An Analysis of Delays in Air Transport in Japan

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***Abstract*—To cope with growing traffic demand, improvement of ATM performance becomes important. This paper describes an analysis on delays in air transport in Japan under a part of ATM performance evaluations. Investigation of the delays provides us with the perspective of punctuality and predictability which are areas of ATM performance. Firstly, arrival punctuality and departure punctuality at Japanese major airports are studied. Furthermore delay is studied from the viewpoint of predictability. To study predictability in operational phases, an aircraft operation is divided into four distinct phases: pre-departure, taxi-out, airborne and taxi-in. Setting standard time-distance for each phase, delays is computed and the averages as well as the standard deviation are studied on a monthly basis. Moreover, ATFM (Air Traffic Flow Management) impact on pre-departure predictability was studied. Compared with those in the US or Europe, characteristics of punctuality in Japan are shown. Divided operational phases revealed that pre-departure delay is the main driver of predictability variation.**

***Index Terms*—ATM Performance, Delay, Punctuality, Predictability, Air Traffic Flow Management**

I. Introduction

Air Traffic Management (ATM) is the dynamic and integrated management of air traffic and airspace through the provision of facilities and seamless services to airspace users in collaboration with all involved stakeholders, with the objective of achieving safe, economical and efficient operations. To accommodate air traffic demand increase, in the last few decades ATM has significantly improved its performance. However, since further traffic demand is anticipated, further ATM performance improvements are required. For that purpose, ATM performance evaluations are required to provide valuable assessment information. Through such ATM performance assessment, performance bottlenecks can be identified and prioritized in order to be dealt with and hopefully removed appropriately. Furthermore, any ATM performance study should facilitate the estimation of the effect of planned improvements prior to implementation.

Since ATM has, by definition, multiple objectives to accomplish, its performance must be assessed through multiple assessment viewpoints. ICAO (International Civil Aviation Organization) has defined Key Performance Areas (KPA)[1]. The KPA are comprised of 11 areas corresponding to society impact (Safety, Security, Environment), ATM prosperity (Access and Equity, Participation by the ATM community), and ATM operation performance (Cost Effectiveness, Capacity, Efficiency, Flexibility and Predictability). The KPA are by nature almost contradictory[2].

Among many performance metrics, aircraft operational delays are focused on. Delay belongs to the area of punctuality and predictability[3]. In the interest of financial performance and predictability of operations, it is usually deemed desirable that the actual arrival times agree with their scheduled values. However, it was realized that, due to the application of ATM procedures, as well as due to other contributing factors such as weather or carrier action, the actual arrival times at destination airports usually differ from the scheduled values. A numeric target for delay reduction is set out in the ATM transformation plan presented in [4]. At the same time, current delays are analyzed in some states. For instance, in Europe, CODA (Central Office for Delay Analysis) publishes aircraft operational delays on a regular basis[5].

Concerning air transport as well as ATM, each state has its specific character. Thus, delays need to be studied for each state. In this paper, delays in Japan are studied. Firstly, punctuality at Japanese major airports is compared. Punctuality is measured based on industry-standard indicators. Then, predictability is studied. An aircraft flight operation is divided into distinct phases based on values of the time stamps of various events across an aircraft's operational mission. For each phase, operational delays are computed for the study of punctuailty. Moreover, ATFM (Air Traffic Flow Management) impact on pre-departure predictability is studied.

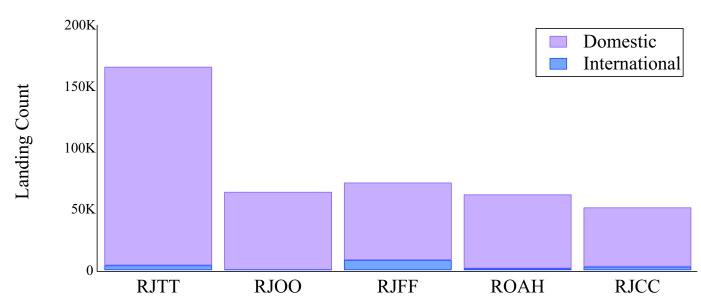

Fig. 1. A Comparison of Landing Count in 2007

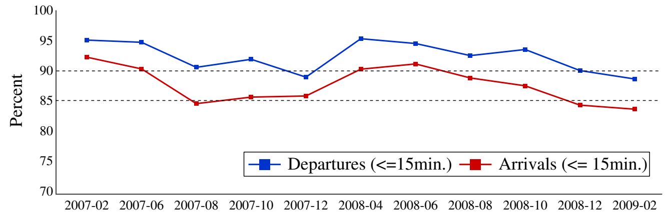

Fig. 2. Air Transport Punctuality (To/From the Five Airports)

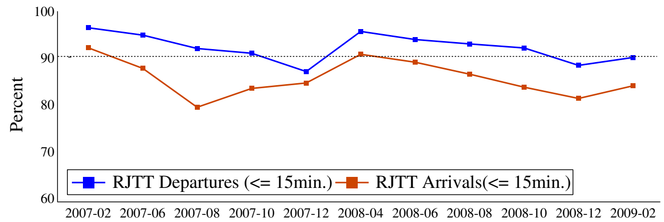

Fig. 3. Air Transport Punctuality (To/From RJTT)

