management for the flights through all of the airports in Korea. FIMS is an information management system for the departure and arrival flights through ICN. It provides the controllers with the information, which includes the given input data from FOIS and the other available data for ICN operations.

The data items of ASDE track data, flight plans, FOIS and FIMS outputs are described in Table 1. Flight data from each data source includes specific data items which are for identification of each individual flight. Using those data items, the flight data have been reconstructed by matching the flight plans and FOIS/FIMS data with the valid ASDE tracks.

Table 1. Flight Data Sources and Data Items

Data Source	ASDE	ARTS-FDP	FOIS	FIMS
Data Items	• Callsign (ICAO) • SSR Code • Tail No. • Ground Track (X,Y) • Etc.	• Callsign (ICAO) • SSR Code • Destination/Origin • Departure time • Routes • Etc.	• Callsign (ICAO) • Tail Number • Destination/Origin • Aircraft Type • Stand (or Gate) • Assigned Runway • STA (Scheduled Time of Arrival) / STD (Scheduled Time of Departure) • ATA (Actual Time of Arrival) / ATD (Actual Time of Departure) • Etc.	• Callsign (IATA) • Tail Number • Destination/Origin • Aircraft Type • Stand (or Gate) • Assigned Runway • STA/STD • ATA/ATD • AOBT (Actual Off-Block Time) / AIBT (Actual In-Block Time) • Etc.

↓

Reconstructed Flight Data			
• Callsign • SSR Code • Tail No.	• Ground Track (X,Y) • Destination/Origin • Departure time	• Routes • Aircraft Type • Stand (or Gate) • Assigned Runway	• STA/STD • ATA/ATD • AOBT/AIBT

IV. Data Analysis Results

Data analysis of the actual flight data of April 2015 has been conducted for identification of characteristics of ICN surface traffic.

A. Surface Traffic Heat Map

First of all, airport surface heat maps were generated using summations of stop durations[1] during taxi-out phase of flight. These heat maps present direct indications of the locations and severities of the stops. In this heat map, the 'stop' is defined as a moment when the speed of aircraft is less than 1m/s during 'taxi-out'. The valid track data for 'taxi-out' is the track data from the moment when aircraft has moved faster than 3m/s of speed for the first time, after pushback from the stand or gate, and to the moment when aircraft entered into the line-up area for departure. The XY positions in the ASDE tracks are reliable measurements, but too noisy to calculate the speeds. Therefore, the ASDE tracks were smoothed using the Rauch-Tung-Striebel (RTS) smoother, and then stops were identified using the speeds, which were calculated based on the smoothed tracks. Figure 4 shows the comparison of an ASDE track and a resultant smoothed track. The 'interpolated XY' is just an intermediated result from the ASDE track to the smoothed track with a fixed interval of 1 sec.

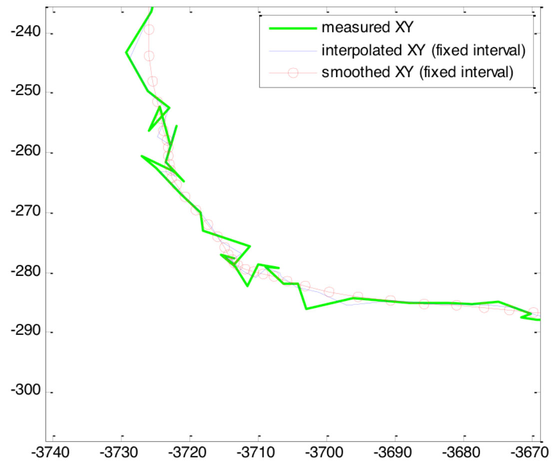

Figure 4. ASDE measured track and smoothed track

Figure 5 and 6 are the heat maps for north and south flows, respectively. The colors represent the intensity of cumulative seconds of stop durations, and the colors change in log scale in both figures. The tracks used in these figures are the valid track data of all departures from ICN in April 2015. The numbers of tracks used for drawing those heat maps are 7,252 for north flow, and 5,180 for south flow, respectively. These figures show that some stops occurred rather in the taxiways of the movement areas than in the ramps, and these stops also illustrate the departure queues of ICN.

