

Analysis of Airborne Delay Characteristics of Flights Controlled by Ground-Holding: Case of the Flights to Tokyo International Airport

Terumitsu HIRATA ^a, Azumanosuke Shimizu ^b, Daichi MIMURA ^c, Tetsuo YAI ^c

^a *Institute for Transport Policy Studies, 3-18-19 Toranomom, Minato-ku, Tokyo, 105-0001, Japan*

^a *E-mail: hirata@jterc.or.jp*

^{b,d} *Tokyo Institute of Technology, 4259 Nagatsuta-cho, Midori-ku, Yokohama, 226-8502, Japan*

^b *E-mail: shimmizu@wing.plala.or.jp*

^c *NTT logisco, Inc.*

^c *E-mail: d.mimura@gmail.com*

^d *E-mail: tyai@enveng.titech.ac.jp*

Abstract: The purpose of this paper is to examine the actual situation of the delay characteristics of the flights controlled by Ground-Holding which arrived at Tokyo International Airport (Haneda Airport (HND)), which is the largest hub airport in Japan. The data analyzed is the flight data of all arrivals to HND from April 2008 to March 2009 including their Estimated Time of Arrival, Expected Departure Clearance Time (EDCT) issued by Ground-Holding, Actual Time of Departure, Actual Time of Arrival, other aircraft characteristics and meteorological condition, and other related data. The results of the analysis clarify the factors that affect the flight airborne delays and the EDCT such as runway capacity fluctuations. Also the possibility of over-controlled delay by EDCT is examined through the comparison between actual airborne delay and expected airborne delay in Ground-Holding program.

Keywords: air traffic flow management, ground-holding, EDCT, delay

1. INTRODUCTION

Air Traffic Flow Management (ATFM) is now widely used in several regions in the world for balancing air traffic demand and airspace system capacity. In Japan, the modernized and system-based ATFM started in 1994, and new Air Traffic Management Center (ATM Center) has been established in 2005 that integrates the airspace management system and advanced oceanic data processing system with new Flight Data Management System (Kimura, 2007). In 2010, Japan Civil Aviation Bureau has formulated the “Long-term Vision for the Future Air Traffic Systems”, which was named “CARATS: Collaborative Actions for Renovation of Air Traffic Systems” (Japanese Civil Aviation Bureau, 2010). This vision states that the shifting to a strategic “trajectory-based ATM operation (TBO)” from the traditional airspace-based ATM operation is necessary for minimizing operational restrictions and optimizing the performance of air traffic as a whole, while also realizing flexible and efficient flights. It is supposed that the current ATFM tools such as Ground-Holding (GH) which holds flights to an over-congested airport at a departure airport to mitigate airborne delay at an arrival airport are the initial phase of TBO considering time-dimension of flight trajectories. Therefore, the review and analysis of the current ATFM performance as well as the characteristics of air traffic flows in Japan are important to design the improved future ATM in Japan. This paper

focuses on the basic aggregate statistics of Ground-Holding by Expected Departure Control Time (EDCT) issuance, which is the most major tools for ATFM, and also looks into the impact of EDCT issuance on the airborne delay. Because the domestic air traffic flows concentrate on Tokyo International Airport (Haneda: HND) (over 65% of the domestic flight passengers is to-and-from HND) and the major cause of the congestion is the capacity constraint in HND runways, we analyze the arrival traffic flows to HND.

Regarding the delay in air transportation, many past researches have been conducted. Ball et al (2010) reported total cost of air traffic congestions and delay in US including direct cost to airlines, costs to passengers and indirect cost to the economy. In terms of aircraft and crew schedule planning, as summarized in Barnhart et al (2004), many mathematical modeling for optimizing aircraft and crew planning have been proposed including operations recovery (e.g. Yu et al, 2003, Bratu et al, 2006). Regarding the capacity and delay in aviation infrastructure (airports and air traffic management system), the analytical runway capacity and delay models are developed (Hockaday et al, 1974, Newell, 1979). For ATFM fields, this is the main interest of this research, many past researches have proposed the models for optimal allocation of ground delays to departing flights such as the models considering single-airport (Richetta, Odoni, 1993), multiple-airports (Vranas, Bertsimas, Odoni, 1994) and capacity uncertainty (Mukherjee, A., Hansen, M., Grabbe, S. (2009)). However few researches focused on the actual situation of the delay of the flights controlled by GH and also few researches focused on the effects of ATC operations in the terminal airspace on the airborne delays of the flights controlled by GH. In the case of the situation in Japan, Gwiggner et al. (2009a, 2009b, 2010) analyzed the airborne delay caused by the metering at entry fix to TMA of HND and the optimal allocation of the airborne delay to high and low altitude. Sakashita et al. (2009) analyzed the flight delays from the scheduled time in the time-tables at HND and clarified the difference among the routes. But these researches did not deal with GH delay. This study tried to explore the actual airborne delay of the flight controlled by ATFM (GH) with comparison to the expected airborne delay in the ATFM system in order to analyze the effectiveness of the GH program in terms of balancing demand and capacity at a reasonable level and to find the effects of ATC operations in the terminal airspace on the airborne delays.