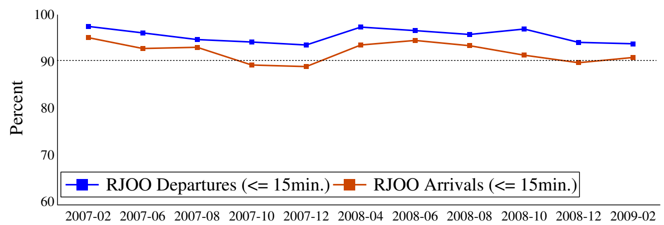

Fig. 4. Air Transport Punctuality (To/From RJOO)

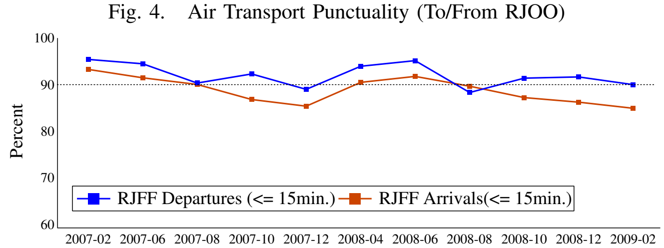

Fig. 5. Air Transport Punctuality (To/From RJFF)

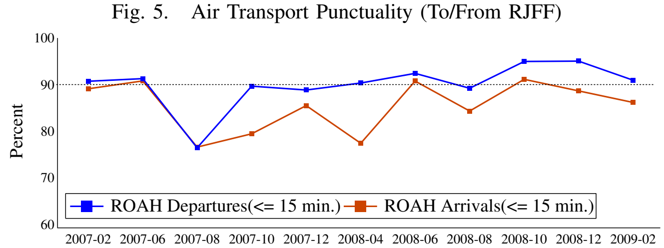

Fig. 6. Air Transport Punctuality (To/From ROAH)

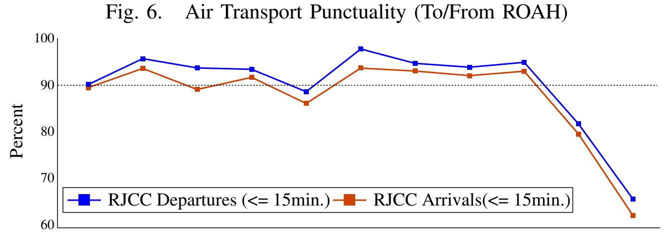

Fig. 7. Air Transport Punctuality (To/From RJCC)

II. Punctuality Study

A. Analyzed Data

According to statistical data, concerning domestic traffic volume, the top five airports were Tokyo International (Haneda) (RJTT), Osaka (RJOO), Fukuoka (RJFF), Naha (ROAH) and Sapporo (RJCC) in the year of 2007. Figure 1 shows the landing count comparison in the year. These airports were regarded as representative of Japanese airports for domestic flights and delay of the flights to/from the five airports was studied. Among the five airports, Haneda Airport (RJTT) at which the landing count was the highest, plays the role of a domestic hub airport.

The generally accepted indicator for air transport delay is the percentage of arrivals more than 15 minutes later than the scheduled time[3]. Hence, the percentages of arrivals 15 minutes late or less were computed as arrival punctuality. Likewise, the percentages of departures no more than 15 minutes later than the scheduled time were computed as departure punctuality.

The analyzed data were recorded in February, June, August, October, December 2007, April, June, August, October, December 2008, and February 2009. 6-7 days worth of data were gathered for each of these months. In total, 76 days worth of data were analyzed. The data items were obtained from ATM system journals as follows: actual gate-in times (ABIT: Actual Block-In Time) and gate-out times (AOBT: Actual Off-Block Time) were obtained from SMAP (Spot Management And Planning system) journals. Schedule times were obtained from timetables. If necessary, radar data from RDP (Radar Data Processing System) journals were exploited to study the traffic situation.

For air transportation, there are factors outside ATM coverage. Bad weather conditions are major examples of such factors. For instance, snowfall or strong wind can cause runway-closure. To measure ATM performance exclusively, the data under such conditions should be excluded. However, due to data source limitation, all the gathered data were analyzed regardless of weather and other conditions.

B. Analysis Results

Figure 2 shows the monthly punctuality at the five airports combined. The red line represents the monthly arrivals punctuality, whereas the blue line represents the monthly departure punctuality.

The indicators were also computed for each of the five airports. Figures 3, 4, 5, 6, and 7 show the monthly arrival and departure punctuality at each airport.

At RJTT (Figure 3), the monthly arrival punctuality tended to be lower than at the other airports. At RJOO (Figure 4) and RJFF (Figure 5), the punctuality was relatively high.

At ROAH (Figure 6) , the arrival and departure punctuality demonstrated significant increase and decrease. On the whole, punctuality was worse than at the other airports. The factors of the fluctuation need to be examined in a future study.

At RJCC (Figure 7), arrival and departure punctuality dropped significantly in December 2008 and February 2009.

