Evaluation of Departure Pushback Time Assignment Considering Uncertainty Using Real Operational Data

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***Abstract*—Delaying pushback time of departure aircraft can reduce the taxi-out time due to reduced waiting at the runway. This initiative is called TSAT operation. Too much of a pushback delay, however, can affect take-off's punctuality. Therefore, appropriate assignment of pushback time is the key to an efficient TSAT operation. The assigned pushback time depends on various factors, such as the runway traffic demand and the uncertainty of traffic movement. This research uses real operational data from a target French airport to develop a realistic airport simulation model and simulate TSAT operation. According to the result, the selection of pushback time assignment algorithm can improve the performance of TSAT operation, but the estimation accuracy of pushback time provided by airlines is insufficient to introduce TSAT operation at this target airport. The improvement of the estimation accuracy will be indispensable to make TSAT operation effective.**

Keywords; TSAT, uncertainty, DMAN, data analysis

NOMENCLATURES

TSAT	Target Startup Approval Time
ETOT	Estimated Take-off Time
EXOT	Estimated Taxi-out time
ELDT	Estimated Landing Time
TTOT	Target Take-off Time
TOBT	Target Off-block Time
ATOT	Actual Take-off Time
AXOT	Actual Taxi-out Time
AOBT	Actual Off-block Time
ATOT	Actual Take-off Time
ARDT	Actual Ready Time (of Off-block)
ARTT	Actual Ready for Take-off Time

I. INTRODUCTION

With the increase of air traffic, airport runway congestion becomes a serious problem. Due to the minimum required take-off/landing separation, both departure and arrival aircraft must wait at the runway queue, which increases fuel burn. To tackle this issue, the concept of arrival/departure manager (AMAN/DMAN) has been proposed and has already been implemented at some major airports in the world. However, the performance of AMAN/DMAN highly depends on what AMAN/DMAN actually does and its algorithm. Therefore, the continuous effort to update the internal algorithm is necessary to improve the performance of the total system.

A large factor that affects the system performance is the uncertainty. Uncertainties cannot be completely eradicated in real world, so various researchers have considered them in AMAN/DMAN systems. A simple way to evaluate the uncertainty is divide the simulation in two steps: in the first step, the uncertainty is not considered and the optimizations are fully deterministic. In the second step, uncertainties are then added to the optimal solutions and evaluated in simulations. Most researchers considering uncertainty use this approach [1][2][3][4]. Since optimality under uncertainty is not considered, performance is worse than the obtained optimal solution used as a reference.

There are, in general, two approaches to account for uncertainty in optimization, though there are less research works. The first method is a robust optimization. The robust optimization considers the worst scenario (the worst uncertainty), and optimizes traffic under these conditions [5][6]. The second method is a stochastic optimization. A certain distribution of the uncertainty is assumed, the traffic is optimized in terms of the average case or the worst case [8][9]. Since these methods consider the uncertainty effect directly in the optimization process, a better performance compared to the deterministic optimization is expected.

This research implicitly considers the uncertainty in the optimization process to improve the total system performance. The author has been doing research on the departure aircraft management considering uncertainty with a stochastic optimization approach, focusing on a DMAN system, especially the assignment of pushback time (i.e. TSAT: Target Start-up Approval Time). TSAT is the time assigned by air traffic control (ATC), and the aircraft can start pushback only after TSAT to avoid the waiting just before the runway with engines on.

However, when considering the uncertainty, it is important to verify that it is described appropriately. The uncertainty is sometimes modeled by a distribution function, e.g. normal distribution, but it is important to evaluate the limitations of such an assumption.

As for departure aircraft management, the key factor is to estimate the time when the departure aircraft will be ready for take-off at the runway, i.e. ETOT (estimated take-off time). Since the departure aircraft has more uncertain factors than the arrival aircraft, the accuracy of ETOT tends to be worse than the estimated landing time (ELDT) of arrival aircraft. Therefore, it is important to estimate the degree of ETOT uncertainty. However, ETOT is calculated based on the target off-block time (TOBT) provided by the airline, and it was difficult to access the data. In the previous research [9], TOBT data was unavailable, and an assumed distribution was used. This time, the author could access the real operational data including TOBT at a French airport. The data analysis of the departure aircraft uncertainty is hardly observed in other researches, and this analysis will help the understanding of the current status, and accelerate the future research on departure aircraft management. In addition to data analysis, the author simulates the airport traffic using the real operational data, and investigates the performance of TSAT operation at the considered airport.

This paper is organized as follows. Section II explains the general idea of TSAT and the proposed TSAT assignment algorithm. Section III analyzes the real operational data at a French airport, and explains the setup of the simulation model. Section IV presents the simulation result, and Section V summarizes this work.

