DESIGN OF OPERATIONAL DATABASE FOR ATM PERFORMANCE ASSESSMENT

Kota Kageyama , Yutaka Fukuda
Electronic Navigation Research Institute

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Abstract

This paper describes an ATM (Air Traffic Management) operational database designed and implemented as a means of ATM performance through operational data analysis, which provides valuable information for continuous improvement. The operational data are recorded in a number of distinct ATM systems and hence the data need to be correlated for identical operations across the various systems.

In the previous operational data analysis efforts, the required data items were collected on a case-by-case basis. The fact that data-collection itself is a time-consuming task hinders efficient analysis of that data and the design and implementation of this operational database is aimed to resolve this problem. This paper describes the design of the database as well as an application of the database with delay results analysis presented.

1 Introduction

To accommodate air traffic demand increase, ATM has significantly improved its performance in the last few decades. However, since further traffic demand is anticipated, further ATM performance improvements and monitoring are required.

To that purpose, ATM performance evaluations are planned that will provide valuable performance assessment information. Through such ATM performance assessment, performance bottlenecks can be identified and prioritized in terms of severity in order to be mitigated and hopefully removed appropriately. Furthermore, such ATM performance studies can and should facilitate the estimation of the benefits of planned ATM improvements prior to their implementation.

Since ATM has, by definition, multiple objectives to accomplish, its performance must be assessed in a continuous monitoring fashion and through multiple assessment viewpoints.

The actual operational data are recorded in a number of distinct ATM systems. In actual operational data analysis instances conducted in the past, the required data items were collected and correlated for identical operations on a case-by-case basis. The fact that data-collection itself is a time-consuming task hinders continuous assessment from multiple perspectives. To resolve this problem, a database was designed and implemented, which collects, correlates and stores the data. The design of this database is described in this paper. Also, as application of the database with delay, analysis results is presented and the efficiency of data collection and analysis achieved through this database is showcased.

2 ATM Performance

For the definition of the various performance assessment viewpoints, ICAO (International Civil Aviation Organization) has defined Key Performance Areas (KPA)[1]. The KPA are comprised of 11 distinct areas related to societal impact (Safety, Security, Environment), ATM prosperity (Access and Equity, Participation by the ATM community), and ATM operational performance

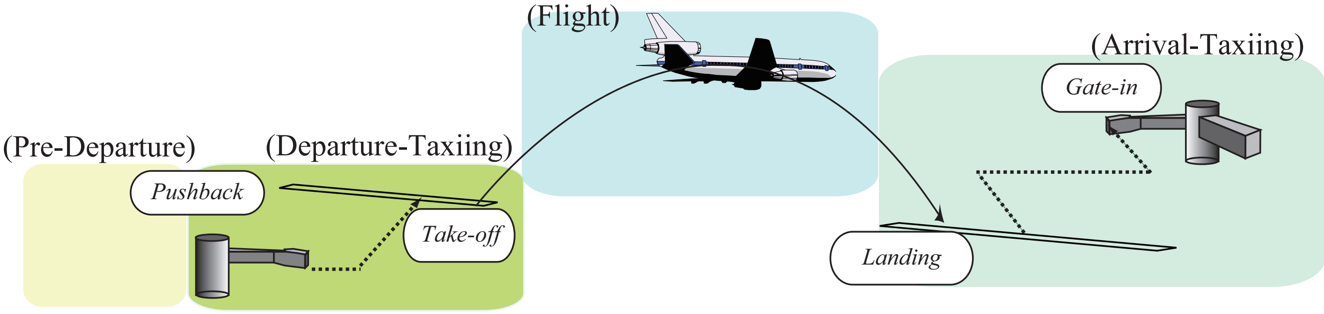

Fig. 1 Examples of the Data Sources

(Cost Effectiveness, Capacity, Efficiency, Flexibility and Predictability).

To cope with expected market growth and meet societal requirements, the future ATM framework needs to be designed and implemented with a service-centric approach[2]. For the verification of the implementation, benefits from the implementation should be monitored periodically and with a solid quantitative foundation. The KPA serve as a guideline for this quantitative assessment. The KPA definition indicates the importance of the ATM performance measurement.