Regional peculiarities in Japan deserve some focus. Because Japan extends north and south, the weather conditions vary among areas. RJCC is located in the north. As a result, runway-closure due to heavy snow can occur during winter at this airport while snow rarely falls at the other four. RDP journal implied the possibility of runway-closure during the months. Except for these months, punctuality at RJCC achieved almost the same level as the one at RJOO and RJFF.

C. Disucussion

For the entire data, arrival punctuality was 87.6% and departure punctuality was 92.3%. The same indicators were computed for the main airports in Europe and the United States. In 2007, arrival punctuality was around 78%(Europe) and 76%(US) whereas departure punctuality was around 78%(Europe) and 80%(US) [6].

To compare results, computation methods including data (airports, data recording period) selection criteria needs to be standardized. In this trial study, the data selection criteria were different from the ones in the study in Europe and the US.

In [6], it was also pointed out that the gap between departure and arrival punctuality was quasi nil in Europe whereas it was significant in the US. From Figure 2, it was observed that Japanese gap was more similar to the one in the US.

At all the airports, trend for increase and decrease between arrival and departure punctuality were the same. The trend implied the possibility of reactionary departure delay caused by arrival delay.

III. Predictability Study

A. The Phases Definition

From the viewpoint of predictability, in an ideal situation, the actual time-distance is equivalent to the expected value for all the flights. Because schedule times on timetables might include some buffer, planned times in the flight-plans were regarded as more suitable than scheduled time for the punctuality study.

In order to examine the predictability in detail, the entire operation between gate-out and gate-in was divided into distinct phases. Recorded times of flight operation events (gate-out, take-off, touch-down and gate-in) were regarded as standard and precisely-defined breakpoints of the various phases [7]. In this study, based on the recorded times of the various events, the flight operation was classified into the following four phases:

1) Pre-departure (ended at gate-out),
2) Taxi-out (began at gate-out and ended at take-off),
3) Airborne (began at take-off and ended at touch-down),
4) Taxi-in (began at touch-down and ended at gate-in).

The data items for the computation were obtained from ATM system journals as follows: the flight plan data items were gathered from FDMS (Flight Data Management System) journals. Take-off and touch-down times were also obtained from FDMS journals. As was the case with punctuality, actual gate-in times and gate-out times were obtained from SMAP journals.

Figure 8 represents the idea of the phase classification. Predictability indicators were defined as amount of variance between expected and actual time distance and computed as follows.

B. The Computation Methods

1) Pre-departure: The pre-departure delay was equivalent to the deviation of the actual gate-out time from schedule time. The actual gate-out times were recorded as AOBT. On the other hand, the schedule gate-out time is available as Standard Time of Departure (STD) .

In the flight-plan, planned departure time is recorded as EOBT (Estimated Off-Block Time). STD is initially applied as EOBT. However, in the case of planned departure time being delayed, flight plans are re-issued so that EOBT is renewed. Although it can be measured as variance between AOBT and EOBT, pre-departure delay was regarded as the variance between initial planned time and actual time and computed as:

$$AOBT - STD.$$

The ATM-related factors of the pre-departure delay include the following items.

- Airport surface design,
- Runway/taxiway congestion,
- Convergence of departures that use the same SID (Standard Instrument Departure) route,
- Take-off time adjustment by ATFM (Air Traffic Flow Management).

2) Taxi-out: Actual taxi-out time was defined as time-distance between AOBT and Actual Take-Off Time (ATOT). To measure delay amount, standard taxi-out time T_o needs to be defined for every pair of departure-gates and take-off runways. The taxi-out delay was computed as:

$$(ATOT - AOBT) - T_o.$$

The ATM related factors of the taxi-out delay include airport surface design and runway/taxiway congestion.

The ATFM (Air Traffic Flow Management) system had the data set of assumed time-distance between each pair of departure gates and take-off runways. The data set was used for take-off time estimation. For convenience, the data set were used as tentative standard values. It should be noted that the data set were comprised of representative values and were not always equivalent to the shortest (unimpeded) ones.

3) Airborne: Prior to departure, based on planned routes and predicted weather conditions, airlines estimate airborne time as EET (Estimated Elapsed Time) and it is recorded in flight-plans. On the other hand, the actual value can be computed as time-distance between ATOT and Actual Landing Time (ALT). As a result, the airborne delay is computed as:

$$(ALT - ATOT) - EET.$$

The ATM-related factors of airborne delay include airspace congestion.