II. TSAT Operation and TSAT Assignment Algorithms

A. *TSAT Operation*

TSAT operation is introduced to minimize unnecessary fuel burn of departure aircraft on the ground. If departure traffic demand exceeds the runway capacity, the departure aircraft have to queue and wait just before the runway. Since the fuel burn of the aircraft on the ground depends on the time spent on the ground with engines on, the fuel burn can be reduced by delaying the departure from the gate as late as possible so that engines can remain off. If there is no uncertainty, TSAT should be set to TTOT – EXOT, and each aircraft can take off without waiting at a queue. TTOT denotes target take-off time, and corresponds to the assigned take-off time by ATC. EXOT denotes estimated taxi-out time. However, there exists various uncertainties in the actual operation. First, the aircraft cannot always start pushback at TOBT. The estimated pushback time is provided by airlines as TOBT, but its estimation accuracy is generally bad because this process is affected by the passengers boarding process. Second, the taxi-out time is also uncertain, i.e. the accuracy of EXOT. It takes some time to reach the runway from the gate by taxiing, but it also varies due to the variable taxi speed and surface congestion. Third, the assigned take-off time (TTOT) is not necessarily reliable. TTOT is decided in ATC system by sequencing departure aircraft considering ETOT = TOBT + EXOT. As mentioned before, TOBT includes a large error, so ETOT also includes a large error. Since TTOT is decided considering ETOT of all departure aircraft, it is very difficult for all aircraft to take off at their exact TTOT.

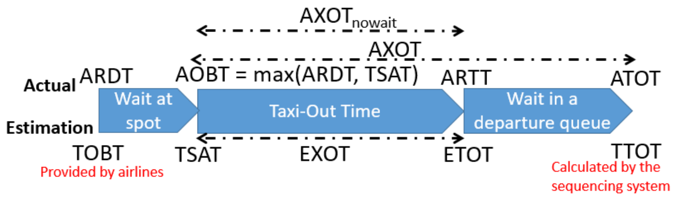

Figure 1. Departure aircraft operation flow.

The flow of this TSAT operation is shown in Figure 1. ARDT denotes the actual ready time, i.e. the time when the aircraft is ready for pushback. Therefore, TOBT is the estimate of ARDT, not AOBT. AOBT denotes the actual off-block time. If TSAT is not assigned, AOBT = ARDT, otherwise AOBT = max(ARDT, TSAT). ATOT denotes the actual take-off time. AXOT indicates the actual taxi-out time, and is calculated as ATOT – AOBT. Since AXOT includes the waiting time at the departure queue, $\mathrm{AXOT}_{\mathrm{nowait}}$ is defined as AXOT – (waiting time in a departure queue). In reality, the aircraft starts pushback at AOBT, and goes to the runway. The aircraft may have to wait at the runway in a departure queue, and finally can take off at ATOT. In this process, the uncertainty exists in TOBT, EXOT, and TTOT, and the problem is formulated how TSAT of each aircraft is assigned to minimize the objective function. In this research, the objective function is formulated in the following form.

$$J = \sum_{i} \left(\mathrm{ATOT}_i + \alpha \mathrm{AXOT}_i \right) \tag{1}$$

The first term minimizes the take-off time. The second term minimizes the taxi-out time. α indicates the weight factor. If TSAT is set too late, the aircraft can avoid the waiting time in a departure queue so AXOT decreases. However, the take-off time can also be delayed (ATOT increases). The delay of take-off time should be avoided in view of both capacity loss and flight punctuality. On the other hand, the first term of the objective function consists of the sum of the take-off time. Even if one aircraft cannot reach the runway by TTOT, another aircraft may be able to take off instead of the delayed aircraft by just swapping the take-off order. When this happens, the take-off time of one aircraft is delayed but the take-off time of another aircraft is pushed earlier, so this swap does not affect the objective function.

However, in general, TSAT is set later, the taxi-out time tends to be smaller, but the take-off time tends to be delayed. Therefore, there is a trade-off between take-off time delay and taxi-out. Since the uncertainty cannot be zero, some take-off delay is caused if TSAT is assigned. In practice, TSAT is set so that taxi-out time is saved while keeping the take-off delay sufficiently small.

B. *TSAT Assignment Algorithm*

There are two basic methods to assign TSAT. The first method is a constant buffer method. As mentioned before,

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TSAT should be TTOT – EXOT without considering uncertainty. Therefore, a constant buffer b is set, and is expected to absorb the uncertainty. Therefore, the assigned TSAT is calculated as: TSAT = TTOT – EXOT – b. b is the buffer parameter, and if b is small, more waiting time is saved but take-off delay is also more likely to be caused. In this calculation, if the calculated TSAT is earlier than TOBT, TSAT is not assigned.

