MSc Thesis

Investigating the effect on departure capacity of changing Target Off-Block Time uncertainty

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Investigating the effect on departure capacity of changing Target Off-Block Time uncertainty

by

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Preface

This thesis concludes my time as a student at the faculty of Aerospace Engineering. It contains a scientific article and a preliminary report with the study I have conducted for the Knowledge Development Centre at Amsterdam Airport Schiphol. I investigated the effect of earlier Target Off-Block Time updates on the runway schedule.

I want to thank my supervisors: Jacco Hoekstra, Joost Ellerbroek and Fredinand Dijkstra for their help and guidance during my project. I would also like to thank my family and friends who have supported me while doing this research. I could not have done this without you! A special thanks goes to Saskia, my partner, who had to deal with me and my thesis for the past two years while sharing a roof with me. It has not always been easy, but I am very thankful that you kept believing in me.

D.C. Snijders
Delft, January 2023

Nomenclature

A-CDM	Airport Collaborative Decision Making
ABS	Agent-Based Simulation
ACARS	Aircraft Communication Addressing and Reporting System
AIBT	Actual In-Block Time
ANSP	Air Navigation Service Provider
AOBT	Actual Off-Block Time
AOC	Airline Operations Center
ARDT	Actual Ready Time
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATOT	Actual Off-Block Time
BP	Back Propagation
CFMU	Central Flow Management Unit
CNN	Concolution Neural Network
CPM	Critical Path Method
CTOT	Calculated Take-Off Time
DAM	Duty Area Manager
DES	Discrete Event Simulation
DMAN	Departure Manager
DPI	Departure Planning Information
DTW	Departure Tolerance Window
EJU	EasyJey Europe
EOBT	Estimated Off-Block Time
HCC	Hub Control Center
HMI	Human Machine Interface
IATA	International Air Transport Association
KLM	Royal Dutch Airlines
LSI	Latent Semantic Index
LVNL	Air Traffic Control The Netherlands
NLR	National Aerospace Laboratory of the Netherlands

NM	Network Manager
OPL	Outbound Planner
OPS	Outbound Punctuality Sequencer
SID	Standard Instrument Departure
SOBT	Scheduled Off-Block Time
STW	Slot Tolerance Window
TOBT	Target Off-Block Time
TSAT	Target Start-up Approval Time
TTOT	Target Take-Off Time

I

Scientific Paper

Investigating the effect on departure capacity of changing Target Off-Block Time uncertainty

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Abstract

With its 500.000 flights per year, Schiphol Airport is one of the busiest airports in Europe. Efficient runway use is vital for a smooth day-to-day operation. This paper investigates the new runway scheduler at Schiphol Airport, also referred to as the Departure Manager (DMAN). The new DMAN is built for a better utilisation of the outbound capacity with a higher predictability. This study aims to verify whether positive behaviour regarding earlier Target Off-Block Time (TOBT) updates leads to the desired results in capacity, predictability and reduced delay, based on historical data. An experimental model was used to simulate a new Departure Manager (DMAN), which uses a set of priority rules to assign flights to the runway slot in which they depart. The simulation did not find an overall significant result for all cases, runways and months, due to the averages influenced by the size of the data. However, a positive trend can be seen in the presented results, indicating that earlier TOBT updates lead to a better runway schedule. One cannot schedule better than on time, but late TOBT updates accumulate like a snowball effect throughout the planning.

1 Introduction

Schiphol Airport operates 500.000 flights per year, it is one of the busiest airports in Europe [1]. Schiphol Airport operates as a hub for global traffic, accommodating a substantial percentage of connecting flights. Due to the hub function of Schiphol Airport, passengers have to arrive in bulk first, before aircraft can depart after transit. The runways are operated in alternating configurations between arrival peaks and departure peaks. During an arrival peak, two runways are used for landings and one runway is used for departures, and vice versa during a departure peak. Efficient runway use is vital for a smooth day-to-day operation, as the departure peak cannot be extended into the arrival peak, due to the runway configuration. The alternating peaks in departure and arrival are in line with environmental regulations, for which optimal use is made of noise-preferred runways.

During an aircraft's turnaround, processes are required to prepare an aircraft and crew for its next flight. These processes entail cleaning, post- and preflight checks, unloading and loading baggage, catering, and fuelling. After these turnaround processes, there are also pre-departure processes such as decoupling to power, removal of the bridge and pushback that need to be executed. All of the processes during the turnaround phase and pre-departure phase require scheduling and because of limited resources, impose a degree of uncertainty. Airlines and handlers communicate this uncertainty with the Target Off-Block Time (TOBT), which represents the time when an aircraft is targeted to be completely ready for pushback.