3 Design of the Database

3.1 Objectives

Since the ATM can be seen as a mechanism for supporting and safeguarding aircraft flying operations, the benefits from any ATM performance are to be reflected to the aircraft operations partially recorded in the ATM systems. As a result, the assessment results can be obtained from ATM system journal analysis.

Efficient analysis of the ATM system journals entails challenges for the following reasons. Firstly, ATM is comprised of numerous systems resulting in data recordings in distinct journals. Secondly, due to the traffic volume growth and a number of distinct data items to be recorded, the data volume in ATM systems grows to be quite substantial.

Adoption of database management system (DBMS) is a good countermeasure against these challenges. Since DBMS is destined to control the organization, storage, management and retrieval of data, the adoption of DBMS achieves the desired ATM performance analysis in an efficient way. Data from the ATM system journals were collected, correlated for identical operations and stored into the database.

3.2 The Data Sources

Japanese ATM systems include FDMS (Flight Data Management System) for managing the operational events across all operational phases, SMAP (Spot Management And Planning system) for managing the operational events data at the gates, as well as radar systems such as ARTS (Automated Radar Terminal System), RDP (Radar Data Processing system). Data are also recorded in the ODP (Oceanic air traffic control Data Processing system), the Air Space Management (ASM) system and the Air Traffic Flow Management (ATFM) system.

Data items were obtained from the ATM system journals and scheduled times were obtained from published timetables.

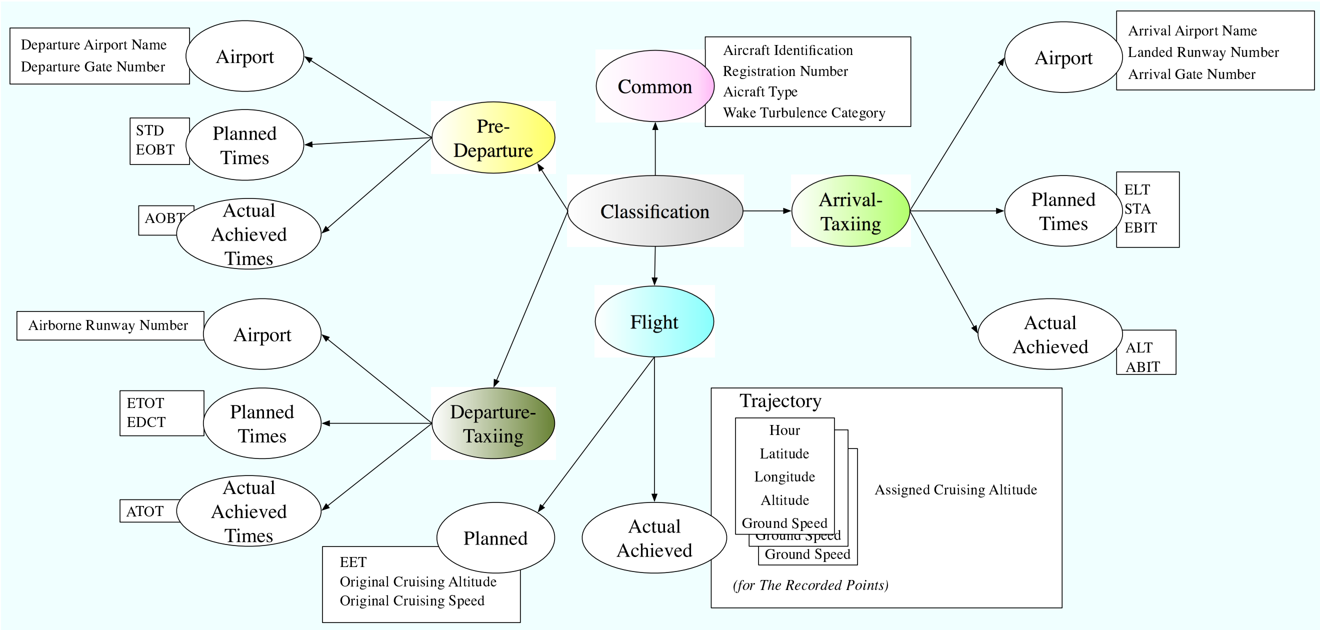

Fig. 2 Item Classification in the Database

3.3 The Operational Phase Classification

In the database, data items were categorized in accordance with the operational phases. Flight events such as pushback, takeoff, touchdown and gate-in are regarded as standard breakpoints between the operational phases[3]. Based on these events, a flight operation was classified into the following four (4) distinct phases