The second method is the constant queueing number method. The general idea of this method is to keep at least a certain number of departure aircraft at a departure queue. As described in the previous subsection, no penalty is given to the objective function if another aircraft can take off instead of the delayed aircraft. Therefore, it is important to keep some aircraft in a departure queue. c is a parameter, which is the target number of a departure queue length. The detailed calculation is provided in [9].

According to the previous author's research, the constant queueing number method performs better than the constant buffer method. However, the previous research considered the specific Japanese operational environment, and some important data were not available. To generalize the conclusion, both methods are used and their outcomes are compared in this research.

III. Data Analysis and Runway Simulation

A. Basic Information at the Airport

This time, the real operational data is provided by a French airport for a month in January 2018. This airport has two runways, and departures and arrivals are operated on each runway separately. Therefore, only departure aircraft are considered in this research. The data includes more than 4000 departure aircraft. At this airport, TSAT is already operational. AOBT, TOBT, TOBT update histories (the airline can update TOBT), EXOT, and ATOT of each aircraft are included in the data. In this section, realistic simulation model will be developed by analyzing the real operational data.

B. TOBT accuracy

First, TOBT accuracy is examined. TOBT is the estimated pushback ready time and is provided by the airline. The accuracy of TOBT affects the performance of the total system significantly. Since TOBT is updated as required, the accuracy of TOBT is expected to be better when the reporting time approaches TOBT. As mentioned before, TOBT is the estimate of ARDT, not the estimate of AOBT. However, only the data of AOBT exists. Therefore, the data where TSAT is not assigned is screened first, and the distribution of TOBT – AOBT is obtained.

Figure 2. shows the average and the standard deviation (SD) of TOBT – AOBT vs. the time to TOBT using 3277 aircraft data. The average is always negative, which means that TOBT tends to be set earlier than AOBT. Also, the average starts around –2 minutes, and increases to about –4 minutes just before TOBT. As for SD, SD decreases as time goes by as expected. TOBT is first issued around 35 minutes before TOBT, and the SD is about 7 minutes at that time. After that, the SD decreases gradually, but even 10 minutes before TOBT, the SD is still about 6 minutes. The SD is still about 5 minutes at the time of TOBT.

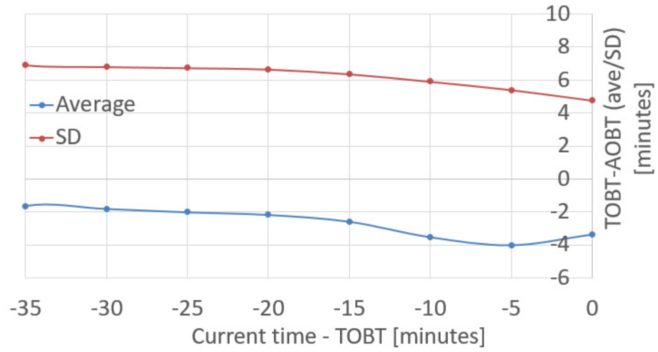

Figure 2. The average and SD of TOBT accuracy.

The reason of the large SD throughout this period is that some aircraft delay TOBT several times. TABLE I. shows an example of the TOBT update history of such an aircraft. At the beginning, the reported TOBT was 06:05:00, but it was updated again and again, and finally the aircraft started pushback at 06:48:31. Therefore, the initial TOBT had an error of more than 40 minutes. When assigning TSAT, these aircraft having large TOBT error should also be considered.

TABLE I. Example of TOBT update history. (Actual off block time (AOBT) = 06:48:31)

TOBT	TOBT reporting time
06:05:00	05:25:07
06:20:00	06:07:51
06:35:00	06:33:31
06:45:00	06:43:26

C. EXOT accuracy

Next, EXOT accuracy is discussed. The DMAN system installed at this airport estimates EXOT, and the performance of EXOT is investigated. Since EXOT is the estimation of $AXOT_{nowait}$, not AXOT, only aircraft ahead of which there is no take-off aircraft are used in the analysis. Figure 3. shows the average and SD of AXOT – EXOT at each spot. In general, the average of AXOT – EXOT is negative, –0.87 minutes for all spots. This means that EXOT is greater than AXOT. The difference of SD of AXOT – EXOT among spots is not large, and the average SD is 2.21 minutes for all spots. The SD of EXOT error is much smaller than that TOBT error (at least 5 minutes). Although the error trend slightly differs among spots, the general trend is the same, and it is assumed that the performance of EXOT is the same regardless of the spot position.