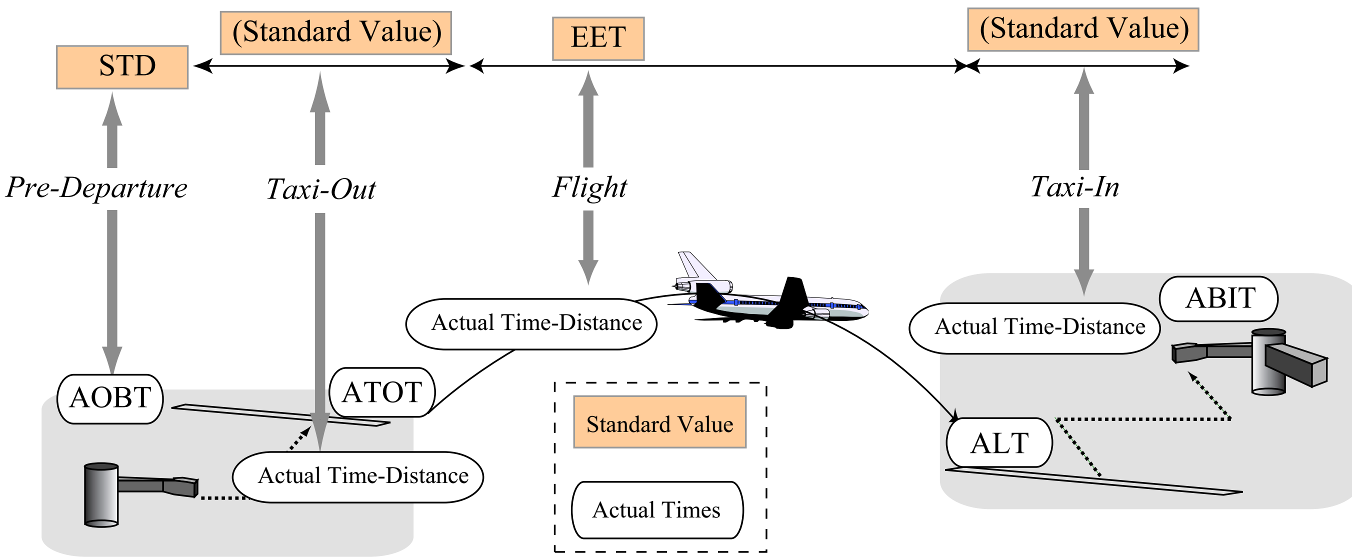

Fig. 8. The Phases Classification of a Flight Operation

It should be noted that the EET computation method including weather prediction may vary among airlines. As a result, even though the planned routes, cruising speed and other items were identical, EET might be different among airlines. In this study, it was assumed that EET represented airlines' expected airborne time-distance and the values were used without modification.

4) taxi-in: Actual taxi-in time was defined as time-distance between ALT and actual gate-in time (ABIT). Standard taxi-in time was represented as T_i. The taxi-in delay was computed as:

$$(ABIT - ALT) - T_i.$$

The ATM related factors of the taxi-in delay include airport surface design and gate congestion.

As is the case with taxi-out, T_i had to be defined for every pair of touch-down runways and arrival gate. The data set from ATFM system was exploited for the definition of T_i. Because the ATFM system did not define taxi-in times, the pairs of departure gates and take-off runways were converted into pairs of touch-down runways and arrival gates. Deducting pre-assumed push-back time (three minutes) from the corresponding T_o, T_i was defined and used as the standard value.

C. Analysis Results

1) Averages: Predictability of arrivals at the five major airports was studied. The analyzed data period was identical to the one in the punctuality study. Due to SMAP application coverage, pre-departure delay and taxi-out delay were computed only for the flights departing from the five major airports.

Firstly, the monthly averages were studied. In an ideal situation, all the averages should be constant and the values should be close to zero.

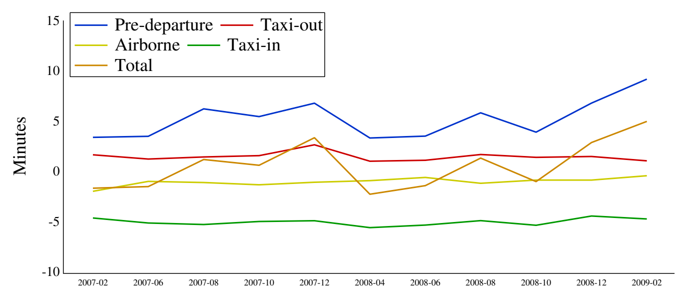

Fig. 9. Trends in the Averages of the Delays (the Five Airports, Monthly)

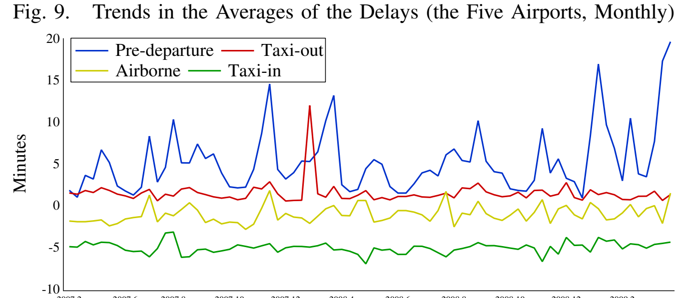

Fig. 10. Trends in the Averages of the Delays (the Five Airports, Daily)

Figure 9 shows monthly averages at the five airports combined. From the figure, it was observed that pre-departure delay fluctuated and the other delays were relatively constant.