- Pre-Departure
- Departure-Taxiing
- Flight
- Arrival-Taxiing

Fig. 1 depicts the classification of the various ATM operational phases. The pre-departure phase corresponds to the stage until push-back and the departure-taxiing phase begins at push-back and ends at take-off. The flight phase begins at take-off and ends at landing at the destination airport and the arrival-taxiing phase begins at landing and ends at gate-in.

Exploiting radar data journals, we obtained flight trajectory data the analysis of which provided useful information such as the flight distance and the flight profile efficiency. Furthermore, the actual achieved times as well as the planned times of flight events were obtained and the variance between planned and achieved values was studied. Fig. 2 represents the data item classification in the database.

3.3.1 Common Data Items

The data items that were common in all flight phases include aircraft identification, registration number and type and wake turbulence categories. The performance of a particular flight operation, especially in the pre-departure phase, corresponds to the incoming aircraft of the chronologically previous operation. Aircraft registration numbers provide valuable information for studying the effect of previous operations on subsequent ones. These data items were obtained from FDMS journals.

3.3.2 Pre-Departure Data Items

The data items for the pre-departure flight phase were further classified into three (3) categories: airport, planned times, actual achieved times. The airport data items were the departure airport name and departure gate number. The planned and actual achieved times data items corresponded to the push-back time. These times data items were obtained from the published airline timetables (Scheduled Time of Departure : STD), from FDMS (Estimated Off-Block Time : EOBT) and from SMAP (Actual Off-Block Time : AOBT).

3.3.3 Departure-Taxiing Data Items

The data items related to the departure-taxiing phase were also classified into the following three (3) categories; airport, planned times and actual achieved times. The airport data item was the airborne runway number and the data items related to the planned and actual achieved times corresponded to the aircraft take-off times, i.e. the estimated (Estimated Take-Off Time : ETOT) and actual (Actual Take-Off Time : ATOT) times were stored. The ETOT was calculated as follows;

$$ETOT = EOBT + MDT.$$

The minimum departure-taxiing times (MDT) were computed from the recorded actual achieved data, for each combination pair of departure gate and airborne runway. Then, the calculated ETOT referred to aircraft that departed on the planned schedule time (EOBT) and taxied onto the corresponding runway without delay.

The ATOT was obtained from FDMS. In case the ATFM system regulated traffic flows, take-off times were revised to the corresponding EDCT (Expected Departure Clearance Time) and the ATFM effect was studied by obtaining the EDCT from FDMS.

Although it was preferable to include departure taxiing routes in the data, the route data were not available in the current Japanese ATM systems and the taxiing data were thus not stored in the database.

3.3.4 Flight

These data items were classified into two (2) categories: planned and actual achieved. The items classified as planned were obtained from FDMS and comprised of the airspace users' originally intended cruising altitude and speed. Also, the planned flight time (Estimated Elapsed Time : EET) was stored. The EET value was determined by airspace users and it was assumed that the planned flight time corresponded to the minimum flight time necessary for the anticipated weather conditions.

The items classified as actual achieved included the assigned cruising altitude and the flight trajectory data. The trajectory data were obtained from the radar data journals. The data encompassed the trajectory in whole the Japanese FIR. For each time stamp, altitude, latitude and longitude coordinates as well as ground speed were stored.

3.3.5 Arrival-Taxiing

As in the case of the departure-taxiing phase, the data items for the arrival-taxiing phase were classified into three (3) categories: airport, planned times and actual achieved times. The airport data category was comprised of the arrival airport name, the landed runway number and the arrival gate number. The planned and actual achieved time data corresponded to the landing and block-in time. For landing time data, the estimated (Estimated Landing Time : ELT) and the actual (Actual Landing Time : ALT) landing times were stored. The ELT was computed as follows;

$$ELT = ETOT + EET.$$

The ELT corresponded to the situation in which aircraft took off and landed at the arrival airport without delay.