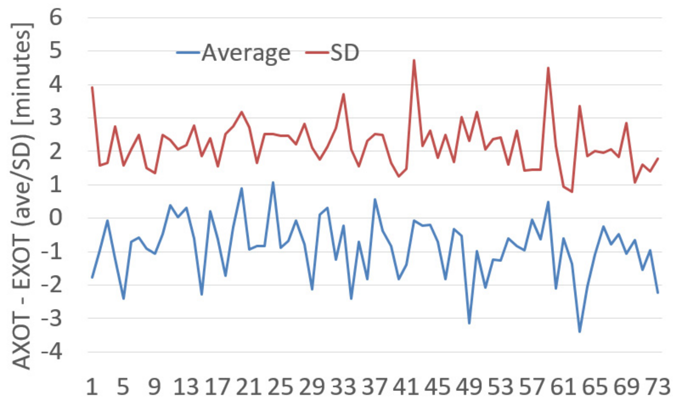

Figure 3. The average and SD of EXOT accuracy at each spot.

D. Distribution of take-off separation

There is a minimum take-off separation defined in Ref. [10], but the actual separation differs from the definition. At this airport, most aircraft are categorized into "medium" aircraft, so the distribution of separation between medium-medium only is obtained. The separation data should include the data where the departure traffic is dense enough and the aircraft wait before the runway only. Therefore, the separation data where AOBT is greater than EXOT by more than 2 minutes for both two departure aircraft. These aircraft can be assumed to wait at the runway. Figure 4. shows the distribution of take-off separation. This distribution is well fitted by gamma distribution, with an average of 96.3 s, a SD of 25.4 s, and a shape parameter of 2.98.

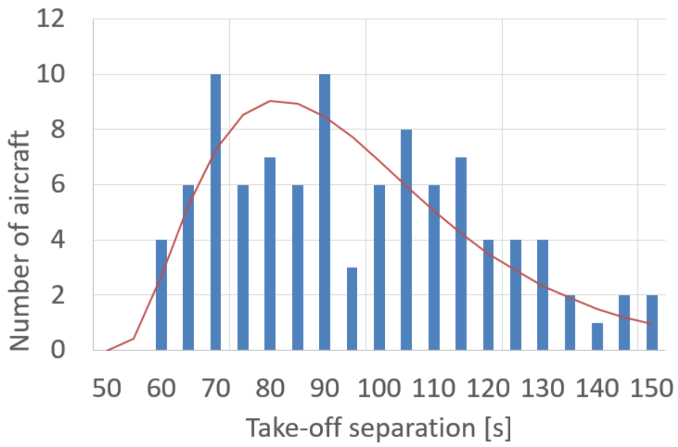

Figure 4. Distribution of take-off separation (medium-medium).

IV. Simulation Results

A. Simulation conditions

Based on the empirical data shown in Sec. III, the simulation is conducted to evaluate TSAT operation. To account for the uncertainty, the simulation model should be simple to minimize the simulation time. Most existing aircraft simulation models[11][12] consider the taxi route of each aircraft, which affects the simulated taxi-out time if there is a conflict. However, these models are deterministic, and it is difficult to model stochastic behavior. On the other hand, some existing stochastic taxi-out time models[13][14] do not account for aircraft routing and simply add the error to the nominal taxi-out time. This research also uses latter approach.

To simulate the airport traffic, ARDT, TSAT, $AXOT_{nowait}$, and take-off separation (*sep*) from the preceding aircraft are required. Once these data are prepared, the time when the aircraft arrives at the runway (ARTT: Actual Ready for Take-off Time) is calculated as max(ARDT, TSAT) + $AXOT_{nowait}$. The take-off is operated with the order of ARTT, and the minimum separation is set to *sep*. In this simulation, TSAT is the only parameter to control the traffic, and TSAT is assigned based on the uncertain information of TOBT and EXOT, as explained in Sec. II.B. Therefore, ARDT, $AXOT_{nowait}$, TOBT, EXOT, and *sep* of each aircraft are required in this simulation. The actual data of these are available on each day (31 days).

This time, to simulate the daily traffic accurately, the above required data are set based on the actual data.

(1) ARDT

Although ARDT cannot be directly obtained from data, ARDT can be equal to AOBT in data if TSAT is not assigned. Therefore, when TSAT is not assigned, ARDT is set to AOBT in data. Otherwise, ARDT is set randomly based on TOBT and the distribution shown in Figure 2. .