2. OVERVIEW OF THE GROUND-HOLDING PROCEDURE IN JAPAN

The major tools of ATFM are Ground-Holding (GH), Miles-In-Trail (MIT) and Re-route, and so on. In this chapter, the procedure of GH in Japan is focused on. In Japan, the ATM center calculates the future 6-hours traffic demand in each airport or airspace based on the Flight Plans of each flight, and also forecast the capacity of each airspace and airport based on the forecast of future meteorological condition. If the excess amount of traffic at certain airspace is calculated by the system, then ATM center decides to start GH by considering the impact of the excessive traffic volume on the workload of Air Traffic Controllers in en-route and terminal airspace (TMA). In terms of an excessive demand index at an airport (runway), they usually calculate expected airborne delay in TMA due to runway capacity constraint. In HND, 10 minutes of airborne delay in TMA is assumed to be the limit of acceptable delay time (see Figure.1). Therefore, if the 10 minutes of airborne delay is expected, then ATM center considers start to issue Expected Departure Control Time (EDCT) after which a controlled flight are allowed to take-off. Because the airborne delay exceeding 10 minutes is change to ground delay at a departure airport by GH, all of the flights that receive EDCT due to HND congestion are basically expected to have 10 minutes airborne delay in HND TMA.

The standard runway capacity of HND that was assumed for calculation of airborne delay in HND TMA are 15-17 landings every 30minutes in north-wind configuration and 13-15 landing every 30minutes in south-wind configuration (see Figure.2) . For the airspace sector congestion, the calculated workload of en-route controllers considering each flight characteristics is used for the index of congestion.

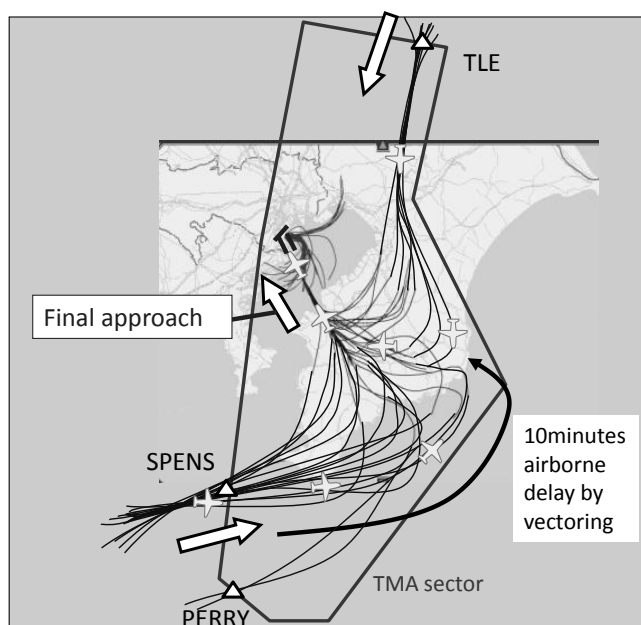


Figure 1. Image of the limit of airborne delay by vectoring in HND TMA assumed in ATFM

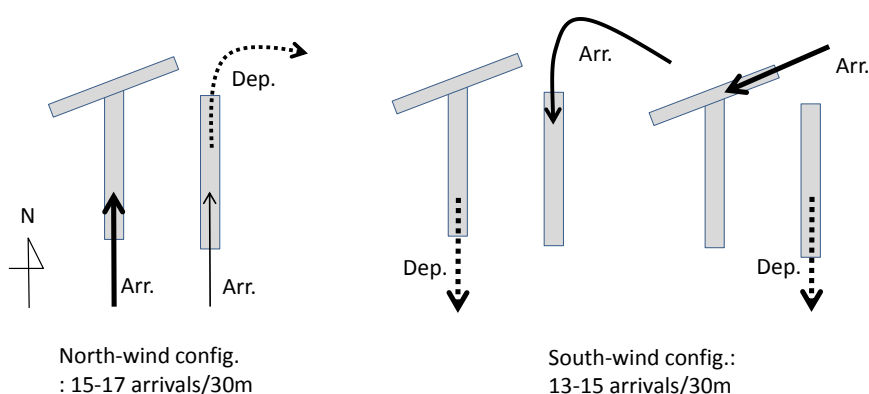


Figure 2. Runway configuration in HND and arrival capacity assumed in ATFM system (*Note: after Oct. 2010 HND has had a new 4th runway and runway configuration has also changed)

3. DATA

The data we used in this paper is the flight data of all arrivals to HND from April 2008 to March 2009 including EOBT (Estimated off-block time), EDCT, ETD (Estimated time of departure), ETA (Estimated time of arrival), ATD (Actual time of departure), ATA (Actual time of arrival), and other related data. NOTAM (Notice to Airmen) information related to ATFM for HND arrivals and ATIS (Automated Terminal Information Service) information at

HND are also integrated to the database for knowing which airspaces were controlled due to the congestion and which runways were used in HND respectively. These data was provided by JCAB.