The Off-Block time of an aircraft has various names during all the stages of a single flight. Initially, upon filing the flight plan it is defined as the Scheduled Off-Block Time (SOBT). Three hours before the flight becomes active, this is changed in the Estimated Off-Block Time (EOBT). Once the flight has landed or the turnaround has started, the name is changed to the Target Off-Block Time (TOBT). Lastly, after the aircraft has gone Off-Block the Actual Off-Block Time (AOBT) is logged as historical data.

At Schiphol Airport, Airport Collaborative Decision Making (A-CDM) ensures that all stakeholders have the same information about a particular flight. The parameters of a flight are at least updated on every milestone defined in the A-CDM manual and sent to all stakeholders [2]. The most relevant parameters for the departure sequence are the Target Off-Block Time (TOBT), the Target Start-up Approval Time (TSAT), and the Target Take-Off Time (TTOT). The Target Off-Block Time (TOBT) is the key parameter on the interface of the turnaround process and the runway scheduling. Based on the TOBT and the estimated taxi-out time, the Estimated Take-Off Time

(ETOT) can be determined. This is used as input to the runway scheduling, resulting in an assigned TTOT. Based on the assigned TTOT, the TSAT is provided to the airlines, such that it is known in which window the pilot can request an engine start-up clearance. An overview of the most relevant parameters can be found in Figure 7 in Appendix A.

For this study, the new runway scheduler at Schiphol Airport, also referred to as the Departure Manager (DMAN), was modelled. The new DMAN was built for a better utilisation of the outbound capacity with a higher predictability. It follows the best-planned-best-served principle, stimulating airlines and handlers to timely give updates of the Target Off-Block Time (TOBT). This study aims to verify whether positive behaviour regarding earlier Target Off-Block Time updates leads to the desired results in capacity, predictability and reduced delay based on historical data. The research question is formulated as: "What is the effect of the current behaviour regarding setting and updating of the Target Off-Block Time (TOBT) by airlines and handlers on the departure capacity of Schiphol Airport?".

2 Background

The main driver to improve the runway scheduling is to reduce delays at Schiphol Airport for all stakeholders. Delays and inefficiencies cause a snowball effect throughout the operations of airlines, handlers, and the airport and increase costs. An efficient runway schedule is vital for a smooth departure operation.

The Off-Block time is used as a starting point and added to the Estimated Taxi-Out Time (EXOT), leading to the earliest possible Estimated Take-Off Time (ETOT). The Air Traffic Control is responsible for the runway schedule and assigns flights a Target Take-Off Time based on priority and available runway capacity.

2.1 Airline / Handler perspective

In the current operation, airlines/handlers perceive the runway scheduler as unpredictable. Updates in the Target Off-Block Time (TOBT) lead to frequent shifts in the Target Take-Off Time, which cause substantial differences between the desired Estimated Take-Off Time and the Actual Take-Off Time. These undesired delays cause airlines to be careful and reserved in sending TOBT updates. During initial analysis, it was observed that the majority of TOBT updates are sent minutes before the previous TOBT expires. It was also seen that TOBT updates expire by up to 15 minutes, causing gaps in the runway schedule. From the airline/handler perspective, it can also be argued that it is not possible to know what the new TOBT should be, as it is often unknown how much time a repair/malfunction will take. If the repair/malfunction is suddenly resolved and the TOBT needs to be brought forward, this request might not be granted by the scheduler. The alternative, in practice, is thus to send multiple last-minute TOBT updates.

2.2 Air Traffic Control perspective

Last-minute TOBT updates create challenges for the departure scheduling. If gaps on the runway are caused, due to flights that are not able to make their window, the declared capacity is not fully used. Flights that are not able to depart within their slot, but are not cancelled, have to depart in a later slot. Schiphol Airport uses peak periods for arrival and departure and is operated at full capacity. Flights that have to be scheduled twice therefore cause problems. For the Air Traffic Control it would be beneficial if the TOBT behaviour would be more conservative; however, for the airlines this does not guarantee a reduction in total delay with the current departure planner.

3 Working DMAN

To determine the effect of positive behaviour regarding earlier Target Off-Block Time updates on capacity, predictability and reduced delay, the Departure Manager (DMAN) needs to be modelled. Modelling this system allows for the analysis of multiple months of data, containing a large number of flights, allowing for a trend analysis. This section elaborates on the steps taken in the construction of a representative model.