Figure 10 shows daily averages for comparison. Comparing Figure 10 with Figure 9 indicates that fluctuation over the months was much smaller than from day to days. It can be attributed to anomalous operation occurrences. With the

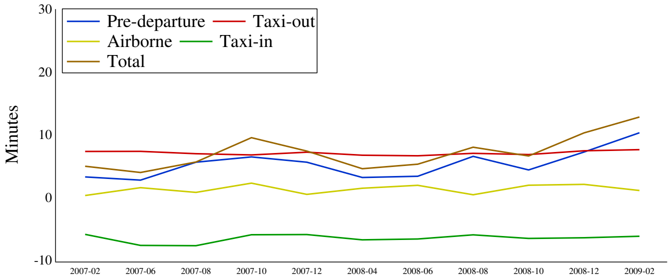

Fig. 11. Trends in the Averages of the Delays (RJTT Arrival)

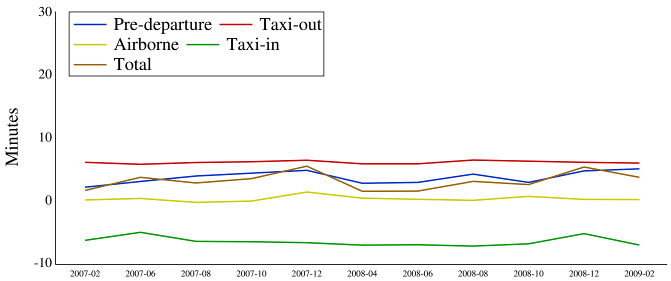

Fig. 12. Trends in the Averages of the Delays (RJOO Arrival)

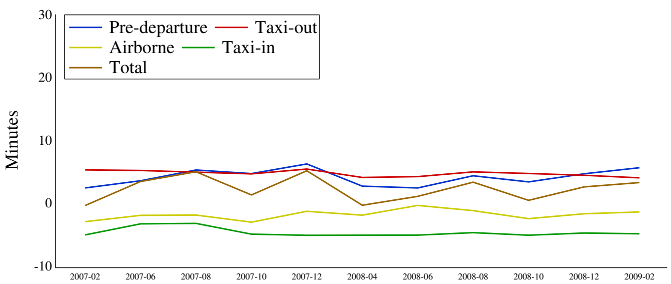

Fig. 13. Trends in the Averages of the Delays (RJFF Arrival)

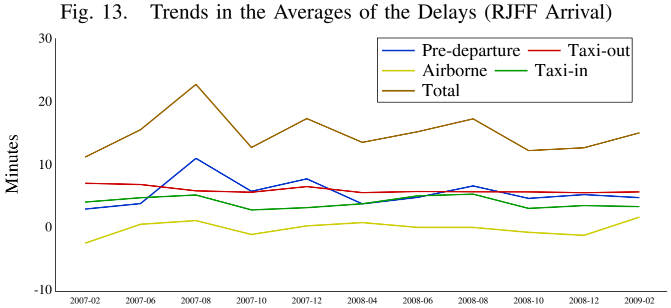

Fig. 14. Trends in the Averages of the Delays (ROAH Arrival)

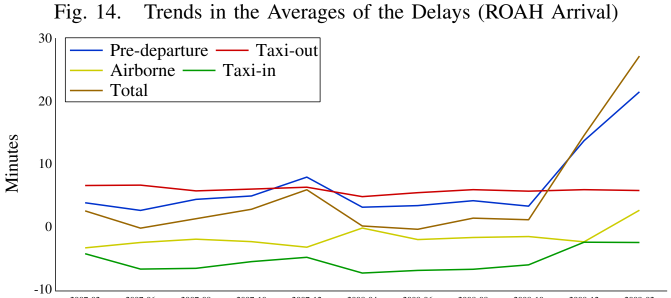

Fig. 15. Trends in the Averages of the Delays (RJCC Arrival)

current technology, anomalous operations occurrences due to unexpected weather and operation events are inevitable. As a result, disturbances could occur. In the computation of the daily averages, these disturbances can affect them to a remarkable degree. On the other hand, the effect was neutralized to some extent in the computation of the monthly averages in which 6-7 days worth of data were combined.

The monthly averages were also computed for arrivals at each of the airports. Figures 11, 12, 13, 14 and 15 show the monthly averages at each airport. At all the airports, pre-departure delays fluctuated more than the other delays. In particular, on December 2008 and February 2009, a huge amount of pre-departure delay was observed at RJCC arrivals. In these months, airborne and taxi-in delays for RJCC arrivals also increased. This can be attributed to the possibility of runway-closure mentioned in II-B.

At the five airports, taxi-out delays were virtually constant. Airborne and taxi-in delays demonstrated small fluctuations.

2) The Standard Deviation: In addition to the average, analysis of variations was indispensable for the predictability study. Variations were measured based on the standard deviations in this study. Ideally, the standard deviation should be small and constant.

Figure 16 shows the monthly standard deviation at the five airports combined. From this figure, it was observed that the standard deviation of the pre-departure delay fluctuated more widely than the others. In addition, the standard deviation of the pre-departure delay was always much higher than the others. While the standard deviation of pre-departure delay was always more than 10 minutes, others were less than 10 minutes.

For comparison, Figure 17 shows the daily standard deviation of the delays at the five airports combined. The daily fluctuation of pre-departure delay was wider than the monthly one.