Likewise, for the gate-in data, estimated (Estimated Block-In Time : EBIT), the actual (Actual Block-In Time : ABIT) as well as the scheduled (STA : Scheduled Time of Arrival) times were recorded. The EBIT was computed as follows;

$$EBIT = ELT + MAT.$$

For each combination pair of landed runway and arrival gate, the minimum arrival taxi times (MAT) were obtained from the recorded actual achieved data. The EBIT corresponded to the situation in which aircraft arrived at the gate without delay.

Similarly to the departure route, the arrival taxiing route data were not stored in the database.

4 An Application Instance

4.1 Delay Analysis

In the implementation of the database design described above, MySQL was used as the DBMS and by exploiting the MySQL API (Application Programming Interface) for the computer programming languages, the required data items were retrieved fast and efficient computation of all ATM performance indices were thus achieved.

As an example of the ATM operational database analysis, delay results are presented in this paper. Due to weather conditions and other ATM related reasons, the actual achieved times often disagree with their pre-assumed / planned values. *Delay* is defined as the difference between pre-assumed / planned time and actual achieved time.

Delay is one of the most important elements in the operational performance because it is strongly linked to flight event time predictability and affects ATM system efficiency. Predictability, which is regarded as one of the KPA, is closely related to delay, because the uncertainty and fluctuation of delay reduces the ability to accurately predict the flight event times.

Delay data analysis was focused on arrivals at Tokyo International (Haneda) Airport. The actual data were recorded in the months of February, June, August and October 2007 and six (6) to seven (7) days worth of data were gathered for each month. In total, the data from 27 days were analyzed.

4.2 Schedule Delay

In this analysis, delays were computed based on the scheduled times. Flight operations may suffer delay in all operational phases from pushback to gate-in. Thus, delay was classified in accordance with the operational phases as follows;

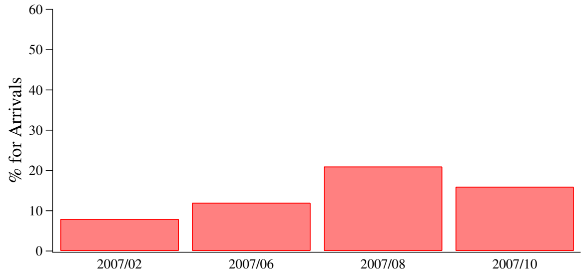

Fig. 3 The Monthly Percentage of *Late Arrivals*

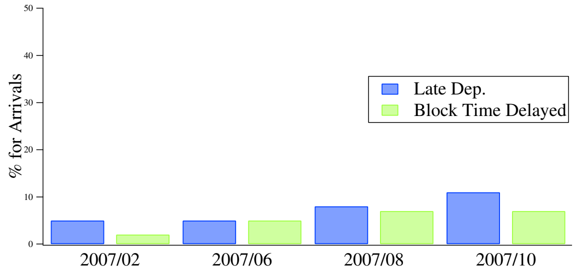

Fig. 4 The Monthly Percentage of *Late Departed, Block Delayed*

- **Departure Delay** corresponded to the pushback delay that occurred by pushback at the departure airports; i.e. the pre-departure phase. The delay amount was computed as follows;

$$AOBT - STD.$$

- **Block Delay** corresponded to the delay that incurred between pushback and gate-in; i.e. departure-taxiing, flight and arrival-taxiing phases. The delay amount was computed as follows;

$$(ABIT - AOBT) - (STA - STD).$$

- **Arrival Delay** corresponded to the sum of all the delays incurred by the time the aircraft docks at its assigned gate at the arrival airport (gate-in event). More specifically, arrival delay was computed as the sum of the departure delay and the block-time delay. This delay calculation was performed as follows;

$$ABIT - STA.$$

In this analysis, the arrival delays at Haneda Airport were studied. The percentage of *Late Arrivals*- arriving later than 15 minutes after STA - is generally accepted as the indicator for air transport operations On-time performance[4].