4. ANALYSIS OF THE DELAY CHARACTERISTICS OF GROUND-HOLDING FLIGHTS

4.1. The trend of Ground-Holding by EDCT and the delay

This chapter shows the basic aggregate statistics of EDCT issuance to HND arrivals from April 2008 to March 2009. Figure.3 shows the monthly trend of departure and arrival delay from scheduled time (>15min.) of HND arrivals (annual average). First, arrival delay rate is larger than the departure delay rate. This implies that, in Japan, the departure (off-block) time is not well-coordinated according to the departure runway capacity (or take-off slot time) that causes waiting for taking-off clearance, and also that the delay is allocated to en-route or terminal airspace, which causes airborne delay. These are similar to US characteristics while EU has different trend where the delay rate of departure and arrival are close (Eurocontrol & FAA, 2009).

Figure .4 shows monthly trend of frequency of EDCT issuance to HND arrivals and the rate of south-wind runway configuration in HND in 2008/2009 (annual average). The EDCT rate significantly fluctuated and correlated well with south-wind configuration rate. As shown in Chapter 2, the runway capacity is relatively lower in south-wind.

Figure.5 shows time trend of frequency of EDCT issuance to HND arrivals in 2008 to 2009 (annual average). The EDCT tended to be issued at evening traffic peak period. When looking at the trend of EDCT rate during a single day, there is no correlation with south-wind configuration rate, rather it correlates with the arrival traffic volume. But there is a time lag between EDCT rate and traffic volume. This is usually natural because delay occurs in a cumulative manner. This occurrence is to be discussed in the next section.

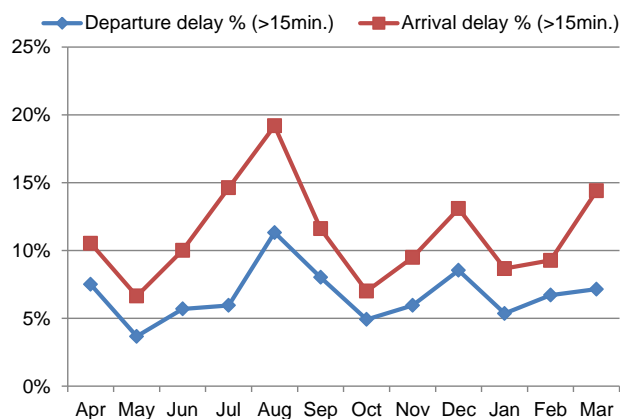


Figure 3. Monthly trend of departure and arrival delay (>15min.) of HND arrivals in 2008/2009

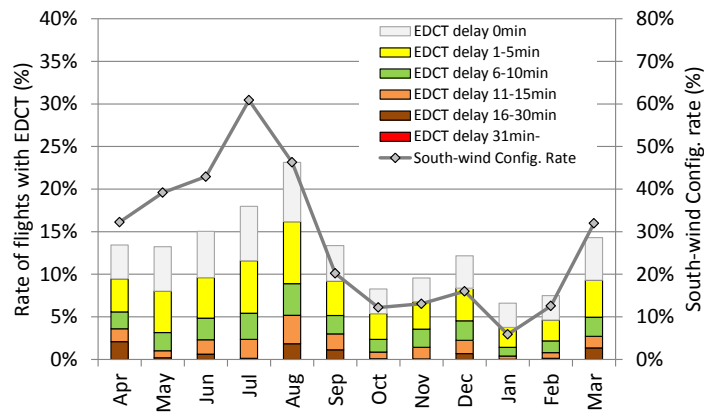


Figure 4. Monthly trend of frequency of EDCT issuance to HND arrivals in 2008/2009

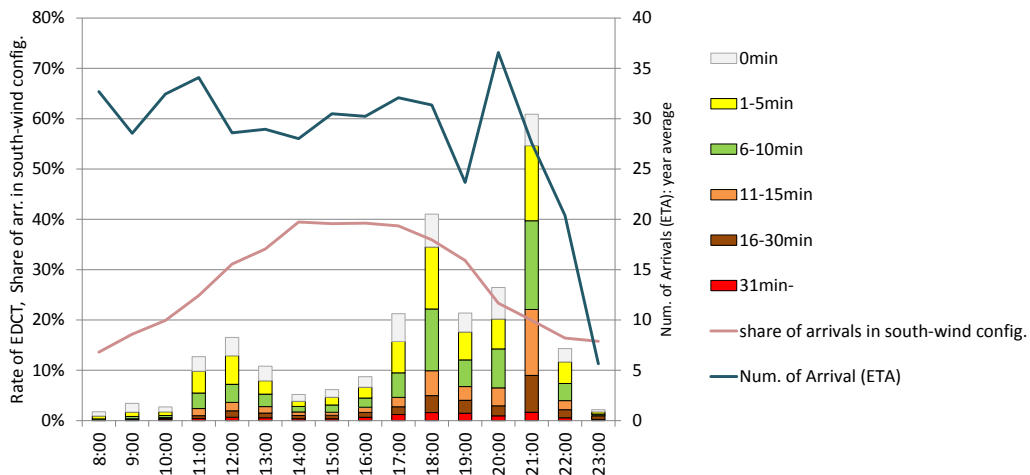


Figure 5. Time trend of frequency of EDCT issuance to HND arrivals in 2008/2009

4.2. Analysis of the airborne delay characteristics of the flights controlled by Ground-Holding

4.2.1 Calculation method of airborne delay

In this study, the airborne delay time are estimated by the flight data shown in Chapter 3 which includes the estimated (= planned) and actual time of arrival and departure to/from the airports. Basically the airborne delay time is defined as the difference between the estimated flight time and the actual flight time in this study (“flight time” means the time duration from take-off to landing). The estimated flight time of each flight planned by airline companies are based on the one specific arrival route to HND, specifically the arrival route designed for the north-wind runway configuration (Runway 34L). However the arrival routes are changed according to the runway configuration at the time of landing. Therefore the estimated flight time should be adjusted for calculating the airborne delay time by taking the runway configuration into account. Then we calculate the airborne delay time (*AD*) of flight *i* departing from an airport *j* by using arrival route *k* by the following equations.