The standard deviations were also computed for each of the airports. Figures 18, 19, 20, 21 and 22 show the monthly standard deviations. As was the case with the five airports combined, the standard deviations of pre-departure delay were always much higher than the other delays at each of the airports. At RJCC, the standard deviation of airborne delay and taxi-in delay increased in December 2008 and February 2009. In common with the averages, it can be attributed to the possibility of runway-closure.

Except for pre-departure delay, delays proved to be relatively constant. It implied predictability after gate-out within a certain range.

D. Discussion

Table I shows the averages and the standard deviation of the delays on the entire data. In the table, the averages and the standard deviation of pre-departure delay were extremely high.

The averages of taxi-in delay took negative values. It is less reasonable to assume that the actual taxi-out time is five minutes shorter than the expected value. Thus the averages

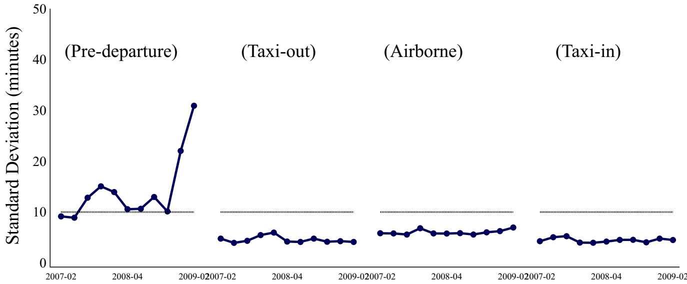

Fig. 16. Trends in the Standard Deviation of the Delays (Five Airports, Monthly)

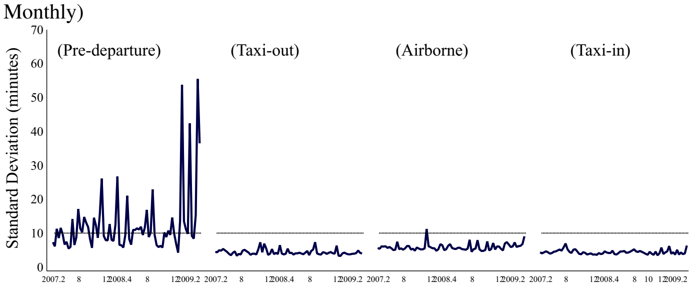

Fig. 17. Trends in the Standard Deviation of the Delays (Five Airports, Daily)

TABLE I
THE AVERAGES AND THE STANDARD DEVIATION (MINUTES)

Phase	Average	Standard Deviation
Pre-depature	5.2	15.4
Taxi-out	1.5	4.6
Airborne	-1.1	6.0
Taxi-in	-5.1	4.5

implied that the computation method for taxi-in delay needs to be refined.

The averages of taxi-out delay and airborne delay were close to zero. The averages of actual taxi-out and actual airborne time-distance were 12.8 minutes and 72.4 minutes respectively. Taking the average of the actual time-distance into consideration, the variability of taxi-out delay can be regarded as being much more than airborne delay. It is generally recognized that uncertainty in taxi-out delay reduces predictability of the entire operation[8].

From this study, weak predictability of pre-departure delay was indicated. The pre-departure delay was computed at the flights departing from the Japanese five major airports. On the other hand, in punctuality study presented in II, it was indicated that departure predictability in the same data sets was high (92.3%).

Figure 23 shows the frequency distribution of pre-departure delay at the five airports combined. The frequently distribution indicates that although the percentage of pre-departure delays of more than 15 minutes was smaller, the spread of the distribution was rather large. The large distribution explains the high averages as well as the standard deviation for pre-departure delay.

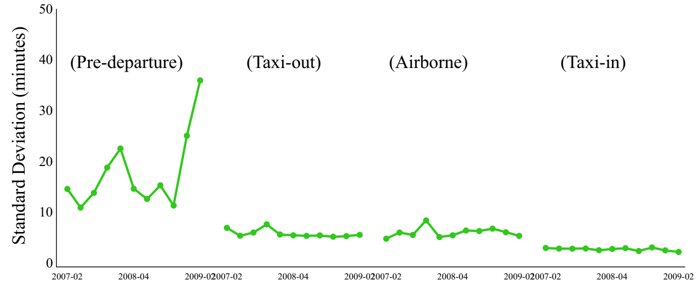

Fig. 18. Trends in the Standard Deviation of the Delays (RJTT Arrival)

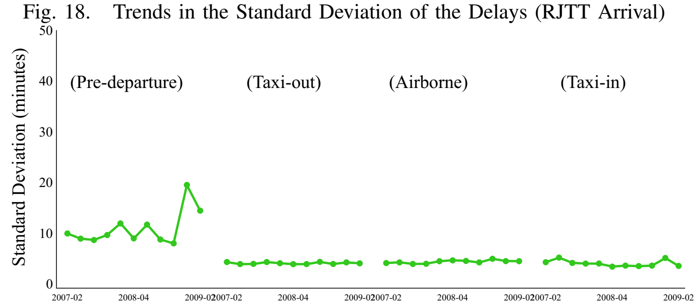

Fig. 19. Trends in the Standard Deviation of the Delays (RJOO Arrival)

