[EN-104] An Analysis of Surface Traffic of a Large Airport – Characteristics of Departure Aircraft Congestion –

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Abstract

Due to the growth of air traffic, some major airports in Japan may expect surface traffic congestion, which not only causes increases in taxiing time and consequent fuel consumption, but also affects the punctuality and reliability of flight scheduling. To cope with this issue, we have to develop some kind of decision support system or operational procedures to make airport operations smooth and punctual. The core technology of such systems and procedures is the prediction of surface movement times. With the aim of developing such a predicting function, we have tried an empirical analysis of surface traffic flow at Tokyo International (Haneda) Airport to extract the characteristics of congestion during taxiing, based on multilateration surveillance data. Focusing on departure traffic flow, we found some factors which determine and influence the surface movement time. In this paper, we describe the characteristics of other ground operation phases before reaching the queue. Finally, we describe the result of the preliminary modeling of surface operation times for departure, based on these characterizations, and discuss the capability for applying this modeling method to surface traffic management.

Keywords: trajectory management, airport surface traffic, surface trajectory, empirical study of traffic phenomena, variable taxi time calculation

1. Introduction

Due to the growth of air traffic, major airports in Japan, such as Tokyo International (Haneda) Airport, may expect the growth of surface traffic congestion, which not only causes increases in taxiing time and consequent fuel consumption, but also affects the punctuality and reliability of flight scheduling.

If we can capture the nature of the effect of surface congestion on taxiing time increases, we can obtain predictability, controllability and manageability about surface traffic situations prior to the execution of schedules. In Europe, for example, there have been some trials of Airport-CDM (Collaborative Decision Making) operations^[1], which are based on the estimation of taxiing times for each aircraft, predicted from each flight's primary schedule, and setting preferable schedules (mainly the schedule of blocked-off times for departure, and landing times for arrivals) by coordination between airport stakeholders.

The core technology of this kind of well-prepared operation is the predicting function of surface operation

time (called "Variable Taxi Time Calculation" in the European context). Thus, the scope of our research is to derive the characteristics of congestion from real operational data, in order to identify predictable and manageable congestion, and to derive some feasible scheme of predicting and managing the surface traffic situation.

This paper is organized into five chapters, to describe the characteristics and mechanisms of major congestion at the departure phase, from two points of view, empirical analysis and mathematical modeling. In the first chapter, we visualize surface congestion to highlight the major congested areas, that is, departure queues before the runway. The second chapter discusses the mechanism of how these observed queues are formed, and the relevance of modeling this queue with queueing theory. The third chapter describes the characteristics of time before reaching the queue. The fourth chapter describes the trial results of the model obtained from the discussion of the second and the third sections. In the fifth chapter, we discuss the validity of this model as a surface movement time predictor for departures, and feasible schemes of surface traffic management derived from this model.

2. Visualization of Surface Traffic Congestion

2.1 Calculation of Taxiing Time and Velocity Using Surveillance Data

As real operational data, we used the trial data of the multilateration surveillance system (MLAT) installed at Haneda Airport^[2]. MLAT receives radio pulses transmitted from an aircraft's mode-S transponder every second at a number of receiving stations, and calculates the position of the aircraft based on the difference in receiving latency among the stations. The mode-S pulses contain an ICAO 24 bit address, which can be used for the identification of the aircraft. Then we can extract individual tracks from the surveillance data.

The MLAT installed at Haneda Airport has an accuracy of within 7.5m at runways and taxiways, and 12m at aprons, which meets the specification of EUROCAE ED-117. Smoothing the position data, we can also get a speed profile for each track, as shown in Figure 1.



Figure 1: Track and speed profile of a departure operation obtained from smoothed MLAT data

2.2 Major Lines of Surface Traffic Flow

At Haneda Airport, two of the three runways are used simultaneously, one for departures and another for arrivals. There are three types of runway combinations, selected according to wind direction. The north wind operation, the major operation at Haneda, uses the C Runway for departures and the A Runway for arrivals (Some aircraft use the C Runway for arrivals when the runway is vacant). Figures 2 and 3 depict each major lines of surface traffic flow for the north wind operation. (we used the Google Earth image for the background)



Figure 2: Major lines of departure surface traffic flow during north wind operation



Figure 3: Major lines of arrival surface traffic flow during north wind operation

2.3 Major Congestion

Using MLAT track data, we visualized the congested areas by the following method;

- Segment the airport surface into cells with a size of 50m x 50m.
- 2. If the aircraft's speed within a cell falls below 10km/h, consider the aircraft in congestion at this cell, then count the elapsed time within this cell as congestion time.