$$AD_{ijk} = AFT_{ijk} - (EFT_{ijk} - A_EFT_{jk}) \quad (1)$$

$$A_EFT_{jk} = \overline{EFT}_{j(north)} - \overline{EFT}_{jk} \quad (2)$$

where,

EFT_{ijk} : estimated flight time

A_EFT_{jk} : adjusted time for EFT_{ijk}

AFT_{ijk} : actual flight time

$\overline{AFT}_{j(north)}$: average of actual flight time of the flights without EDCT from airport j through the arrival route for north-wind runway configuration

\overline{AFT}_{jk} : average of actual flight time of the flights without EDCT from airport j through the arrival route k

The adjusted times are calculated separately for each departure airport and each arrival route by taking the difference between the average of actual flight time of the flights without EDCT from each airport through the arrival route for north-wind runway configuration and that through each arrival route. We use the data of the flights without EDCT (non-controlled flights by Ground-Holding) in order to eliminate the effect of the airspace congestion on flight time. Negative airborne delay time indicates an earlier arrival than estimated (planned).

4.2.2 Analysis of the distribution of airborne delay time of the flights controlled by GH

In ATFM, balancing the demand and capacity at an appropriate level is important to avoid over-loaded demand and also for maximizing the utilization of the limited capacity of the airspaces/runways. In this regard, it is necessary to examine the actual airborne delay of the controlled flight by ATFM in detailed. In this section, we examine the actual airborne delay distribution of the flights controlled by EDCT and its difference among the flight routes.

First, by using the information of NOTAM, we picked up all of the flights with EDCTs during the time when only the flow control due to HND congestion was executed. We can exclude the impact of the flow control due to the en-route congestion by this work. As is explained in the previous section, the airborne delay time is calculated by “actual flight time – estimated flight time”, so this delay includes the en-route delay as well as TMA delay. Figure .6 shows the distribution of the airborne delay of all of the flights with EDCTs. As mentioned in Chapter 2, all of the flights that receive EDCT due to HND congestion are basically expected to have 10 minutes airborne delay in HND TMA. However, the actual total airborne delay of the flights with EDCTs distributes mainly in the lower level than 10 minute. From this figure, the current EDCT flights seems to be over-controlled on the ground at the departure airport but there are also the significant number of the flights that had more than 10 minute airborne delay which can cause over-workload of ATC in TMA. Figure .7 shows the distribution of the airborne delay of the flights with EDCTs and without EDCTs categorized by the entry FIXs to HND TMA (The geographical positions of the entry FIXs can be seen at Figure .1), and the figures are separated by the type of runway use (the north- and south-wind configuration). A clear difference can be seen among the flights from the different entry FIXs. As is shown in Figure 8 which depicts the average airborne delay of the flights with EDCTs and without EDCTs categorized by the entry FIX to HND TMA, the airborne delay of EDCT flight is larger than that of non-EDCT flights but the difference is quite little in the case of the flight entering via TLE (from north) while the flights via SPENS

have a significant increase of airborne delay with EDCTs. Table.1 shows the results of statistical test for the difference of two-means of airborne delay of the flights with EDCTs and without EDCTs categorized by the entry FIX to HND TMA. Since the number of sample is large (see degrees of freedom in Table.1), these statistical test are not necessarily important and rather the magnitude of the difference of two-mean is important to see. Therefore this statistical test is just for reference. There are two possible reasons for this difference. One is the en-route airspace congestion before entering TMA, and the other one is the TMA airspace to be used for the vectoring. Regarding the en-route congestion, the northern en-route airspaces are not so congested while the western en-route airspaces are often congested due to high arrival traffic demand to HND such as from Osaka and Fukuoka, which are the large cities in the western part of Japan. Because of the metering fix at the boundary of en-route and TMA, the flights are usually metered for spacing at that fix by vectoring when traffic volume in en-route airspace is heavy. Therefore, the airborne delay of the flights from western airspaces often increased before entering HND TMA due to the metering. On the other hand, there is almost no difference between with and without EDCT flights in the case of TLE FIX entry. This indicates that even if the flights from the north to HND would receive EDCT they cannot be delayed in the TMA by vectoring due to the airspace constraint in the northern part of HND TMA. Actually, the airspace for vectoring in the northern part in HND TMA is smaller than that in the southern part, which is used for the vectoring the flights from the west and south. And also there are almost no metering delay in the northern en-route airspace due to low traffic volume. The en-route metering delay in the western airspace might also result in reduce the airborne delay of the flights from north by mitigating the traffic congestion in HND TMA.