For various reasons, the collected data included extremely high or low values which have been biased the analysis results should they have been included. However, the range between -60 and 60 minutes was used for the analysis and values outside this range were not considered.

Fig. 3 depicts the percentage of *Late Arrivals* for each month, with an average value of 15% *Late Arrivals* across the entire data set. The monthly average value fluctuated between 8% and 21% and the value in August was the highest.

As it was mentioned, the arrival delay was the sum of the departure delay and the block-time delay. In order to study the contribution of each distinct flight phase to the total arrival delay, we analyzed the departure delay and the block-time separately. The percentages of *Late departed* flights of which departure delay was more than 15 minutes - and *Block Delayed* flights of which block-time delay was more than 15 minutes were studied.

Fig. 4 depicts the monthly percentage of *Late Departed* and *Block Delayed*. The average value of the *Late Departed* across the entire data set was 7%, whereas the average value of *Block Delayed* was 5%. As shown in Fig. 4 , the departure delay contributed to the total arrival delay slightly more than block delay.

The daily percentages were also analyzed and are shown in Fig. 5 and Fig. 6 for *Late Arrivals* and *Late Departed*, *Block Delayed*. Fig. 5 attests that the percentages of *Late Arrivals* on June 22 and October 27 were extremely high, while at the same time, the percentages of delayed flights are relatively high on all the examined days in August.

Fig. 6 shows that the percentages of *Late Departed* flights fluctuated among the examined

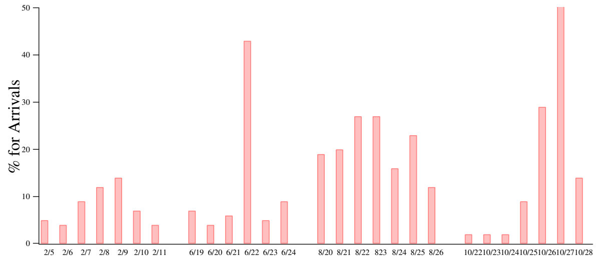

Fig. 5 The Daily Percentage of *Late Arrivals*

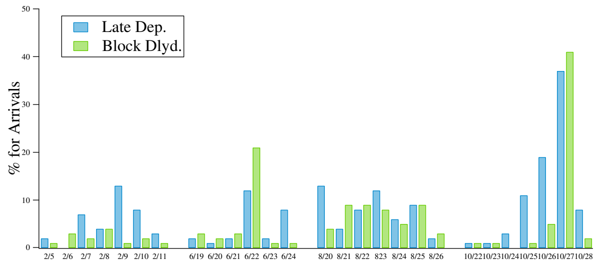

Fig. 6 The Daily Percentage of *Late Departure, Block Delayed*

dates and furthermore, it was again June 22 and October 27 that demonstrated highest percentages of *Block Delayed* flights.

4.3 Flight-plan Delay

In 4.2, the percentages of *Block Delayed* on June 22 and October 27 proved to be much higher than those of any other day. In order to investigate the factors contributing to these high percentages of delayed flights, the block-time was further bro-

