Proceedings of the Eastern Asia Society for Transportation Studies, Vol.12,2019

Estimation of Delay Causes of Arrival Flights Considering Delay Propagation in Japanese Domestic Air Transport Network

Terumitsu HIRATA [a*], Teruaki SATOH [b], Shin-ichi TAKAKURA [c]

[a,b] *Graduate School of Science and Technology, Ibaraki University, Ibaraki, 316-8511, Japan;* [a] *E-mail: terumitsu.hirata.a@vc.ibaraki.ac.jp*
[b] *Faculty of Engineering, Ibaraki University, Ibaraki, 316-8511, Japan; E-mail: 15t5028l@vc.ibaraki.ac.jp*
[c] *Chiba Prefecture, Chiba, 260-0855, Japan*

Abstract: The purpose of this study is to quantify the propagation delay and specify the root cause of the propagation delay by using the actual delay data from Japanese civil aviation bureau (JCAB). First, we developed the calculation method for separating the original and propagated delay. Then, by integrating the propagated delay data and delay cause data from JCAB, we estimated the delay cause share of arrival flights with the different ways of aggregation.

Keywords: Air Transport, Delay Cause, Delay Propagation, Arrival Delay

1. INTRODUCTION

In Japan, the long-term vision on the future air traffic system (named “CARATS: Collaborative Actions for Renovation of Air Traffic Systems”) has been formulated in 2010, and the government, industry and academia has collaboratively introduced various measures to improve the operation of air traffic (ref. CARATS website). But, the flight delay which is one of the key performance indicators of air traffic system in Japan, has been continuously deteriorated after CARATS started (Figure 1), while the on-time performance in Japan is still high revel. As for the delay cause for the departure flights, about 70% of the delay cause is "Late-arriving aircraft" which is caused by a previous flight with same aircraft arriving late (CARATS 2015) (Figure 2). This is kind of propagated delay from upstream flights, so they should have a root cause of the delay. While only the departure delay causes are analyzed in Japan, it is important for air service and airspace system users to analyze “arrival delay cause” ultimately. In order to investigate the delay cause more precisely for planning more effective delay mitigation measures, it is better to analyze the propagated delay with its root delay cause and arrival delay causes in the network basis. In this research, we analyze the delay propagation and arrival delay cause in Japanese domestic air network.

Regarding the analysis of delay cause of air transport, US and Europe have been conducting comprehensive analysis of delay cause data such as by the Bureau of Transportation Statistics (BTS) in US and Central Office for Delay Analysis (CODA) in Eurocontrol. In the analysis by those organizations, the delay cause also for arrival flights are shown in detail but there are not necessarily shown the detailed procedures to be analyzed. Also our research focus on how to estimate arrival delay cause only from the delay cause data for departure, and it is not sure but those regions is consider to have such data including arrival delay causes. Muller et al. (2002) introduced several delay cause statistics for

[*] Corresponding author.

departure and arrival flight and analyzed the delay statistics of 10 major airports in US for predicting delay time by some probabilistic functions. Regarding the delay propagation, there are many existing researches. For example, Welman (2010) proposed the methodology to separate the original delay and the propagated delay from the observed total delay time and computed the delay propagation multiplier. Kafle et al. (2016) proposed the new econometric model to estimate the delay propagation multiplier considering operational buffer time effect. But there are few researches that analyze the propagation of delay with the cause of the delay. This research, by considering insufficient statistics about delay cause data, proposes the methodology to calculate the arrival delay cause from departure delay cause data and delay time data with considering delay propagation.