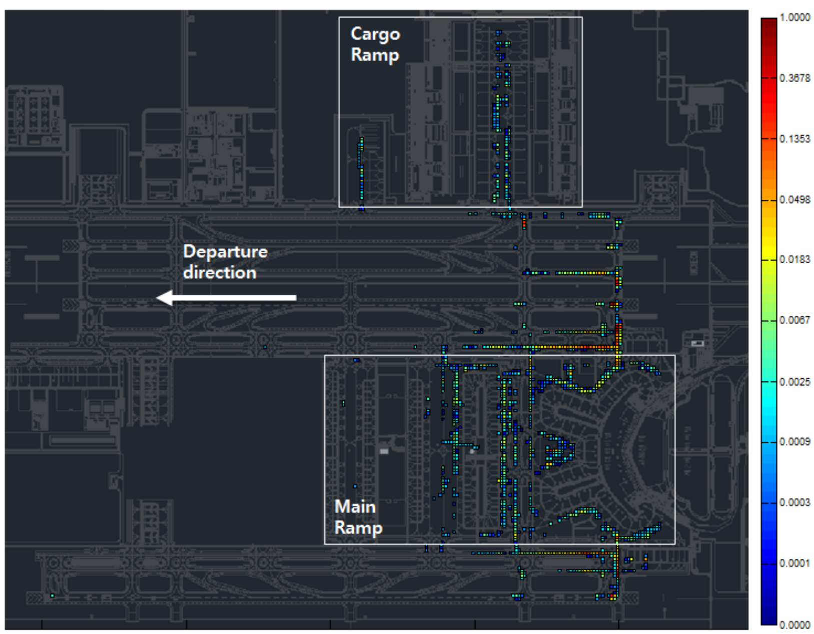

Figure 5. ICN Surface heat map for the stops during taxi-out of north flow departures (April 2015)

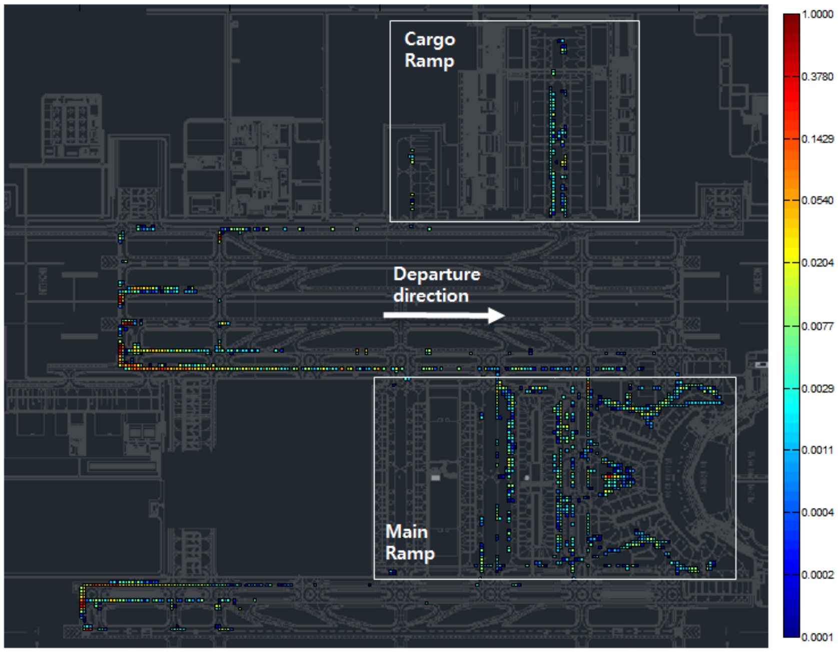

Figure 6. ICN Surface heat map for the stops during taxi-out of south flow departures (April 2015)

This heat map analysis can provide us with enhanced understandings for the characteristics of departure queues. For example, Figure 7 shows the heat map using stop durations of the flights, which departed during the time period, 22:30 – 23:00 on April 2nd, 2015. Multiple queue lanes for departure through runway 15L were identified. More comprehensive findings will be included in the final manuscript.

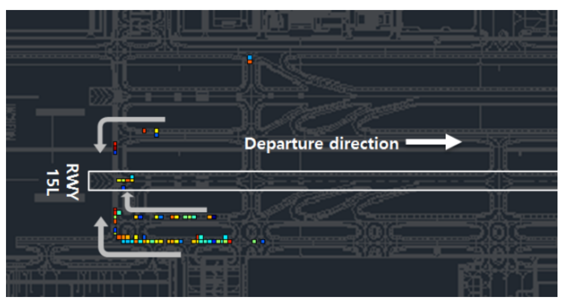

Figure 7. Multiple queue lanes for departure through RWY 15L

B. Runway Assignment Strategy

Departure route directions of the flights and fleet mixture in terms of wake turbulence categories were checked using the actual flight data of April 2015 in order to identify runway assignment strategies. Figure 8 shows the assigned runway mixture ratio of departure flights for each departure route direction during the time period when RWY 16/34 was used for departures, and it simply shows that the runway assignment of departure flights mainly depends on the departure route directions.