In the case of the flights from south-west via PERRY FIX (only from Okinawa), they usually flies through the non-congested airspace over the sea. This allows them to fly a short-cut route and consequently their flight time tends to be shortened. However, they can be vectored in TMA similarly to the flight via SPENS, which resulted in the increase of the airborne delay of EDCT flights.

These results indicate a possibility that the airborne delay of the flights with EDCTs is significantly smaller than expected in the ATFM system. Although there are also the significant number of the flights that had airborne delays more than expected, some portion of the flights seems to be over-controlled by EDCTs. Also, a clear difference of the airborne delay among the flight routes indicates that there may be structural bias of the delay and the ATC workload depending on the flight routes. For making the procedure of ATFM more efficient, these characteristics of the air traffic flows should be considered. For example, by estimating the metering delay before TMA of each flight, that delay can be incorporated in forecasting time-series arrival demand at the runway, and then ground-holding delay time can be assigned with consideration of metering delay. In terms of the operation of arrival flow around TMA, en-route metering system can be effective which manages the sequence of all of arrivals including the flights from north, west and south. With this system, more proactive sequencing and spacing can be attained. This kind of metering system has been already used in US and Europe (Traffic Management Advisor (TMA) in US (Robinson et al, 2010), Arrival Manager in Europe (Eurocontrol, 2010)).

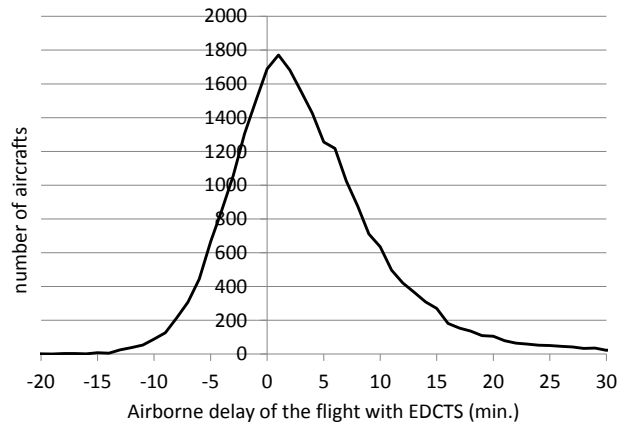


Figure 6. Distribution of the airborne delay of all of the flights with EDCTs

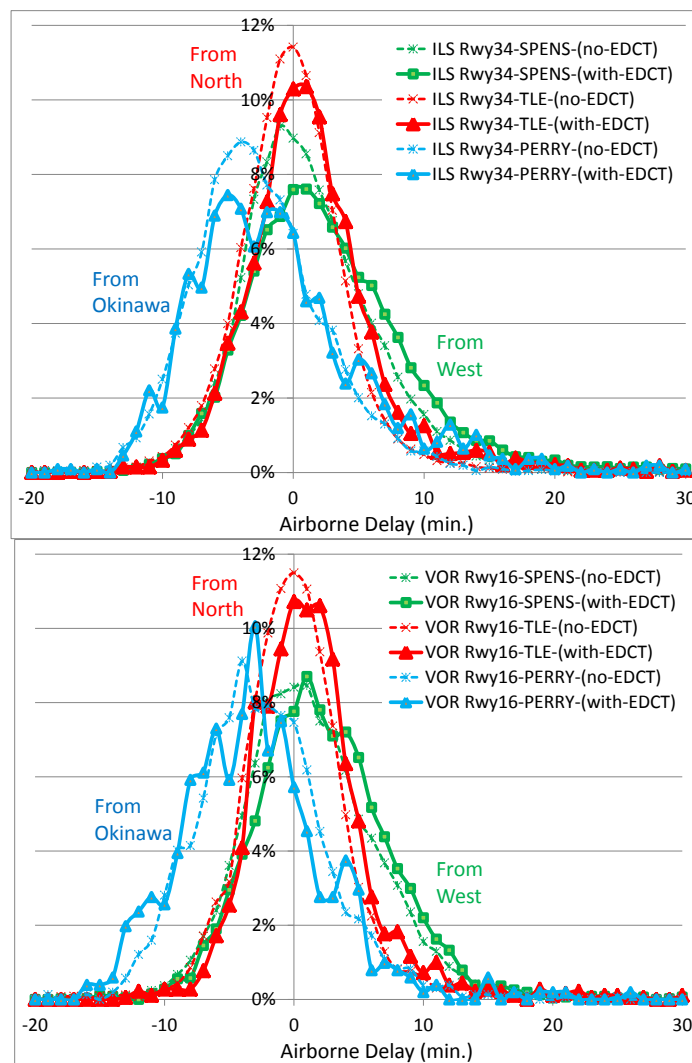


Figure 7. Distribution of the airborne delay of the flights with EDCTs and without EDCTs categorized by the entry FIX to HND TMA (North-wind configuration: Above, South-wind configuration: Bottom)