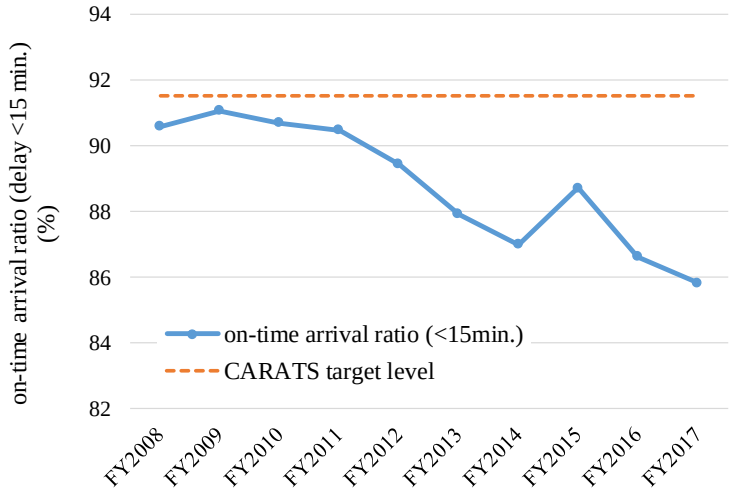


Figure 1. One-Time arrival performance (>15min. delay) of domestic flight in Japan (Source: CARATS, Japan Civil Aviation Bureau, 2019)

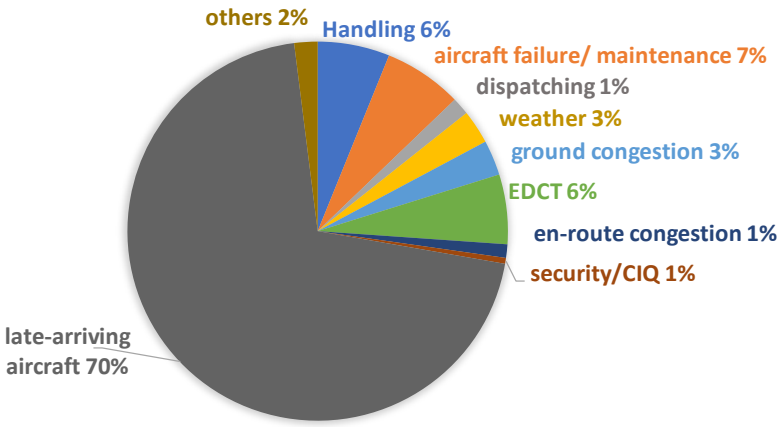


Figure 2. Delay cause share (2014, JCAB: aggregated the delay cause of the flights with 15 minutes or more delay at the number of flight basis) (source: CARATS, 2015)

2. DATA

In this research, the domestic flight operation data including flight delay statistics in FY2016 which is provided by Japanese Civil Aviation Bureau (JCAB) in the Ministry of Land, Infrastructure and Transport (MLIT). The data includes the origin/destination airport,

aircraft type, the scheduled time of departure and arrival, actual time of departure and arrival, actual time of take-off and landing and departure delay causes (that is reported by each airline). The multiple departure delay causes are recorded for each flight with delay time by each cause, but the total of each delay time is sometimes not equal to the departure delay time that is calculated by the difference of scheduled and actual time of departure. Therefore, it is necessary to adjust them for calculate the delay time of each delay cause. Also, we excluded the data which cannot trace all of the flights with same aircraft in every single day for the analysis of the delay propagation, and which lacks the delay cause for the analysis of delay cause. As a result, the number of sample data used is about 650,000 flights for the analysis of the delay propagation (around 76% of the domestic flights), and about 540,000 flights for the analysis including delay cause (around 63% of the domestic flights).

3. METHODOLOGY FOR ANALYSING ARRIVAL DELAY CAUSES CONSIDERING DELAY PROPAGATION

3.1 Basic Concept

Our goal is to grasp the delay time due to multiple delay causes of each arrival flight. The delay cause data in Japan includes the cause of departure delay only. Therefore, the arrival delay cause should be defined by using the other flight data such as the scheduled and actual time of departure and arrival. Since the data also includes the time of take-off and landing, we can estimate the delay time in each flight phase like the delay in taxing at departure airport, that in flight and in taxing at arrival airport by defining the nominal time of operation in each phase.