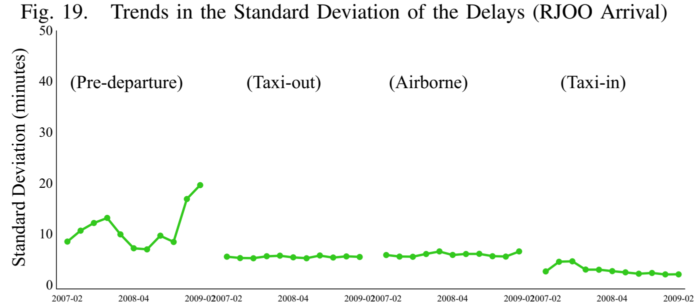

Fig. 20. Trends in the Standard Deviation of the Delays (RJFF Arrival)

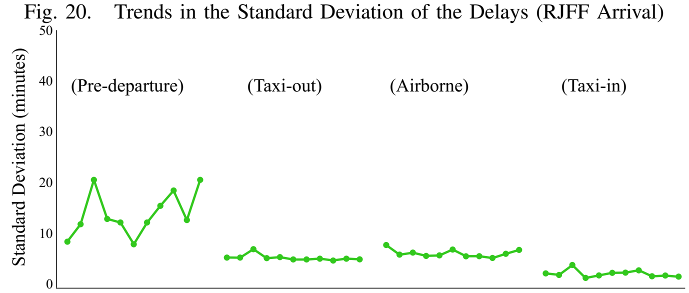

Fig. 21. Trends in the Standard Deviation of the Delays (ROAH Arrival)

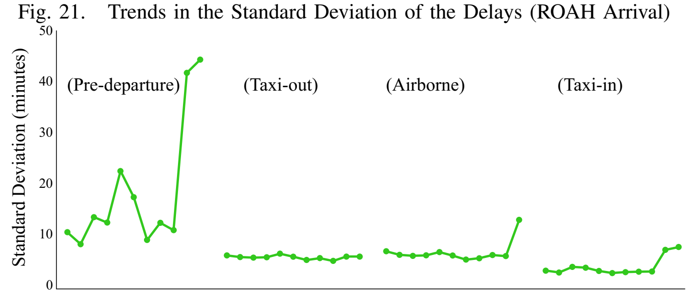

Fig. 22. Trends in the Standard Deviation of the Delays (RJCC Arrival)

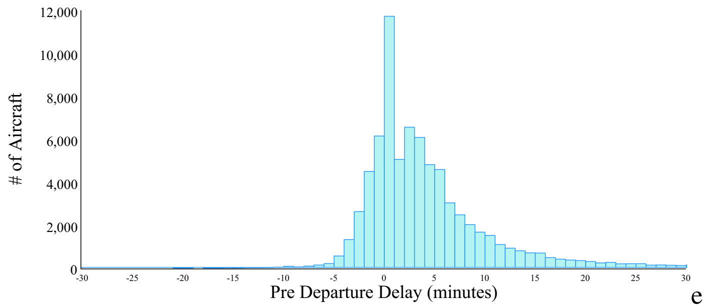

Fig. 23. Frequency Distribution : Pre-departure delay (Five Airports)

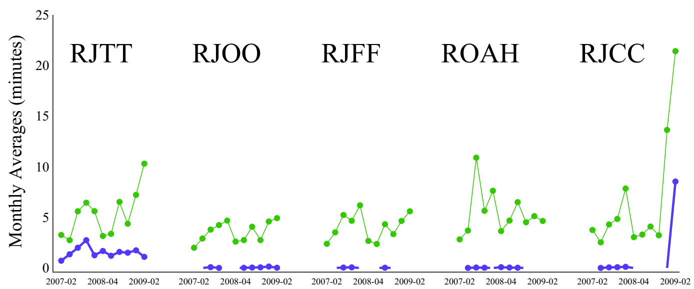

Fig. 24. Averages of Pre-Departure Delay and ATFM Delay (Monthly)

As was the case with the study for flights in Europe and in the US[6], the Pre-departure delay proved to be the main driver of punctuality fluctuation in the flight operations.

IV. Study of Causes of Pre-departure Delay

In the analysis results mentioned above, pre-departure delay fluctuated widely over the observed months. The causes of the fluctuation need to be studied. For instance, CODA classifies the causes of pre-departure delay into categories based on the data supplied from airlines[5]. However, because the data on delay causes were not available, it was impossible to classify pre-departure delay in this study.

Exploiting ATM journals, one of the ATM-related causes of pre-departure delay was examined. ATFM is a typical ATM function that affects pre-departure delay. To avoid airspace congestion, ATFM applies take-off times as EDCT (Expected Departure Clearance Time) to delay flights prior to departure. As a consequence, gate-out or taxi-out time can be delayed. Meanwhile, the delay amount during the airborne phase should be reduced due to ATFM interventions.

There was a possibility that the gate-out time adjustment for ATFM had caused for the observed fluctuation of pre-departure delay.

To analyze the impact of ATFM, ATFM delays were computed as:

$$EDCT - ETD.$$

ETD (Expected Departure Time) which corresponded to planned take-off time, was computed as the sum of EOBT and T_o. EDCT was issued only for the flights with regulated take-off time. ATFM delay was computed for each of the EDCT-issued (delayed) flights. Then, the sum of ATFM delays were computed.