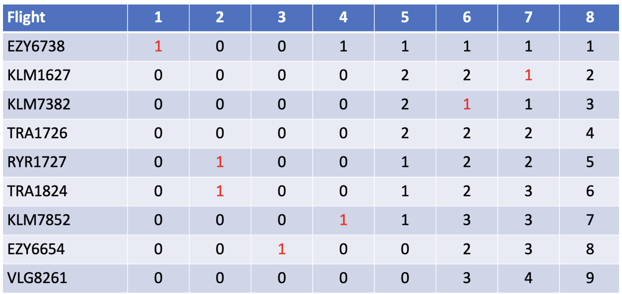
The DMAN model runs through all historical data for the selected months to generate a runway schedule for a particular runway and date. The Departure Manager schedules flights based on 10 min intervals, also referred to as slots, in which a pre-set number of flights can depart.

The Departure Manager creates a table indicating the priority of all flights within a slot based on the priority rules listed below for slots in which demand is larger than capacity [3]. An example table can be found in Table 1, for which the slot demand is 9 flights, even though the slot capacity is 7, meaning 2 flights have to be delayed into the next slot. If two flights are considered to have similar priority based on a particular column, the next column is looked at, as can be seen in column 5 between KLM1627, KLM7382, and TRA1726.

Priority rules:

1. Flights with more than 10 Calculated Take-Off Time updates.
2. Flights with more than 2 shifts.
3. Flights with a Calculated Take-Off Time that would violate the Slot Tolerance Window (STW) if shifted (and would therefore have to receive a new Calculated Take-Off Time).
4. Flights with cancelled Calculated Take-Off Time that would be planned later than the cancelled Calculated Take-Off Time if shifted.
5. Flights with 1 or 2 previous shifts.
6. Flights with an earlier Target Off-Block Time get priority in ascending order.
7. Time between Target Off-Block Time and Scheduled Off-Block Time, taking into account Target Off-Block Time before Scheduled Off-Block Time situation sorting in ascending order.
8. If flights are similar in all priority rules above, priority is given based on the flight sorted ID.

Table 1: *Priority table Departure Manager (DMAN) (The callsigns used are hypothetical)*



Flight	1	2	3	4	5	6	7	8
EZY6738	1	0	0	1	1	1	1	1
KLM1627	0	0	0	0	2	2	1	2
KLM7382	0	0	0	0	2	1	1	3
TRA1726	0	0	0	0	2	2	2	4
RYR1727	0	1	0	0	1	2	2	5
TRA1824	0	1	0	0	1	2	3	6
KLM7852	0	0	0	1	1	3	3	7
EZY6654	0	0	1	0	0	2	3	8
VLG8261	0	0	0	0	0	3	4	9

4 Experiment

An experiment is performed to verify whether positive behaviour regarding earlier Target Off-Block Time updates leads to the desired results in capacity, predictability and reduced delay. Besides the experimental set-up, also the data, pre-processing and verification & validation will be discussed in this section.

4.1 Experimental set-up

A schematic overview of the simulation can be found in Figure 1. After pre-processing the data, which will be discussed in subsection 4.3, a time loop is used, which loops through all DPI messages in chronological order. Each DPI message triggers an iteration of the runway schedule. Initially, all flights are assigned to the preferred slot, based on the Scheduled Off-Block Time. If the demand in a slot is higher than its capacity, the Departure Manager constructs a priority table. Flights with the lowest priority are delayed by one slot. Should this cause an overload in the subsequent slot, then the Departure Manager also resolves this by applying the priority rules.

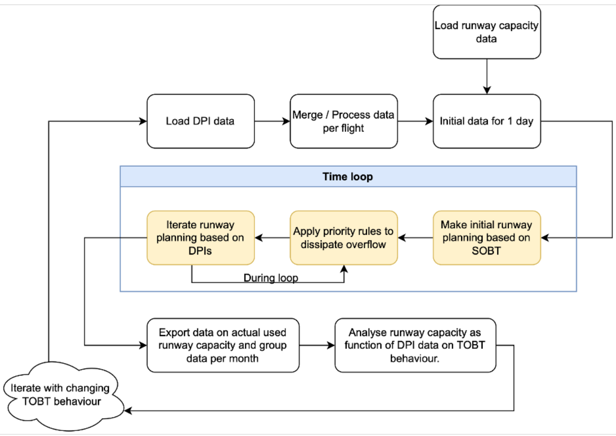


Figure 1: *Simulation loop*

The Departure Manager can schedule and prioritise flights in the current and future slots. Flights of which the Target Off-Block Time is updated after the end time of the slot cause a gap on the runway.