As for the delay propagation, around 70% of the delay cause of departure flight is the “late-arriving aircraft” that is the cause related to delay propagation (Figure 2). But it must have a root cause (original cause) that links to the upstream flight. Therefore, in order to grasp more precise delay causes, we break down the calculated propagated delay time into the root delay causes. Then, finally, the delay time due to multiple delay causes of each arrival flight can be calculated by combining the arrival delay calculation and break-down of the delay cause for propagated delay. The detail calculation methods are presented in the following subsections.

3.2 Calculating Arrival Delay Cause

In this section, we focus on arrival delay time and its delay cause. Since only the delay cause for departure is known in the data from JCAB, the delay cause of arrival flight is unknown. Then, we estimate the individual delay time of each arrival delay cause (IDT-A) by proportionally allocating the individual delay time in each departure delay cause (IDT-D) if the arrival delay decreased from the departure delay, and otherwise (if the arrival delay increased from the departure delay) we set the increased portion of delay time as “gate-to-gate delay”. Since there are some inconsistent data in the database, we set such data as “unknown” delay cause. For example, if the delay time by “late-arrival aircraft” cause increased (this increase cannot occur in real life), the increase time was set as “unknown” delay time. And if the sum of the departure delay time of each delay cause was is different from the “total departure delay time (Actual time of departure: ATD – Scheduled time of departure: STD)”, we adjust the difference by proportionally decrease/increase each IDT-D to be the same value as total delay time (ATD-STD).

3.3 Breaking-down of “Late-arriving aircraft” into its Root Delay Causes

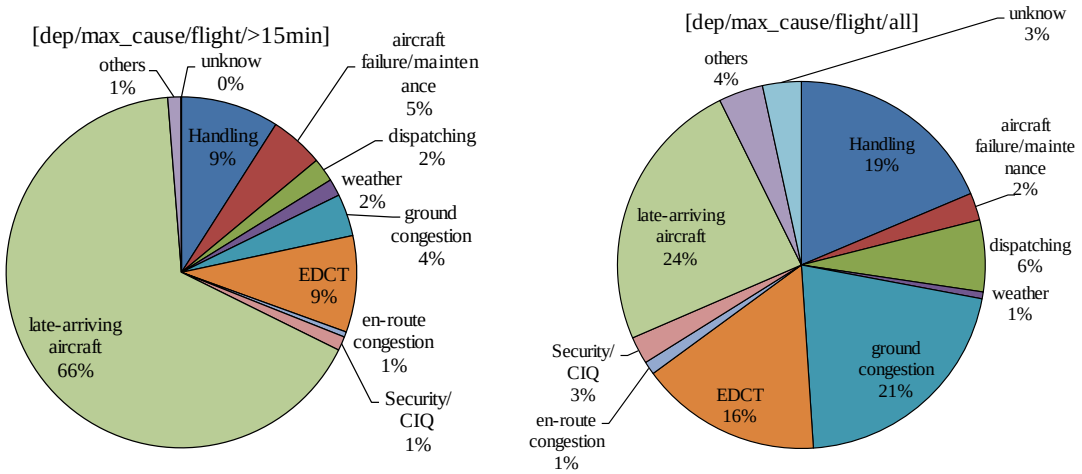
The breaking-down of "late-arrival" delay in the departure delay (that is originally recorded in JCAB database) into the root (original) delay cause was done by distributing the individual delay time of the arrival delay of the previous arrival flight (ITD-A’) by decreasing each delay time in proportion to the ratio of “late-arriving delay” time and “IDT-A’”. As there are some data including “late-arrival” delay cause even in the first flight of the day, there remained “late-arrival” in such case.