However, the following movements are naturally slow, irrespective of the traffic situation, then do not count as congestion.

i. Departures: push-back, stop after push-back, 1

minute after start of taxiing, lining-up.

- ii. Arrivals: 1 minute before block-in.
- Sum up congestion time at each cell for all aircraft for 1 day of operation, considering departures and arrivals separately.
- Display each cell's congestion time by vertical bars on an airport chart, with each bar's horizontal position corresponding to the position of the cell.

Figure 4 shows the "congestion map" for departure surface traffic flow, obtained with this method, for a day with north wind operation throughout the day. Figure 5 shows the congestion map for the arrival surface traffic flow for the same day, with the same vertical scale as Figure 4.



Figure 4: Congested area and congestion time of departure traffic flow under north wind operation



Figure 5: Congested area and congestion time of arrival traffic flow under north wind operation

Since Figures 4 and 5 are displayed with the same vertical scale, it is clear that the major congestion occurs under departure traffic flows. In particular, the major congestion for departure flows occurs at the segment (called "waiting segment") from the points approximately 500m before the C4 crossing (called "merging points"), to the entrances of the runway.

Therefore, prior to any other kind of surface traffic congestion, we have to deal with the congestion at the waiting segment. Thus, in order to discuss the predictability or controllability of the departure traffic congestion at this segment, we have analyzed the departure operation as following;

- 1. Characterization of congestion in the waiting segment
- 2. Characterization of movement time before reaching the waiting segment

3. Analysis of Congestion in the Waiting Segment 3.1 Visualization of Dynamics of Congestion

In order to clarify the growth and decay dynamics of congestion at the waiting segment, we visualized a time series of the traffic situation with a concise diagram. As depicted in Figure 6, we represent each aircraft's movement time as one line, starting with block-off time and terminating with take-off time. And accumulating the lines upward according to take-off sequence, we visualized the operation of many aircrafts in a single diagram. Then, marking up the time of passing the merging points, this diagram highlights the growth and decay of congestion at the waiting segment.



Figure 6: Method to visualize the time series of traffic situations

Using this method we visualized the traffic situation in the periods when the congestion grows and subsequently decays, as shown in Figure 7. In this period of 27 minutes, 15 aircraft took-off.



Figure 7: Growth and decay of congestion at the waiting segment

As shown in Figure 7, when the runway is used densely, each take-off time on the diagram tends to lie in a straight line (called the "departure curve") with a constant gradient. The gradient of this line means the average of departure intervals (this "interval" does not directly mean the air traffic control minimum separation). On the other hand, the gradient of the line fitting the array of merging time (called the "merging curve"; not always straight) means the interval of time between merging.

3.2 Theoretical Modeling Using Queueing Theory

Comparing the gradients of the departure and merging curves in Figure 7, we can see the following trends;

- 1. When the merging interval is narrower than the departure interval, congestion continues growing.
- 2. When the merging interval is wider than the departure interval, congestion continues decaying.

These trends can be modeled mathematically as follows;

If the waiting segment is vacant, an aircraft will have an unimpeded taxiing time, T_{smooth} , from passing the merging point to take-off. On the other hand, if there are some aircraft forward at the waiting segment, the elapsed time after the merging point will depend on that of the preceding aircraft. If the merging interval between the preceding aircraft is narrower than the departure interval, the aircraft's elapsed time at the waiting segment will increase, compared to that of the preceding aircraft. Specifically, the added time is as much as the difference between the departure interval and the merging interval. If the merging interval between the preceding aircraft is wider than the departure interval, this difference acts likewise as a subtractive factor.

These arguments can be summarized in the following formula;

$$T(i) = max(T_{smooth}, T(i-1) + S_d(i) - S_m(i))$$
(1)
where,

i: the aircraft's number in the queue

 T_{smooth} : unimpeded taxiing time after passing the merging point

 $S_d(i)$: departure interval between the preceding aircraft

 $S_m(i)$: merging interval between the preceding aircraft

This formula corresponds to the general property of theoretical queues with one exit (GI/G/1 queue)^[3]. Thus, it is shown to be relevant to treat the congestion's growth and decay dynamics as queueing phenomena.