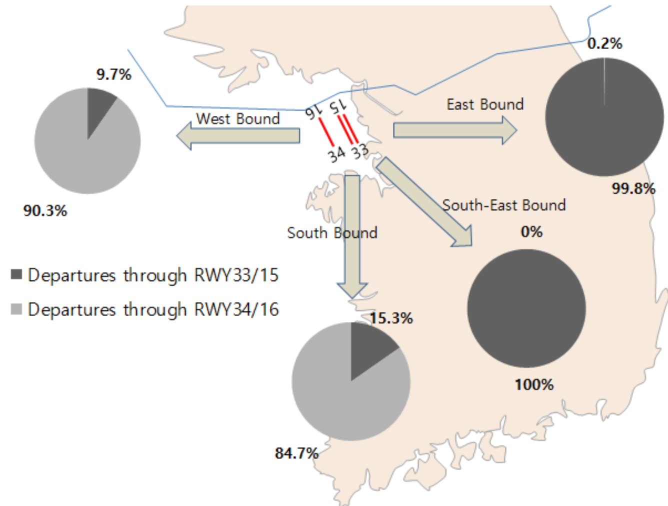

Figure 8. Assigned runway mixture ratio for each departure route direction

The fleet mixture ratio in terms of wake turbulence category at each runway is presented in Table2, and Table 3 shows the assigned runway ratio of each wake turbulence category. These ratios were calculated using the flight data of departures and arrivals during the time period when RWY 16/34 was used for departures and arrivals exclusively. The wake turbulence category mixture ratio of each runway in Table 2 does not show any significant distiction, suggesting a similar tendency with the total mixture ratio, while the runway assignment ratio of super heavy class jets (A380) in Table 3 has somewhat distinct characteristics. The number of stands for super heavy class jets are limited, and more than half are located on the east side of the terminal and concourse, closer to the RWY 33/15. Moreover, landing on RWY 15/33 involves crossing the departure runway (RWY 15R/33L) for the passenger flights, which is not preferred by both the controllers and airlines for such a big aircraft. Movement of super heavy class aircraft is one of the high priority considerations even for the controllers, and they assign the aircraft to the most convenient runway for taxi-out and taxi-in.

Table 2. Fleet mixture ratio in terms of a wake turbulence category

		Small	Medium	Heavy	Super Heavy	Sum
	Total	0%	47.0%	51.1%	1.9%	100%
Departure	RWY 15/33	0%	48.3%	49.4%	2.3%	100%
	RWY 16/34	0%	44.4%	54.4%	1.2%	100%
Arrival	RWY 15/33	0%	46.4%	52.1%	1.5%	100%
	RWY 16/34	0%	48.9%	47.7%	3.4%	100%

Table 3. Assigned runway mixture ratio of each wake turbulence category

		Small	Medium	Heavy	Super Heavy
Departure	RWY 15/33	0%	36.4%	35.8%	71.5%
	RWY 16/34	0%	63.6%	64.2%	28.5%
	Sum	0%	100%	100%	100%
Arrival	RWY 15/33	0%	44.5%	55.0%	35.3%
	RWY 16/34	0%	55.5%	45.0%	64.7%
	Sum	0%	100%	100%	100%

C. Runway Departure Throughputs

As last, airport departure throughput performance evaluation using departure rate saturation curves[4] was conducted to identity the capacity limit for the runways and movement areas, and to define traffic congestion level criteria for ICN. First of all, Figure 9 shows the variation of Airport Departure Rate (ADR) for a day, which are the averaged values of the flight data in April 2015. The departure rate is defined as the number of departure flights, of which wheels-off times were in a time interval of 15min. As was mentioned previously, usage of the RWY 16/34 changes several times in a day depending on the arrival and departure traffic demands. The time period with zero departure rates for RWY 16/34 in Figure 9 is the time when RWY 16/34 was used for arrivals only or closed. Figure 9 shows that the RWY 16/34 was used for departures when ADR was higher than normal, and during the time when RWY 16/34 was used for departures, the departure rate of RWY 16/34 was higher than RWY 15/33.

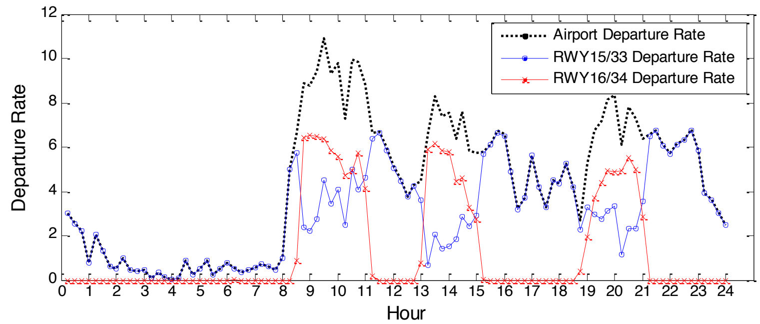

Figure 9. Departure rate variation

The airport-level departure and arrival throughput saturation curve is presented in Figure 10, where the numbers of aircraft taxiing-in and taxiing-out are defined as the numbers of aircraft inside of the movement areas (after passing a spot and before wheels-off for a departure, after wheels-on and before passing a spot for an arrival) during the same 15min intervals of the throughput. In ICN, since the departure rates of RWY 15/33 are affected by the rates of arrivals due to runway crossing by arrivals, combined departure rates and arrival rates were considered as the airport throughput. Two graphs in Figure 11 are the departure throughput saturation curves of RWY 15/33 and 16/34, respectively.