4. RESULTS

4.1 Basic Aggregated Analysis by JCAB

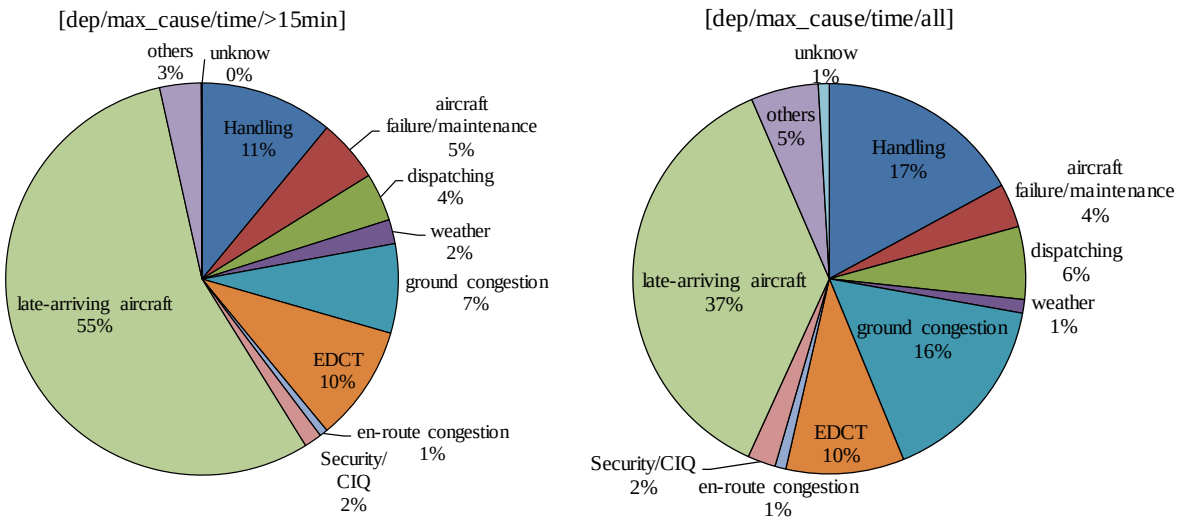
First, the basic aggregated analysis that is the same method by JCAB is conducted for the comparison. JCAB has analyze the delay cause only for departure and just aggregate the share of one of the major delay causes of each flight. Also JCAB use only the flights delayed 15 minutes or more and aggregate the data on a “flight” basis, that means there is no difference among the delay causes with different delay time. For example, the delay cause of 20 minutes delay and that of 40 minutes is the same weight in the aggregation.

Figure 3 shows the calculation result in JCAB basic style, just aggregating the share of one of the major delay causes on a “flight” basis for the 15 minutes or more delayed flights and for all flights. And figure 4 shows the same aggregation results but aggregated with “delay-time” basis (weighted by the delay time of each cause). From these results, the picture for delay cause share is significantly changed just by applying the different aggregation basis, especially whether the delay causes of the flight with less than 15 minutes delay (all flights) are considered or not is quite big impact on the share. Considering “late-arriving aircraft” is major and important cause of delay and it usually affects delay in a cumulative manner, relatively small delay time like less than 15 minutes is also important to analyze.



(a)Flight basis / >15min (b)Flight basis / all

Figure 3. Departure delay cause share: JCAB’s basic style (aggregated the delay cause of the flights on a flight basis for (a) 15 minutes or more delayed flights and for (b) all flights, 2016)



(a)Time basis / >15min (b)Time basis / all

Figure 4. Departure delay cause share: JCAB's basic style (aggregated the delay cause of the flights on a delay-time basis for (a) 15 minutes or more delayed flights and for (b) all flights, 2016)

4.2 Arrival Delay Cause

Figure 5 shows the result of calculating arrival delay cause by considering gate-to-gate delay and its breakdown into the three operational phases. All of the delayed flight data and multiple delay causes are used and aggregated on a delay-time basis. For the arrival delay cause, it is clearly shown that "gate-to-gate delay" which occurs from off-block (gate-out from the departure airport terminal building) to in-block (gate-in to arrival airport terminal building) has 40% share of the delay cause.