3.3 Impact of Changes in Departure Interval

Considering the congestion after the merging points as queueing phenomena, we can expect theoretically the tendency that, when the traffic demand is high, a small difference in the departure interval (corresponding to "service time" in the terminology of queueing theory) may greatly affect the elapsed time after passing the merging point.

Then, we introduced another example of congestion. Figure 8 depicts the congestion map of another north wind operation day (called "Case 2"; accordingly, calling the former case "Case 1"). The vertical scale is the same as Figure 4, so we can say that the congestion of the Case 2 day was much milder than that of the Case 1 day. And the difference in the distribution of the departure intervals between these two days is shown in Figure 9.



Figure 8: Congested area and congestion time of another north wind day (Case 2)



Figure 9: Difference in distribution of departure intervals between Case1 day and Case 2 day

From Figure 9, we can see that the departure interval of the Case 1 day was generally longer than that of the Case 2 day. Comparing these two distributions by medians (because there were quite a number of outliers, average is not relevant for representative value), Case 1 has a median of 109s, and Case 2 has a median of 98s.

The number of departures in the Case 2 day was 447, almost the same as for the Case 1 day, and we cannot find a significant difference in hourly block-off rates between the two days. Then, as for the relationship between traffic demand and service, the departure interval was the only different factor that may affect queue growth.

We still have to identify the cause of the difference in departure intervals between these two cases, but it is clear that the congestion time at the waiting segment was sensitive to the departure interval, as expected theoretically.

4. Analysis of Surface Movement Time before Reaching the Waiting Segment

4.1 Basic Components of Surface Movement Time

Surface movement time before reaching the waiting segment consists of three different phases, as follows;

- 1. Push-back: slow movement by a towing car, from the parking stand to the starting point of taxiing.
- 2. Stop after push-back: disconnection of the towing car.
- 3. Taxiing before merging: self-powered movement until passing the merging point.
 - As these phases have totally different dynamics, it is

relevant to analyze the characteristics separately.

4.2 Characteristics of Push-Back Time

In the track and speed profile diagram as shown in Figure 1, the push-back phase appears as a slow movement within the apron, followed by a long stop. Some tracks lack the initial rise of speed, and some tracks cannot be smoothed enough to identify the falling edge of speed. So, we only collected tracks with a distinct rising and falling edge of speed, and obtained 266 push-backs out of 443 departure tracks for the Case 1 day. The histogram of push-back time is shown in Figure 10.



Figure 10: Distribution of push-back time (266 tracks)

Push-back time may vary due to the push-back route (length depending on the location of the parking stand, and the route itself is often modified to vacate the entrance taxilane of the apron when congested), the weight of aircraft, or speed limitations of the towing car. But, as shown in Figure 10, the observed distribution has a sharp peak, with an average of 130.7s, and a standard deviation of 41.7s. 88.4% of the data was contained within ± 1 minute deviation from the average. Thus, requiring an accuracy of ± 1 minute, we can consider the push-back time as a constant, and select some statistical representative value like an average.

If we need more precise information, we need further analysis of the above-mentioned factors.

4.3 Characteristics of Stop Time after Push-Back

In the track and speed profile diagram, the stop after push-back appears as the first stop after push-back, with a duration of more than 1 minute. We collected tracks with distinct falling edges of push-back speed and rising readiness to taxi, latency to receive taxiing clearance in a crowded communication channel, and the blocking of

routes by other aircraft. But, as shown in Figure 11, the observed distribution has a sharp peak, with an average of 150.9s, and a standard deviation of 38.5s. 91.0% of the data was contained within ± 1 minute deviation from the average. Thus, requiring an accuracy of ± 1 minute, we can consider the stop time after push-back as a constant.

edges of taxiing speed, and obtained 377 stops out of the

443 departure tracks for the Case 1 day. The histogram of

stop time after push-back is shown in Figure 11.

average

-60s +60s

60

50

r of aircraft 30

number 20

10

0 L 0

tracks)

100

200

300

stop time after push-back [s]

Figure 11: Distribution of stop time after push-back (377

The stop time after push-back contains some complicated factors, such as the time required for

disconnecting the towing car, time for confirming

400

500

600

Since the stop after push-back is a complex process with many implicit factors, further analysis and precise modeling will be difficult.