(2) $AXOT_{nowait}$

$AXOT_{nowait}$ can be calculated as ATOT – AOBT – waiting time in a queue. Although it is difficult to estimate the waiting time in a queue, the waiting time in a queue is assumed to be zero if the separation from the preceding aircraft is sufficiently large. This time, the separation from the preceding aircraft is 3 minutes or larger, $AXOT_{nowait}$ is set to ATOT – AOBT. Otherwise, $AXOT_{nowait}$ is randomly distributed based on EXOT and the distribution shown in Figure 3. .

(3) TOBT

All TOBT histories in data are used for all departure aircraft.

(4) EXOT

All EXOT in data are used for all departure aircraft.

(5) *sep*

The actual separation is also difficult to estimate because it is difficult to distinguish whether the aircraft wait in a queue or not. Therefore, if the separation from the preceding aircraft is [50 120] s, the actual separation is set to *sep*. Otherwise, the distribution shown in Figure 4. is used.

When assigning TSAT, the accuracy of TOBT is the most important. Since TOBT is provided by airlines, its accuracy has not been revealed in the previous research. This time, TOBT update history is obtained, and it is directly used in the simulation. Therefore, the inaccurate TOBT data as shown in

TABLE I. is also included in the simulation, so more realistic environment can be simulated.

In reality, there are some aircraft to which CTOT (Calculated Take-Off Time) is assigned. CTOT is the earliest take-off time assigned by ATC to reduce the congestion on the air. Such aircraft cannot take off prior to CTOT even if the aircraft arrives at the runway. Therefore, the waiting time at the runway is calculated regardless of the runway congestion level. These aircraft are also included in the simulation, and TSAT is assigned to these aircraft at CTOT – EXOT – 5 minutes.

Since there are still some random parameters in the simulation as explained above (1)-(5), 100 times simulations are conducted in each traffic sample, and the average is discussed.

B. Simulation accuracy

To validate accuracy, the simulation is conducted when all ARDT are set to AOBT in data regardless of TSAT assignment. Additional TSAT is not set in the simulation, so AOBT of all aircraft in the simulation match exactly AOBT in data. Once all AOBT are set the same as AOBT in data, all ATOT in the simulation are expected to be the similar to the ATOT in data. Figure 5. shows the average of ATOT (simulation) – ATOT (data) on each day. The error bar indicates the one sigma range because these simulations are the results of 100 time simulation with some random parameters. The 1 sigma error bar falls in "0" for 20 days out of 31 days, and this result is appropriate because 68 % of result should fall into 1 sigma range. There is no data which has a significant difference between the simulation and data, either. There are some days when the average of ATOT in the simulation is more than 20 seconds smaller than that in data. According to the data for these days, the runway was temporarily closed Since such a temporary runway close is not simulated, it makes sense that ATOT in data tends to be late. Apart from this, the simulation in general matches the data, and the variation of ATOT due to random parameters is not quite big. Therefore, it is concluded that the simulation can accurately model the operation at this airport.

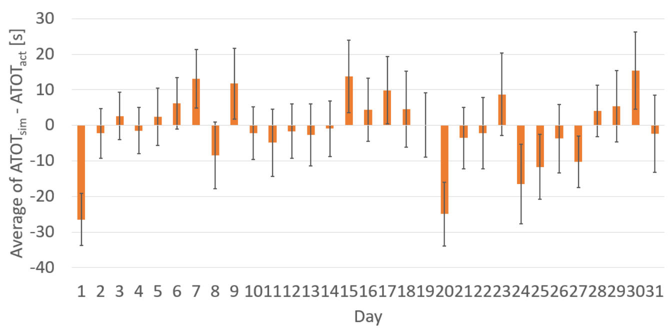

Figure 5. Average of ATOT by simulation minus ATOT in data of all aircraft on each day.

C. TSAT assginment and daily performance

Before evaluating the TSAT operation, the characteristics of daily traffic are examined. Figure 6. shows the total waiting time of all departure aircraft on each day assuming TSAT is not assigned. Therefore, this graph corresponds to the maximum possible reduction of taxi-out time of all departure aircraft. The waiting time caused by CTOT is shown separately in red. This graph shows several interesting facts. First, the traffic volume varies significantly among days, and the larger waiting time tends to be observed with higher traffic volume. Second, the waiting time caused by CTOT is about 40 % of total waiting time. This means that only about 60 % waiting time is caused by the runway congestion. Third, the waiting time per aircraft is at most about 1 minute, which is not quite big. Since the waiting time in a departure queue is not large at this airport, the benefit of TSAT operation may be limited.

Figure 7. shows the waiting time of individual aircraft on January 29 when the largest waiting time is observed among 31 days. There are some aircraft having large waiting time, all of which are caused by CTOT. The maximum waiting time caused by the runway congestion is less than 5 minutes. Since the TOBT uncertainty is about 5 minutes of SD just before pushback, it seems to be difficult to set TSAT to reduce the waiting time caused by runway congestion.