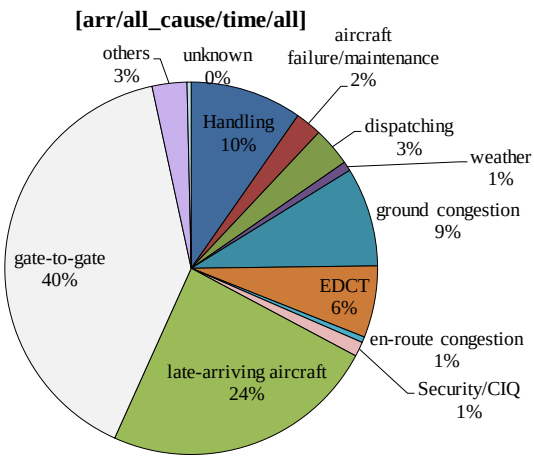


Figure 5. Arrival delay cause share including late-arriving aircraft

Among gate-to-gate delay, while its breakdown of in-flight delay, departure and arrival taxi delay is still unknown in this study, the delay in flight phase can be considered to be due to the waiting time (radar-vectoring: flight route extension for adjusting landing time) in the airspace surrounding arrival airport due to arrival runway congestion and/or meteorological

conditions such as strong head-wind and bad weather that forces aircrafts to reroute. And the delay in taxing on the ground at departure airport can be considered to be due to mainly congestion of departure runway (lack of departure capacity) and the traffic congestion surrounding parking spots (apron area).

4.3 Breakdown of "Late-arriving Aircraft"

Figure 6 shows the result of the breakdown of "late-arriving aircraft" into the root (original) delay cause. By comparing with the original delay cause share, we can know which delay cause can easily propagate in the network.

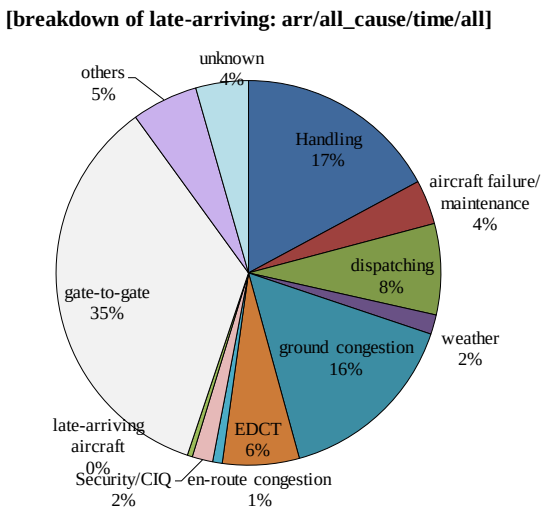


Figure 6. Breakdown of "late-arriving aircraft" into the root (original) delay cause

4.4 Final Result of the Arrival Delay Cause Share Reflecting the Breakdown of Late-arriving Aircraft

Finally, by reflecting the breakdown of late-arriving aircraft shown in figure 6 to the arrival delay cause share shown in figure 5, we can obtain the root (original) delay cause share for arrival flight. The results are shown in figure 7. And figure 8 shows the comparison of delay cause share of (a)final result in figure 7 and (b)JCAB original result without late-arriving aircraft in figure 4(a), and red-lined cause indicates airline-related cause and blue-lined cause indicate ATC/airspace system-related cause. From these figures, it is shown that the share of the delay cause is quite different if we apply the different way of delay data aggregation such as "flight-basis or time-basis", "departure delay cause or arrival delay cause" and "with or without breakdown of late-arriving aircraft" shown in this research. For example, if we compare (a) and (b) in figure 8, the share of ATC/airspace related cause is much higher in the final result in the analysis in our study than that in the result of original JCAB aggregation of departure delay with flight basis. This is the implication for the importance of introducing new technologies and aviation infrastructure like CARATS program.