4.4 Characteristics of Taxiing Time before Merging

Taxiing before the merging point appears as the track from the end point of the push-back to the merging point, and also appears in the speed profile as the segment from the rising edge after the stop after push-back, to the moment of passing the merging point. Since the major factor determining the taxiing time is the taxiing distance, we firstly examined the relationship between the taxiing distance and time. We collected the track with a distinct start of taxiing, and obtained 390 tracks out of 443 tracks from the Case 1 day. Then, we calculated the distance of taxiing by summing up every second's movement length on the smoothed track. The correlation diagram of taxiing distance and time is shown in Figure 12.



Figure 12: Correlation between taxiing distance and time (390 tracks)

From Figure 12, a plain dependence between taxiing distance and time was observed.

As well as taxiing distance, some other factors may influence the taxiing time. The route characteristics will be a major factor, such as the number of curves and length of straight segments. The traffic situation will be another major factor, such as taxiing in line with other departing aircraft before merging points, and the blocking of the taxiway intersection by other aircraft.

In Figure 12, operation influenced largely by such factors (especially the traffic situation) appears as outliers. But, fitting the data using a polynomial with square root term, 89.7% of the data was contained within ± 1 minute deviation from the fitted curve. Thus, requiring such accuracy, we can consider the taxiing time as simply distance-dependent.

5. Validation of Queueing Model

5.1 Structure of Surface Movement Time Model

Summarizing the arguments above, an estimation model of the departure surface movement time can be derived as follows;

(Merging time)

= (Time of starting push-back)

+ (Push-back time) + (Stop time after push-back)

+ (Taxiing time before merging) (2)

(Take-off time)= (Merging time) + (Queueing time) (3)

As mentioned in Sections 4.2 and 4.3, we assume the second and third terms on the right-hand side of the equation (2) to be constant. We also assume the fourth term as dependent only on distance. In this manner, each term contains about ± 1 minute error, so the calculated value of this equation contains several minutes of error.

The second term on the right-hand side of the equation (3) is the value calculated by the queue equation (1).

5.2 Method of Validation

As for equation (2), we made another assumption that the taxiing distance is constant for each parking stand. This means that the elapsed time from block-off to merging for each parking stand is determined as a unique constant, because the time of push-back and stop are assumed constant. Then we sorted the departure tracks for the Case 1 day by parking stand, and obtained a representative value for the surface movement time for each stand as a table, by calculating medians of time from block-off to merging (as shown in Figure 12, there were some large outliers in taxiing time, then we adopted the median for robustness). Values in the table range from 350 to 650 seconds, constant for each stand.

As for equation (3), as shown in Figure 13, the departure interval can be assumed as constant for a certain length of time (around 1 or 2 hours), and there is some kind of switching of this constant value (the cause of this switching is unidentified yet). Then, we selected the periods when the average of the departure interval can be assumed as constant, as follows;

- 7:30-9:30 (morning): average departure interval was 104s
- 2. 19:00-21:00 (evening): average departure interval was 116s



Figure 13: Average of departure intervals at every 15 minutes of the Case 1 day

 T_{smooth} of equation (1) is another parameter to be configured. As we will discuss later, this parameter acts as an adjuster for bias error, then we chose this parameter ad hoc to minimize the prediction error.

Additionally, in order to calculate the surface movement time under actual departure sequence condition, we made another assumption that aircraft enter the queue in the actual departure sequence, which does not always coincide with the sequence of estimated merging time calculated by the equation (2).

Under these conditions, we calculated the surface movement time for the Case 1 day, using the model equations (2) and (3), by substituting the actual time of starting push-back into (2). Then we tested the model by comparing the length of the calculated and actual surface movement times.

5.3 Results

i) Calculation of Surface Movement Time in the Morning

As for the morning period of the Case 1 day, we chose a T_{smooth} parameter of 150s as suitable. In Figure 14, the actual surface movement time is plotted by round markers with stems, where the abscissa means take-off time. The calculated surface movement time of the same aircraft is plotted by an X-shaped marker on the same abscissa.

Since 8:30 to 9:10, a trend is observed where the surface movement time exceeds 1000s and increases. In contrast to the sum of the T_{smooth} parameter and values in the table, this trend means that congestion is continuously existing and growing. The queueing model successfully simulated this trend and the calculated surface movement time came near the actual time.