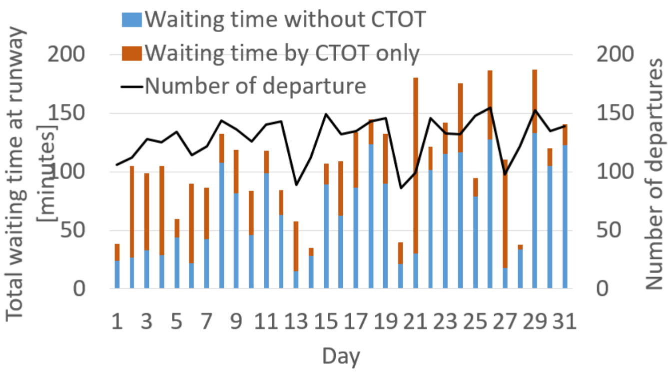

Figure 6. Total waiting time at runway and number of departure on each day.

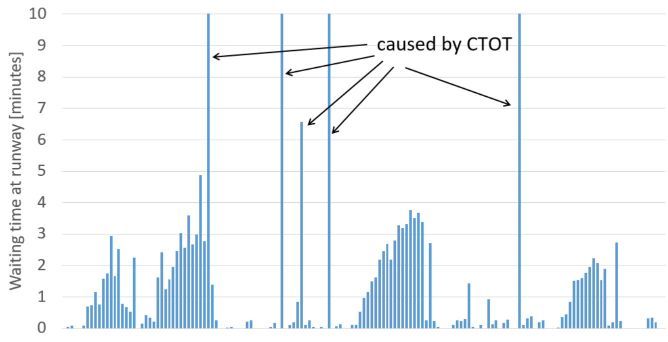

Figure 7. Waiting time of each aircraft on January 29.

To confirm that TSAT may not be beneficial at this airport, Figure 8. shows the waiting time saved and the delay caused by TSAT in each method explained in Sec. II.B for 31 days average. The simulation is conducted several times on each day; the first simulation does not use TSAT operation for the comparison purposes, and the rests of simulations use TSAT operation with different parameters with either constant buffer method or constant queueing number method. In each calculation set, the waiting time saved by TSAT and the take-off delay caused by TSAT are calculated. Since there are two TSAT assignment algorithms, simulation results by each method with different parameters (constant buffer *b*, minimum departure queue length *c*) are shown in the figure. When TSAT is assigned to aircraft to which CTOT is set (CTOT aircraft) only, 18 minutes waiting time is saved by TSAT while 0.6 minutes delay was caused by TSAT. Therefore, it is meaningful to assign TSAT to CTOT aircraft. However, when TSAT is assigned to all aircraft using constant queueing number method with *c* = 5, additional waiting time saved is about 2 minutes while the additional delay caused is about 3 minutes. 2 minutes taxi-out time is saved by 3 minutes take-off delay. This means that TSAT operation does not work well. Compared between two TSAT assignment algorithms, the constant queueing number seems to work slightly better, but neither of them is useful at this airport.

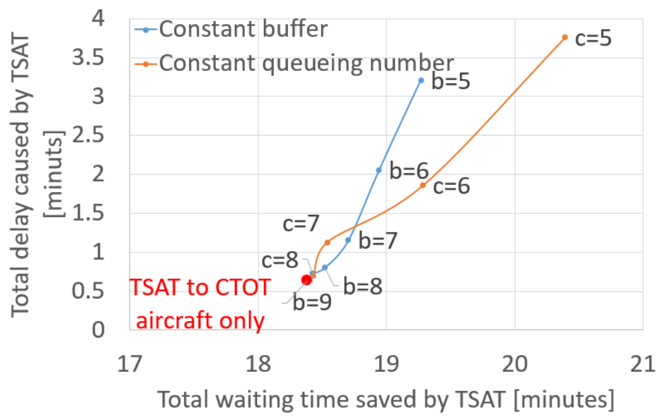

Figure 8. Relationship between waiting time saved by TSAT and delay caused by TSAT for 31 days average.

D. Larger traffic assumptions

Since this airport does not have enough traffic to use TSAT operation considering the TOBT accuracy, a larger traffic situation is assumed. To account for the larger traffic, two days traffic are merged into a single day's traffic (e.g. both January 1 traffic and January 2 traffic are assumed to be a single day's traffic), and the simulation is conducted. This time, the two consecutive days traffic are merged to a single day's traffic, and new 15 days of traffic are generated. Figure 9. shows the total waiting time of new 15 days without TSAT. The waiting time varies significantly among days, the minimum about 200 minutes (1.06 minutes per aircraft) and the maximum about 2200 minutes (7.39 minutes per aircraft). Especially on the days when large waiting time is observed, the waiting time without CTOT is dominated, which means that most waiting time is caused by runway congestion. These 15 days traffic are used to evaluate TSAT algorithms.