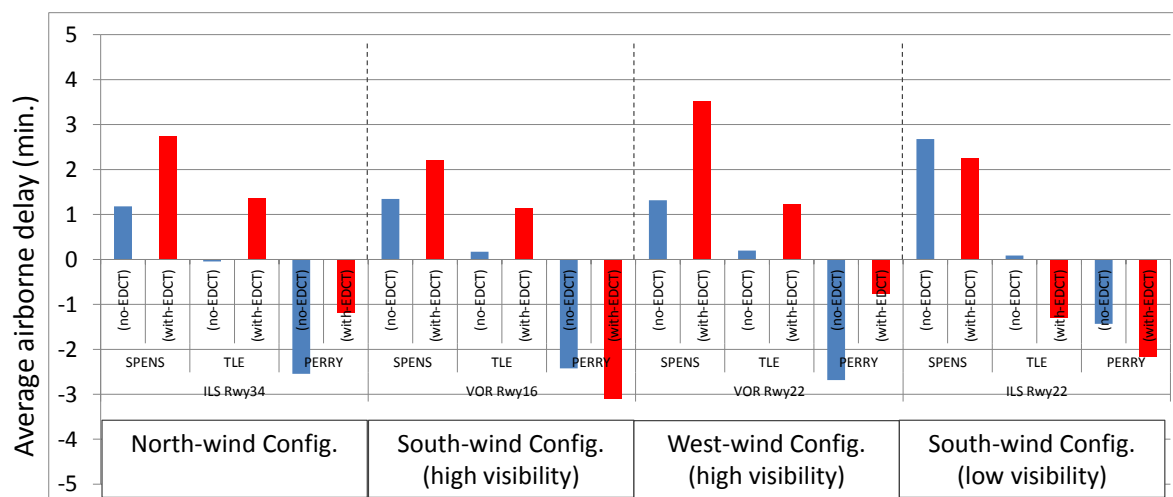


Figure 8. Average airborne delay of the flights with EDCTs and without EDCTs categorized by the entry FIX to HND TMA (Runway capacity: North-wind>South-wind(high-visibility)>South-wind(low-visibility))

Table. 1. Results of statistical test for the difference of two-means of airborne delay of the flights with EDCTs and without EDCTs categorized by the entry FIX to HND TMA

	ILS Rwy34			VOR Rwy16			VOR Rwy22			ILS Rwy22		
	SPENS	TLE	PERRY	SPENS	TLE	PERRY	SPENS	TLE	PERRY	SPENS	TLE	PERRY
t-value	2669.9	941.2	234.6	624.4	309.7	49.2	487.0	86.6	48.7	19.3	21.3	2.2
p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
df	78319	28404	7321	21661	8664	2073	5828	2350	800	1552	551	115

4.2.3 Analysis of the impact of runway capacity fluctuation and the drift of the take-off time on airborne delay time

One of the reasons for the smaller airborne delay time than expected in GH program is the difference between the assumed runway capacity and the actual landing counts. Figure.9 shows the distribution of the actual landing counts at arrival peak time (17:35-18:04) in north-wind and south-wind configuration. The standard runway capacity of HND that was assumed in GH program is 15-17 landings every 30minutes in north-wind configuration and 13-15 landing every 30minutes in south-wind configuration. However the actual runway capacity can be higher than that assumed in ATFM system. Obviously higher capacity leads to smaller airborne delay. Figure 10 shows the actual relationship between the average airborne delay of the flights with EDCTs and the number of the actual landing aircrafts in the different runway uses. From this figure, the lower airport acceptance rate tended to result in higher airborne delay. These results can confirm again that the one of the major factors causing the variation of the airborne delay is the uncertainty in the airport capacity forecast. These results indicate the importance of taking the airport capacity variation into account.

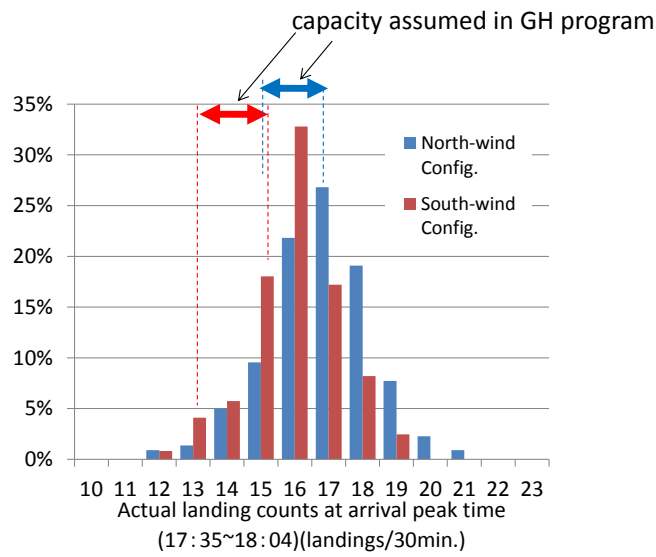


Figure 9. Actual landing counts distribution at arrival peak time (annual average)