Figure 14: Surface movement times of departures in the congested period (morning), and calculated values by queueing model

Figure 15 depicts the correlation diagram between the actual and calculated surface movement times. The plotted points lay closely around a straight line from the origin with a gradient of 1 (auxiliary slant dotted line in the figure) with a deviation within 100s. The coefficient factor proved to be 0.98.



Figure 15: Correlation between actual and calculated surface movement times in the congested period (morning)

ii) Calculation of Surface Movement Time in the Evening

In the same manner, the comparison between actual and calculated surface movement time, in the evening period, is shown in Figure 16. The T_{smooth} parameter was chosen as 230s.

In this period, the surface movement time almost always exceeds 1000s. This means that the traffic flow is continuously congested. The queueing model successfully simulated this congestion.



Figure 16: Surface movement times of departures in the congested period (evening), and calculated values by queueing model

Figure 17 depicts the correlation diagram between the actual and calculated surface movement times. The

plotted points lay closely around a straight line from the origin with a gradient of 1 with a deviation within 100s. The coefficient factor proved to be 0.99.



Figure 17: Correlation between actual and calculated surface movement times in the congested period (evening)

5.4 Impact of Wrong Setting of Departure Interval Parameter

As discussed in Section 3.3, the elapsed time in the queue is sensitive to the departure interval, due to the property of the queueing phenomena. Therefore, if the setting of the departure interval parameter is wrong, the correctness of the calculated surface movement time degrades enormously. Figure 18 shows the failure of calculation, caused by setting a departure interval parameter of 116s (appropriate value for the evening data) to calculate the surface movement time for the morning data.



Figure 18: Result of the wrong setting of departure interval parameter

This result confirms that the successful calculation of surface movement time, shown in Figure 14, was obtained by the correct setting of the departure interval parameter. Thus, it also implies the importance of the adequate setting of the departure interval parameter to use this queueing model as a surface movement time predictor.

6. Discussion

6.1 Necessity of Prediction of Departure Interval

As shown in the analysis of Chapter 3 and the modeling of Chapter 5, queueing time is sensitive to the departure interval. This means that the information about the departure interval plays the most important role in the surface traffic scheduling of departures. If the interval is underestimated, the coordinated schedule based on this wrong information will be unfeasible, only to promote the growth of congestion. Also, if the departure interval is overestimated, the coordinated schedule will be too loose. Therefore, it is clear that the prediction of the available departure interval is essential for planning.

The departure interval may change by many factors. Primarily, it is bounded from below by air traffic control regulations, such as runway separation, wake turbulence separation and initial flight path (SID) separation. Additionally, there are some other factors, such as the aircraft latency of the reaction to air traffic controller instructions, or weather conditions.

The comparison between Case 1 and Case 2 is a straight example of the weather effect on the departure interval. Between Case 1 and Case 2, there is no significant difference in the hourly rates of setting the wake turbulence separation. But, as for weather conditions, there is a large difference. The Case 1 day was rainy through the day, and visibility was as low as 3 to 7 km. On the other hand, the Case 2 day was sunny, and visibility was above 10 km. Wind and temperature conditions were similar.

We still have to clarify the mechanism whereby such external factors affect the departure interval (there might exist some additional procedures for air traffic controllers or pilots in bad weather). But, by collecting more data for the departure interval, together with the data of any possible factors, we could capture some correlation and build some statistical models of the departure interval. This is a future project.

6.2 Cause of Accuracy of Surface Movement Time Calculation Using Queueing Model

The surface movement of aircraft is executed by the

manual operation of engine thrusts, brakes and steering wheels, without automation. Thus, the operation time inherently contains some range of variability, which is hard to model. This is a tough barrier for building a precise model for surface movement time prediction.

On the other hand, in our validation model, even though the movement time before merging was roughly modeled (allowing several minutes of error), we got an estimation of surface movement time with good accuracy. This result can be explained from the property of queueing model equation (1), as follows;

First, we make two assumptions;

- The queue exists constantly: i.e. T(i) of equation
 (1) takes the latter argument of the max function for all i>1.
- 2. All aircraft merges in the sequence just the same as the departure sequence (FIFO condition): i.e. if we represent the merging time as $t_m(i)$, $t_m(i-1) < t_m(i)$ for all i > 1.