If traffic becomes double in real world, the traffic will not be the same as the simple merge of two days traffic, e.g. TOBT accuracy could be worse, and further congestion will be expected around spots. Therefore, the merge traffic used in this research does not model the future traffic at this airport, but just assumes the larger traffic to evaluate TSAT algorithm under heavy traffic.

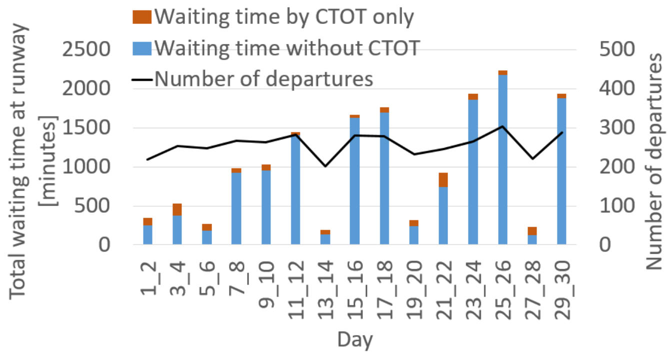

Figure 9. Total waiting time at runway and number of departure on new 15 days.

Using new 15 days traffic, the similar calculation like Figure 8. is shown in Figure 10. . Compared to the result in Figure 8. , the waiting time saved becomes much larger. For example, in the case of constant queueing number with c= 10, about 170 minutes waiting time is saved by TSAT, while about 5.5 minutes take-off delay is caused. Considering the obtained waiting time saved and delay, the TSAT operation will be meaningful. In addition, the constant queueing number method always performs better than the constant buffer method, which also agrees with the result obtained in [9]. When assigning TSAT, The constant buffer method is popular for TSAT assignments, but the constant queuing number method should be used instead.

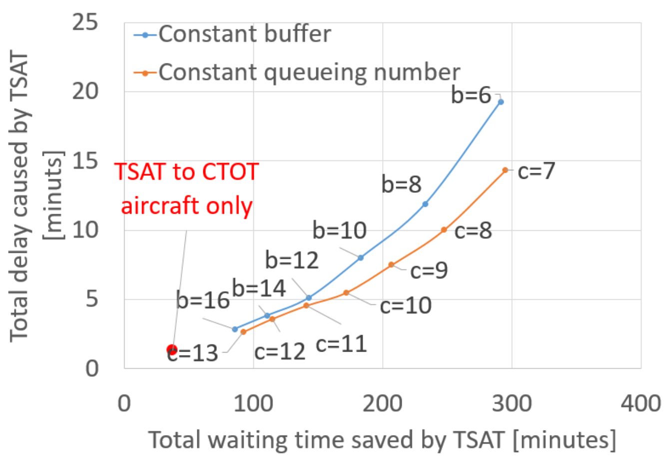

Figure 10. Relationship between waiting time saved by TSAT and delay caused by TSAT for new 15 days average.

Figure 11. shows the waiting time saved and delay on each day. This figure shows the case where the constant queueing number method with *c* = 10 is used. As expected, more waiting time is saved when the total waiting time is larger. However, on Jan 25&26 when the largest waiting time is saved by TSAT, only about 18 % waiting time is saved out of total waiting time. This is due to the uncertainty. Using whichever constant buffer method or constant queueing number method, a "buffer" is required to absorb uncertainty, so each aircraft should arrive at

the runway earlier by the assumed "buffer", which corresponds to the waiting time at the runway. As for the delay, there is no clear relationship between the waiting time saved and the delay caused by TSAT. This fact makes sense because the delay is caused especially when TOBT and ARDT has a big difference, which is not affected by the traffic volume. Figure 12. shows the waiting time of individual aircraft on Jan 25&26 for non-TSAT case and TSAT case with c = 10. On this day, without TSAT, the maximum about 25 minutes waiting time is observed. Using TSAT, the maximum waiting time is about 15 minutes, so roughly 15 minutes corresponds to the required "buffer". Even assigning about 15 minutes buffer, total 7 minutes take-off delay is expected. Considering the TOBT accuracy, such a large "buffer" should be set to absorb uncertainty. In other words, TSAT operation works only when such a large waiting time at the runway is currently observed under the current TOBT accuracy.