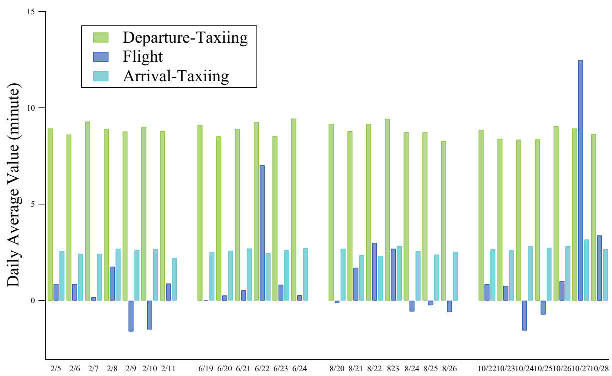

Fig. 7 The Daily Average Value of Delay

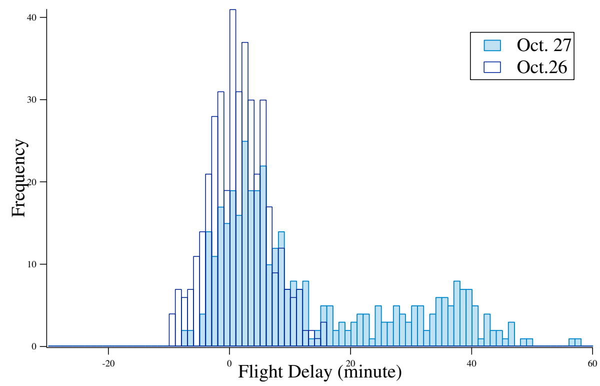

Fig. 8 A Comparison of Frequency Distribution from Flight Delay

ken down into the phases; the departure-taxiing, flight and arrival-taxiing phases.

Block delays were computed by comparing actual block times to these in the published timetables. However, since timetables list only STD and STA, which were the start and end time points of any flight operation, the delay amount in each phase was not computed. Instead of the scheduled times, EET, MDT and MAT were used as standard values. As stated in 3.3.3, 3.3.4 and 3.3.5, these values correspond to the minimum values in each of the distinct phases.

It should be noted that scheduled operation times were determined based on past actual values and thus, buffer values were added to the minimum values in the schedule. As a result, the computed delay values based on the minimum operational values were not equivalent to the delay values calculated based on the schedule. In the end, the computed variance values were used as the basis to compare and assess the performance in and between the different flight operation phases.

The delay amount in each phase was classified into the following categories and computed.

- **Departure-Taxiing Delay** corresponded to the delay that occurred during the departure-taxiing phase. The delay amount was computed as follows;

$$(ATD - AOBT) - MDT.$$

- **Flight Delay** corresponded to the delay that occurred during the flight phase. The delay amount was computed as follows;

$$(ATA - ATD) - EET.$$

- **Arrival-Taxiing Delay** corresponded to the delay that occurred during the arrival-taxiing phase. The delay amount was computed as follows;

$$(ABIT - ATA) - MAT.$$

The ranges between 0 and 60 minutes for the departure and arrival-taxiing delays and between -30 and 60 minutes for the flight delays were setup for the analysis and values outside the range were excluded from the computation.

Fig. 7 presents the computed daily average value for each of the defined phases. It is observed that the average value of departure-taxiing delay amount tended to be much higher than flight and arrival-taxiing delay. Thus, it is highly possible that a major part of the block-delay was generated during departure-taxiing phase.

It was also observed that, while the average value of departure-taxiing and arrival-taxiing delays remained relatively constant, the average value of flight-delays amount fluctuated among the various days. It should be noted that, again on June 22 and October 27, the average flight delay was at its highest, which correlates to the highest value observations for block delays in Fig. 6.

Fig.8 demonstrates a comparison of frequency distribution between two different ways: October 27 with the highest average value of flight delay, and October 26 with a normal level of flight delay. From this comparison, it was confirmed that on October 27, many more aircraft suffered flight delays as the corresponding frequency distribution is spread across a wider range of values. The flight phase can be further subdivided into a series of phases: climbing, cruising and descending and such a refined classification of the flight phase can assist in the detailed identification of delay bottlenecks.

5 Conclusion

The ATM operational database was designed and implemented. As a foundation for efficient and reliable ATM performance analysis, ATM system data journals were collected and stored into the database. Exploiting the DBMS API, the required data items were retrieved expeditiously and efficient computation of ATM performance indices was achieved.

As an example of the analysis facilitated by this ATM operational database, delay analysis results were presented. In this analysis, arrival delays at the Haneda airport were classified in accordance with the various operational phases and it was observed that departure delays impacted on the arrival delays slightly more than block delays. Also, block-time was further classified in accordance with the operational phases and this classification showed that flight delay tended to fluctuate across the data set. Delay bottleneck and contributing factors in the flight phase need to be further identified.

In addition to ATM practices, there are several other factors (eg. weather) that can cause aircraft operational delays. The fluctuation trends of the flight phase delays seem to emanate from the effect of other factors. It is without doubt that ATM performance indices including delay need to be continuously monitored and trends must be studied for achieving a detailed ATM performance analysis.

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Copyright Statement

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