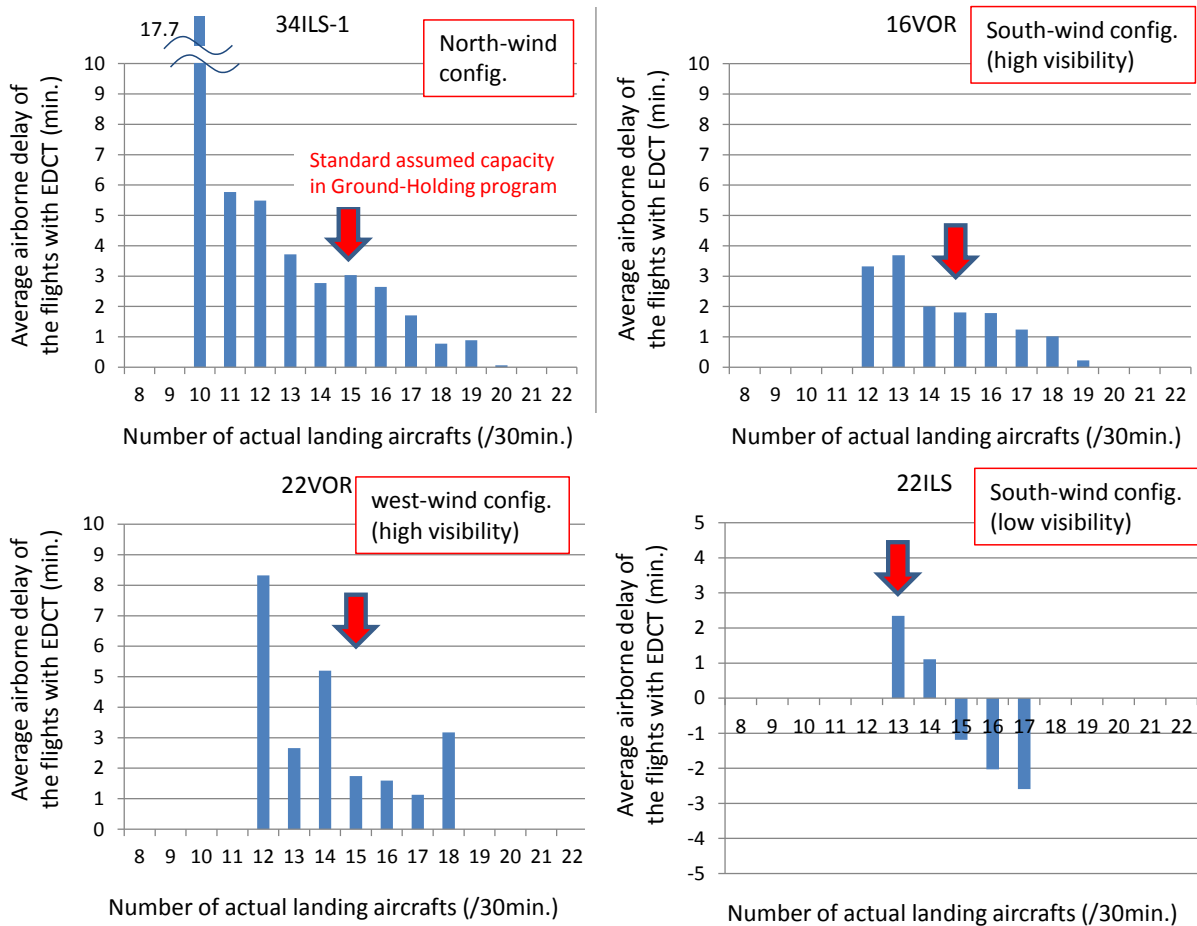


Figure 10. Average airborne delay of the flights with EDCTs and the number of actual landing aircrafts (actual airport acceptance rate)

Another aspect is the demand side. ATC provides the aircrafts to be delayed on the ground at departure airports with EDCT. ATC expects the flights with EDCT will take-off at

the time of EDCT. However the take-off time can be drifted due to the delay of gate-off, runway operation constraints and so on. This drift can also impact on the airborne delay because the drift (delay) of the take-off time means increase of ground-holding time. Figure 11 shows the distribution of the drift (delay) of take-off time from EDCT (ATD-EDCT). In Japan, the departure aircrafts cannot be released before EDCT. Therefore, the drift (delay) of take-off time from EDCT occurred easily depending on the situation of departure and arrival queuing at the departure airport or by the other reasons. Although the impact of this take-off time drift would not be so severe, the restriction on the drift or penalty for the drift can improve the demand forecast that lead to more efficient air traffic flow control.

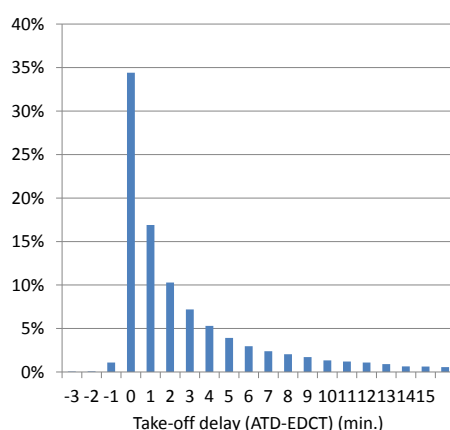


Figure 11. Take-off delay distribution of flights with EDCT (ATD-EDCT)

4.2.4 The impact of runway operation change in HND with new 4th runway

From October 2010, HND has had new 4th runway, and runway operation becomes more complicated where the departure and arrival traffic are operated interdependently in the same or a pair of crossing runways. Therefore, the trade-off between departure and arrival capacity should be considered in ATFM system. In this case, a dynamic optimization concept for allocating the runway capacity to departure and arrival traffic (Gilbo, 1993, 1997) can be incorporated into ATFM system with consideration of runway capacity model for HND with 4th runway (Hirata et al, 2013). In this current and future situation of HND, the findings and recommendations in this study can be utilized in designing the ATFM system for HND traffic.