Monthly averages of the ATFM delays were computed by dividing the sum by the number of all the arrival in each month. It should be noted that the ATFM delay did not cover the entire ATFM adjustment, because sometimes take-off times were adjusted without the issuance of an EDCT.

Figure 24 shows a comparison of the monthly averages between pre-departure and ATFM delays. The comparison represents the magnitude of ATFM impact on the entire pre-departure delay. In the figure, the averages were categorized by arrival airports.

RJTT arrivals incurred ATFM delay primarily. It implied the frequency of demand and capacity balancing due to heavier arrival traffic volume at the airport.

It was also observed that in February 2009, RJCC arrivals incurred a huge amount of ATFM delay. As mentioned earlier, there was a possibility of runway-closure on this month. The ATFM delay could be correlated with the possibility of runway-closure. Excluding this case, strong ATFM impact on monthly pre-departure fluctuation was not recognized at the airports.

TABLE II
Statistical Data of ATFM Delay

	% of Flights Delayed	Delay per Flight (minutes)	Delay per Delayed Flight (minutes)	Pre-deparute Delay per flight (minutes)
All	6.7%	0.7	10.5	5.2
RJTT	15.8%	1.5	9.8	5.3
RJCC	16.4%	8.5	51.8	21.4

Table II shows the statistical data for ATFM delay from the analysis results. In the table, the averages of pre-departure delay are also presented for comparison. For the arrivals at the five airports combined, the arrivals at RJTT, and the arrivals at RJCC (February 2009), the respective statistical data were computed. For the arrivals at the five airports combined, the percentage of ATFM delay to pre-departure delay was around 13.5%(= 0.7/5.2). On the other hand, the percentage was 28.1%(= 1.5/5.3) for RJTT arrivals and 39.7%(= 8.5/21.4) for RJCC arrivals (February 2009). It was indicated that, for the arrivals at RJTT and RJCC (February 2009), ATFM delay accounted for a certain degree of percentage of pre-departure delay.

V. Conclusion

Results from an analysis of delays in air transport at Japanese major airports were presented in this paper. Although long term analysis is required, the following items were observed from this trial study.

In the entire data, the arrival punctuality was 87.6% and departure punctuality was 92.3%. Also, there was a possibility of extreme impact from weather conditions at one of the airports.

Delay was also studied from the viewpoint of predictability. The flight operation was divided into distinct phases. The monthly averages and the monthly standard deviation of pre-departure delay demonstrated rather wide fluctuation whereas those of the other delays were relatively constant. Although the percentage of departures no more than 15 minutes later than the scheduled time was small, the spread of the distribution was rather large. As a result, pre-departure delay proved to be the main driver of punctuality fluctuation. The previous study of air transport in Europe and the US indicated the same results.

ATFM delay was examined for the study of pre-departure delay causes. ATFM impact on pre-departure fluctuation was not recognized. However, for some aspects, ATFM delay accounted for a certain degree of percentage of pre-departure delays. In particular, for arrivals at a domestic hub airport, ATFM delays always had some degree of impact.

To study punctuality more precisely, refinement of the computation method for taxi-in delay is indispensable. In addition, to investigate and classify pre-departure delay causes, data from airlines are required.

To compare results from separate analyses, computation methods including data selection criteria need to be standardized. Setting proper standards for the computation methods can contribute to establishment of international harmonization for delay-related ATM performance assessment. In addition, data exchange would realize detailed study on delay of international flights.

It is without doubt that delay factors need to be continuously monitored and trends must be studied to achieve a detailed ATM performance analysis. Continuous application of the data analysis presented in this paper can assist in monitoring and controlling the delay transitions and consequently offer significant insights into future ATM improvements.

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References

[1] ICAO, "Global air traffic management operational concept," Doc 9854 AN/458, 2005.

[2] J. J. Schotle, H. A. P. Blom, H. v. d. Bos, R. B. H. J. Jansen, "Management of ATM performance in operational concept development and validation : A case study," in *8th USA/Europe Air Traffic Management Research and Development*, 2009.

[3] Performance Review Commission, "Performance review report 2006," 2007.

[4] SESAR Consortium, "Milestone deliverable D2: The performance target," 2006.

[5] Central Office for Delay Analysis, "Digest - annual 2008 delays to air transport in Europe," Eurocontrol.

[6] J. Gulding, D. Knorr, M. Rose, J. Bonn, P. Enaud, H. Hegendoerfer, "US/Europe comparison of ATM-related operational performance," in *8th USA/Europe Air Traffic Management Research and Development*, 2009.

[7] E. R. Mueller and G. B. Chatterji, "Analysis of aircraft arrival and departure delay characteristics," in *Aircraft Technology, Integration and Operations*. NASA Ames Research Center, 2002.

[8] P. Balakrishna, R. Ganesan, L. Sherry, "Accuracy of reinforcement learning algorithm for predicting aircraft taxi-out times," in *3rd Intanational Conference on Research in Air Transportation*, 2008.