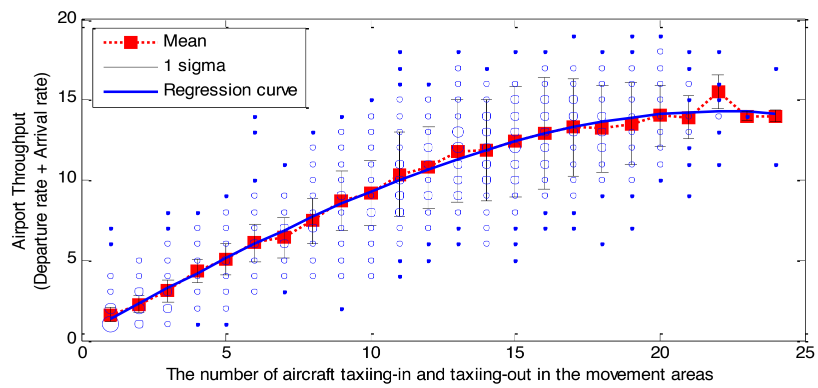

Figure 10 Airport throughput saturation curve

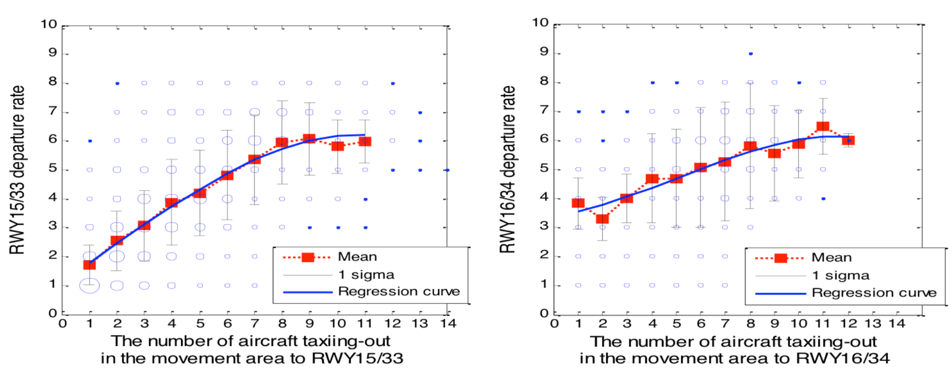

Figure 11. Departure throughput saturation curves for RWY 15/33 (left) and RWY16/34 (right)

V. Fast-time Simulation Model and Validation

SOSS is NASA's fast-time modeling tool for airport surface operations simulation. During simulation run, SOSS allows to receive scheduling outputs generated from an external scheduler algorithm that would drive the aircraft on the airport surface.[5] The objective of developing an ICN model (or SOSS ICN model) is to establish a surface traffic management environment and capability to help test and validate new and promising operation concepts. Once congestion conditions and their variables and constraints are identified, strategies and potential solutions will be developed and evaluated using the model in fast-time simulations before higher fidelity and complex human-in-the-loop studies are conducted. Both the fast-time and human-in-the-loop studies will use the same airport model configured and validated against the current day operation data and conditions.

Figure 12 shows a snapshot of ICN SOSS node-link graph of taxiways and runways. The taxi-in and taxi-out routes for the simulation had been initially built using the pushback guideline descriptions in Aeronautical Information Publications (AIP), and was updated with the actual routes identified from examining the ASDE track data of April 2015. The frequency of usage for each taxi route was checked and reflected to the taxi routes in SOSS, so that most frequently used routes were defined as the default taxi routes during the simulations.

Figure 12. Visualization of ICN node-link models in SOSS

The simulation scenarios are derived from the real flight data of April 2015 using a few selected time periods as discussed in the previous data analysis. As a result, the scenarios consist of a pair of high traffic and normal traffic situations for each runway configuration.

VI. Conclusion

In the final manuscript, detailed description of traffic scenarios used for SOSS simulations will be presented. Also, model tuning and verification will be conducted by comparison between real flight data and simulation results, in a similar way described in Ref. 5. Performance metrics such as taxi time, departure throughput, departure queue length, and averaged taxi speed will be used for comparison between real operational data and simulation results.

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