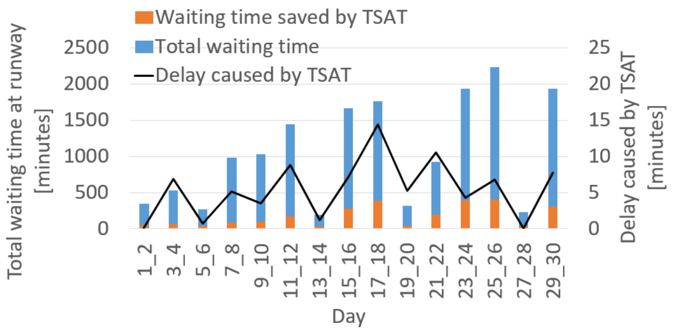

Figure 11. Waiting time saved and delay caused by TSAT on each day using constant queueing number method with c = 10.

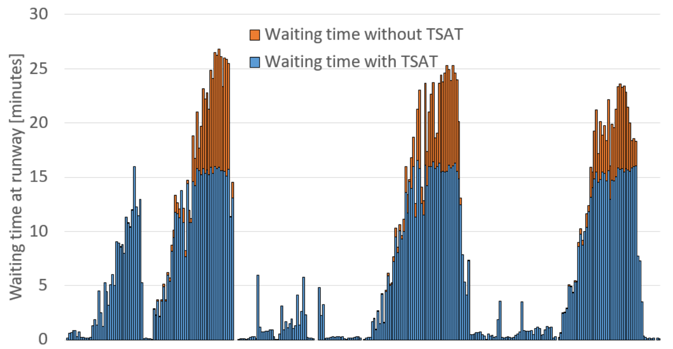

Figure 12. Waiting time of each aircraft using constant queueing number method with c = 10.

E. Further improvement to minimize delay

Apart from the refinement of TSAT assignment algorithm, another action is possible to minimize the take-off delay. Figure 3. shows that the EXOT is set larger than actual by about 1 minute on average. Figure 2. shows that TOBT tends to be set earlier than ARDT. Therefore, if EXOT and TOBT are adjusted based on the empirical data, the TSAT performance could be improved. This time, all EXOT is adjusted by 1 minute earlier, and all TOBT is adjusted according to the current tune – TOBT based on Figure 2. . For example, when the current time is 09:00 and the reported TOBT by the airline is 09:30, the average difference of TOBT and ARDT is 2 minutes according to Figure 2. , so TOBT = 09:32 is used in the calculation of TSAT assignment instead of 09:30.

Figure 13. shows the simulation result when the adjustments of EXOT and TOBT are made. Using both methods (constant buffer method and constant queueing number method), the adjustments reduce the delay. In this way, both the refinement of TSAT assignment algorithm and the adjustment of the reported data could improve the performance of the TSAT operation. However, the most important factor is the accuracy of TOBT, and the accuracy is low according to the data analysis at the French airport. Therefore, at this airport, TSAT operation does not work except for the aircraft to which CTOT is assigned. To improve the performance of the TSAT operation further, it is important for airlines to estimate TOBT more accurately.

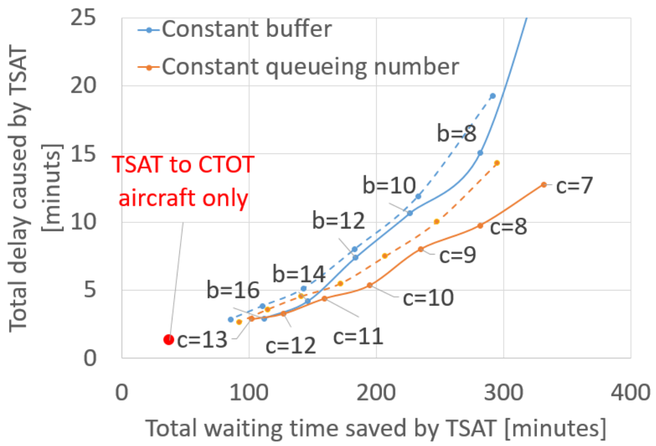

Figure 13. Relationship between waiting time saved by TSAT and delay caused by TSAT for new 15 days average. (solid line: EXOT and TOBT adjustments are made, dotted line: no adjustment)

V. Conclusions

This research investigated the impact of TSAT operation at one of the French airports using the real operational data. TOBT accuracy is a key factor for the performance of TSAT operation, but the accuracy was not good enough to introduce TSAT operation at this airport. Assuming the double traffic volume at this airport, TSAT operation would work well. The result showed that the appropriate selection of the TSAT assignment algorithm and the adjustment of the reported data (such as TOBT) would improve the performance of TSAT operation. To introduce TSAT operation at the mid-size airport, the research should focus on the improvement of TOBT accuracy, which will be a subject of the future work.

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