Besides assigning delay, the Departure Manager is also able to move a flight back to an earlier position in the runway schedule. This occurs if another flight is delayed (due to delays in the turnaround process) and this is communicated on time. Similarly, all flights that have an earlier TOBT and can therefore depart earlier, are prioritised by the DMAN to be selected for this gap. Flights are only moved forward in future slots, as the current slot is not feasible due to the taxi-out times.

After all DPI messages are processed, a realised runway schedule is the output of the model. The model is applied to 36 configurations, all cross combinations in Table 2. The runways are selected for analysis, based on the most frequent configuration. 24 and 18L are used when departing in a southern direction and 36L is used when departing in a northern direction. For the analysis, two winter months and two summer (peak) months are used. The model is run for three scenarios and the analysis contains a comparison between the original data (baseline) and the improved Target Off-Block Time updates (earlier TOBT updates). The moments of updating the Target Off-Block Time are entered in the system 5 minutes and 10 minutes earlier, to investigate the effect on the runway schedule. It is hypothesised that earlier TOBT updates lead to reduced delay (a higher ideal slot usage), improved slot usage (higher slot usage ratio) and lower total shifts in the runway schedule (more stability).

Table 2: *Experiment simulation cases*

Runway	Case	Month
24	Original / Baseline	January
18L	TOBTs 5 min earlier	Februari
36L	TOBTs 10 min earlier	Juli
		August

4.2 Data

The data used as input for the model are CDM data from Schiphol Airport (obtained via LVNL) from the year 2019, thus the pre-COVID level in number of flights. The data contain all Departure Planning Information messages that are sent while the flight is active in the A-CDM database. The dataset consists of a big table in which all updates are registered. Each row contains one changed variable of a particular flight. For this study, multiple variables are relevant as input providing information on a specific flight. These variables are used to determine the priority of a flight in the DMAN, which is described in more detail in section 3.

Using historical data has the main advantage that no synthetic data has to be generated matching the complexity of the real system. The historical data already contain this form of complexity. Although the data were obtained while a different Departure Manager tool was operational, it is deemed representative to observe the behaviour of the airlines and handlers, as this behaviour is based on scenarios outside the system. These scenarios would be the same for a different departure managing tool. The output of the previous departure managing tool is not taken as input for the new model, as this study compares three outputs of the new model.

4.3 Pre-processing

Before the Departure Manager model can be applied, the data need to be processed. The CDM data need to be reduced to Departure Planning Information (DPI) updates per flight, which enter the Departure Manager step-wise during the simulation. In Figure 2, the merge/processing of the data is shown visually. Updates that occur within 3 seconds of each other are merged into one DPI message, (for example a TOBT and TTOT update) triggering one iteration of the model. Flights that have not departed, such as cancelled flights, are removed from the data. The data is analysed per flight and variables relevant for the Departure Manager are added (such as the number of Calulated Take-Off Time (CTOT) updates and TOBT expiration). Lastly, the moment of updating is changed with 5 or 10 minutes for the adapted cases.

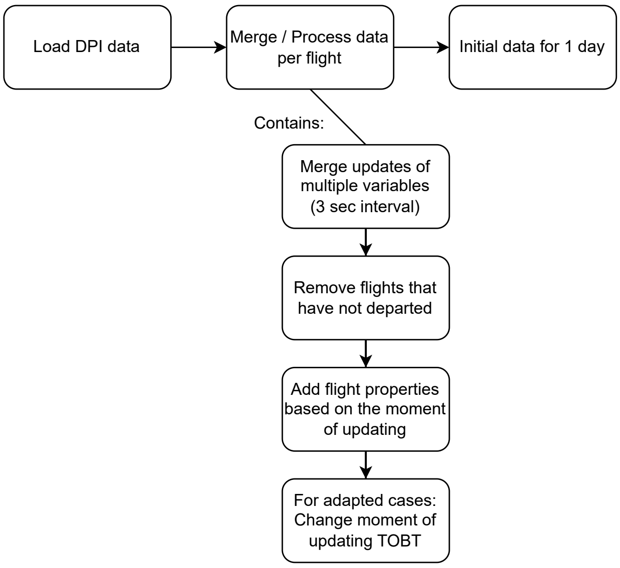


Figure 2: *Pre-processing data*

4.4 Verification & validation

Throughout the construction of the model, verification and validation are considered. During the set-up of the pre-processing, the model construction and the simulation, each step was unit-tested with a sample containing one day of data. A sample for which the outcome was known previously is used as input, for which the output is validated. During the debugging phase, the model was checked for errors by requesting monitoring variables, such as the realisation of slot usage, which could not be above the indicated capacity. The model was verified for multiple runway conditions, by adapting the number of flights scheduled in a 10-minute runway slot.