5. CONCLUSIONS

This paper examined the actual situation of air traffic flow management by Ground-Holding especially for the arrivals to Haneda Airport, which is the largest hub airport in Japan. The results of the analysis clarify the major factors that affect the flight delays and the trend of EDCT issuing such as the runway configurations, traffic flow structures in Japan and the runway capacity fluctuations. Also, the possibility of over-controlled delay by EDCT is examined through the comparison between actual airborne delay and expected airborne delay in Ground-Holding program. These characteristics can be useful information to design more efficient air traffic flow management procedures. In the future researches, we need to consider the delay caused by airline operations, the delay in en-route airspace. For the development of more efficient procedure of ATFM, we need to consider how to predict the future runway

capacity more precisely as well as how to deal with the demand uncertainty.

Acknowledgement

The authors are grateful to the Japan Civil Aviation Bureau of the Ministry of Land, Infrastructure, Transport and Tourism for their cooperation in the provision of flight data and this research was partially supported by the JSPS research grant.

REFERENCES

- Ball MO, Barnhart C, Dresner M, Hansen M, Neels K, Odoni A, Peterson E, Sherry L, Trani A, Zou B (2010) Total delay impact study: a comprehensive assessment of the costs and impacts of flight delay in the United States. *Federal Aviation Administration report*.
- Barnhart, C. and Cohn, A. (2004) Airline Schedule Planning: Accomplishments and Opportunities, *Manufacturing and Service Operations Management*, Vol. 6, No. 1, 3-22.
- Bratu S, Barnhart C (2006) Flight operations recovery: new approaches considering passenger recovery, *Journal of Scheduling*, Vol.9, Issue.3, 279–298.
- Eurocontrol (2010) *AMAN Status Review*.
- Eurocontrol & FAA (2009) U.S./Europe Comparison of ATM-related Operational Performance.
- Gilbo, E. P. (1993) Airport Capacity: Representation, Estimation, Optimization, *IEEE Transactions on Control Systems Technology*, Vol.1, No.3, 144-154.
- Gilbo, E. P. (1997) Optimizing Airport Capacity Utilization in Air Traffic Flow Management Subject to Constraints at Arrival and Departure Fixes, *IEEE Transactions on Control Systems Technology*, Vol.5, No.5, 490-503.
- Gwiggner, C., Kimura, A., Nagaoka, S. (2009a) Data and Queueing Analysis of a Japanese Arrival Flow, *Proceedings of Asia-Pacific International Symposium on Aerospace Technology*.
- Gwiggner, A., Nagaoka, S.(2009b) Sequencing Strategies for a Japanese Arrival Flow. Preliminary results, *Proceedings of 9th American Institute of Aeronautics and Astronautics(AIAA) Aviation Technology, Integration, and Operations Conference (ATIO)*.
- Gwiggner, A., Nagaoka, S.(2010) Analysis of Fuel Efficiency in Highly Congested Arrival Flows, *Proceedings of 2010 Asia-Pacific International Symposium on Aero-space Technology (APISAT)*.
- Hirata, T., Shimizu, A., Yai, T. (2013) Runway Capacity Model for Multiple Crossing Runways and Impact of Tactical Sequencing -Case Study of Haneda Airport in Japan-, *Asian Transport Studies* Vol.2, Issue. 3, 295-308.
- Hockaday, S. L. M. and Kanafani, A. K. (1974) Developments in Airport Capacity Analysis, *Transportation Research*, Vol. 8,171-180.Japanese Civil Aviation Bureau (2010) Long-term Vision for the Future Air Traffic Systems -Changes to Intelligent Air Traffic Systems-.
- Kimura, A. (2007) ATFM status in Japan, *4th Global Air Traffic Flow Management Conference*, Capetown, South Africa.
- Mukherjee, A., Hansen, M., Grabbe, S. (2009) Ground Delay Program Planning Under

- Uncertainty in Airport Capacity, *Proceedings of AIAA Guidance, Navigation, and Control Conference*.
- Newell, G. F. (1979) Airport Capacity and Delay, *Transportation Science*, Vol. 13, No. 3, pp. 201- 241.
- Richetta, O., Odoni, A.R. (1993) Solving Optimally the Static Ground-Holding Policy Problems in Air Traffic Control, *Transportation Science*, Vol. 27, No. 3, 228-238.
- Robinson M. et al. (2010) Traffic Management Advisor (TMA) – weather integration, *14th Conference on Aviation, Range, and Aerospace Meteorology*.
- Sakashita, A., Morichi, S., Hibino, N. (2009) A Study on Flight Delays and Departure-Taxiing Time at Tokyo International Airport, *Proceedings of Infrastructure Planning and Management, JSCE*, Vol.40. (in Japanese)
- Vranas, P.B., Bertsimas, D., Odoni, A.R. (1994) The Multi-Airport Ground Holding Problem in Air Traffic Control, *Operations Research*, 42, 249-261.
- Yu, G., Argüello, M., Song, G., McCowan, S., White, A. (2003) A new era for crew recovery at Continental Airlines, *Interfaces*, Vol.33, No.1, 5-22.