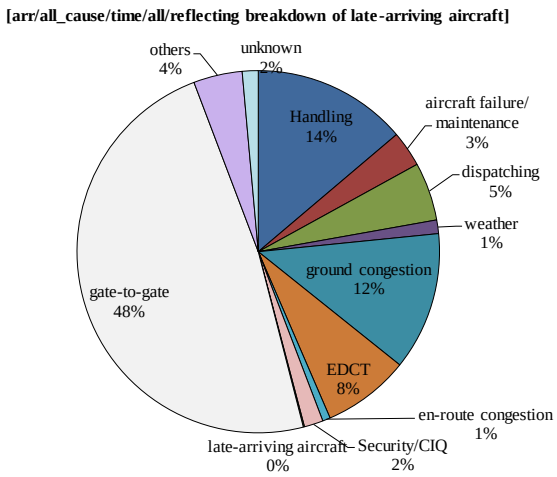
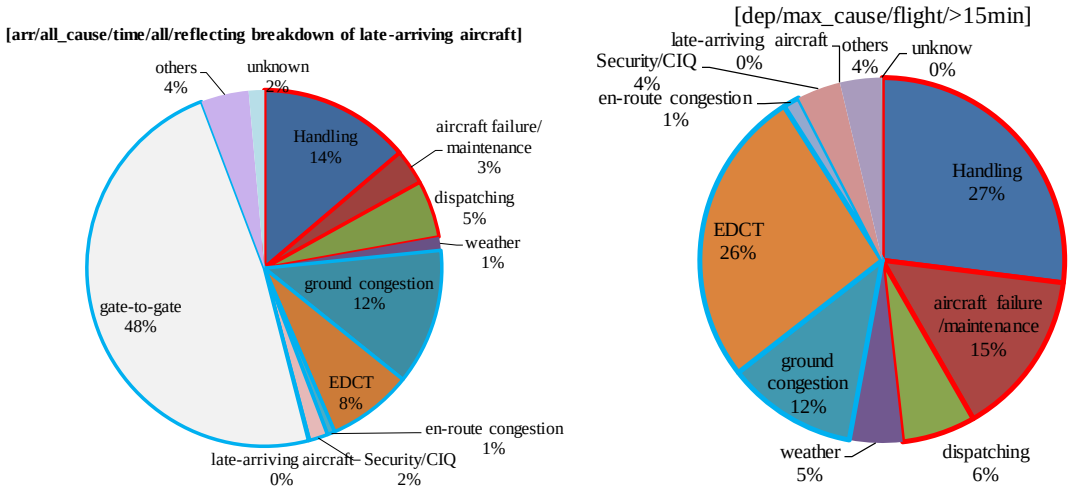


Figure 7. Arrival delay cause share reflecting the breakdown of late-arriving aircraft



(a) final result in figure 8

(b) JCAB original result without late-arriving aircraft in figure 4(a)

Figure 8. Comparison of delay cause share: (a)final result in figure 7 and (b)JCAB original result without late-arriving aircraft in figure 3(a) (red-lined: airline-related cause, blue-lined: ATC/airspace system-related cause)

5. CONCLUSIONS

In this study, we try to grasp root (original) delay causes of arrival flights in Japanese domestic air transport network by considering the delay propagation. The results show the significant impact of the way of aggregation of delay cause data on the delay cause share, and the main causes seems to be different if we apply different way of aggregation. For example, it is indicated that the share of ATC/airspace related cause is much higher in the final result in the analysis in our study than that in the result of original JCAB aggregation of departure delay with flight basis. This is the implication for the importance of introducing new technologies and aviation infrastructure like CARATS program.Although several issues remain to be solved such as how to estimate true cause of gate-to-gate delay like airspace congestion and meteorological condition effects, the analysis proposed in this research have a potential to examine more effective countermeasures to mitigate flight delay and estimate the

network effect of the benefit of such countermeasures in specific airport/airspace.

ACKNOWLEDGEMENTS

We used the flight delay statistics data provided by Japan Civil Aviation Bureau of the Ministry of Land, Infrastructure, Transport and Tourism in Japan.

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