Then, equation (1) is transformed as follows;

$$T(i) = T(i-1) + S_d(i) - (t_m(i) - t_m(i-1))$$
(4)

Applying this relationship for all of the aircraft from the 2nd to the i th, we obtain the following equation;

$$T(i) = T(1) + \sum_{k=2}^{i} S_d(k) - (t_m(i) - t_m(1))$$
(5)

Now, we make another assumption, that the actual operation subject to this equation, and the departure interval is correctly estimated. Then, representing the calculated values of T(i) and $t_m(i)$ as $\hat{T}(i)$ and $\hat{t}_m(i)$, we obtain the relationship between the actual and calculated values of T(i) and $t_m(i)$ as follows;

$$\hat{T}(i) = T(i) + (t_m(i) - \hat{t}_m(i)) + E(1)$$
(6)

where,
$$E(1) = (T(1) - \hat{T}(1)) + (t_m(1) - \hat{t}_m(1))$$
 (7)

As E(1) is determined only by the 1st aircraft, we can treat this term as a constant for all i>1. And the second term of equation (6) represents the prediction error of $t_m(i)$. From equation (6), it can be seen that the prediction error of $t_m(i)$ is equivalently compensated in the form of the increase or decrease in the calculated queueing time. And it is also shown that E(1) behaves like bias error for every aircraft taxiing through the queue.

Therefore, if the estimation of the departure interval is correct, the prediction error of the surface movement time of each aircraft taxiing through the queue is caused only by bias error due to the prediction error of the 1st aircraft's surface movement time. And if we select an unimpeded aircraft for the 1st, we can suppress the bias error by adjusting the T_{smooth} parameter.

From this property of the queueing model, we can say that, if the queue exists constantly, the prediction problem of the surface movement time becomes easy to deal with, and we can obtain quite an accurate prediction for surface movement time, which inherently contains variability. This consequence may seem paradoxical, considering that our initial objective is to mitigate queueing congestion. But, this suggests the feasibility of traffic management by queue management, considering a trade-off between the queue length and predictability.

6.3 Basic Scheme of Airport Surface Traffic Management at Departure Phase

Considering the predictability of surface movement time using the queueing model with a fixed departure sequence condition, we can expect a scheme with the following steps to be feasible;

- 1. Collect the information for planned block-off times.
- Plan the departure sequence, based on each aircraft's estimated merging time.
- 3. Calculate each aircraft's queueing time with the queueing model under the condition of the departure sequence specified in the 2nd step.
- Re-plan the block-off time so as to mitigate queueing time. Specifically, shift the planned block-off time by some range corresponding to the calculated queueing time.

The effectiveness of this scheme depends on the possibility that the actual merging rate complies with the coordinated merging rate obtained from the 4th step of this scheme. Then it is necessary for the merging time to be accurately predictable prior to operation, or controllable within the operation.

As for predictability, there exists a limit to accuracy due to the inherent variability of aircraft surface operation. Therefore, as a future project, we have to evaluate the impact of this variability on the effectiveness of surface traffic management, using detailed simulation.

As for controllability, we have to find some way to suppress variability. For example, if the information of each aircraft's departure sequence and remaining time before merging is shared appropriately, pilots can choose their actions to improve the effectiveness of the traffic management, by slight increases or decreases in thrust and braking. We have to study whether such kind of information sharing is feasible with existing equipment and small changes in operational procedures, or if some new equipment or large changes in operational procedures would be necessary.

Additionally, despite the inherent variability, a precise prediction of the movement time before merging is still necessary. Because, if the prediction error of merging time exceeds the amount that can be absorbed within operations by the above-mentioned means, traffic management based on the prediction will be unfeasible. Therefore, we have to study some method of prediction, considering the range of predictability and operability.

7. Conclusions

We analyzed traffic congestion at Haneda Airport based on multilateration surveillance data, and derived the fact that the major congestion occurs at departure queues before the runway. From this analysis, we also identified that this congestion can be modeled using queueing theory. Then, using a theoretical queueing model, we have built an estimation model of surface movement time (from block-off to take-off) and reconfirmed the relevance of treating this congestion using queueing theory. Finally we discussed the feasibility of a traffic management scheme based on the prediction of surface movement time by queueing model.

Acknowledgements

The authors express special thanks to JCAB (Japanese Civil Aviation Bureau) of the Ministry of Land, Infrastructure, Transport and Tourism, for providing the multilateration surveillance data.

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