After the pre-processing and the simulation were combined, the model was validated by checking the operation against the functional specification of the Departure Manager [3]. The simulation cannot be validated against the real-life situation, as the new Departure Manager is not operational yet.

4.5 Hypotheses

The experimental model contains one independent variable: the moment a TOBT is communicated. The independent variable leads to three hypotheses which are listed below.

- Earlier Target Off-Block Time updates lead to a higher ideal slot adherence.
- Earlier Target Off-Block Time updates lead to a higher runway slot usage ratio during slots in which demand exceeds capacity.
- Earlier Target Off-Block Time updates lead to a lower total shift.

4.6 Dependent measures

The dependent measures used to evaluate the results of this study are presented in this section. These are used to answer the hypotheses presented in the previous section. For all hypotheses, the dependent measures are a comparison between the scenario containing the original data (baseline) and the scenario with improved Target Off-Block Time updates (earlier TOBT updates). For this reason, the dependent measures are always expressed as a difference between scenarios.

The first measure shows the delay reduction that can be realised at the end of the day, in the number of slots with delay that are assigned to flights, with a TOBT improvement of 5 minutes and 10 minutes. Positive values indicate that the realised runway schedule contains less delay with earlier TOBT updates. Less delay means that a higher ideal slot adherence is realised. Besides looking at this measure for each day, the cumulative delay reduction is also visualised, indicating the net effect of the number of slots that can be gained with earlier TOBT updates.

The second measure shows the reduction of gaps in the slot usage on the runway when demand exceeds capacity. A positive difference in slot usage would indicate more efficient use of the runway when demand exceeds capacity.

The third measure shows the total slot shift reduction per day. A positive reduction with earlier TOBT updates would indicate increased stability in the runway schedule. The first measure looks at the net result at the end of the day, whereas the third measure is an indication of an improved scheduling process.

5 Results

This section presents the results obtained from the experiment. In the following section, these results will be discussed. The output of the model, as described in section 4, provides a departure schedule for a specific runway. The results contain a comparative presentation between three cases of the model. In Figure 3, the difference between the simulation based on the original data and the simulations with earlier Target Off-Block Time (TOBT) updates are shown for each day in a particular month. On the vertical axis, the difference in assigned delayed slots between the original and improved TOBT cases is shown. This difference is found by summing the gap between the requested and assigned runway slots for all flights on a day. For most days, the 0-5 minute TOBT improvement is larger than the 5-10 minute TOBT improvement. Looking at the various dates, it can be seen that for some days there is a difference between the 5-minute improvement and 10-minute improvement, whereas for some days there is no difference. There are no days for which the summed delay is larger with an improved TOBT setting, meaning that the net result of this study is positive; however, within these days there might be flights for which this is not the case.

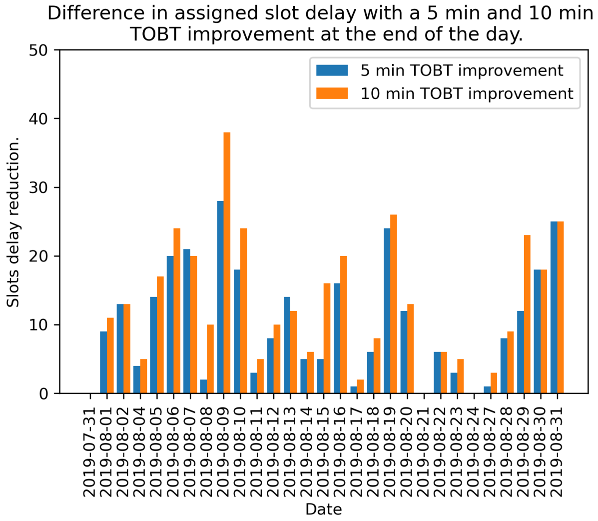


Figure 3: *Difference in realised runway delay reduction for runway 24*

Looking at this data cumulatively for runway 24 and 18L, as shown in Figure 4, shows that the net effect of earlier Target Off-Block Time updates over a period of time leads to a reduction in delay. In this figure, the difference between having an improvement of 5 minutes and an improvement of 10 minutes is also visible.

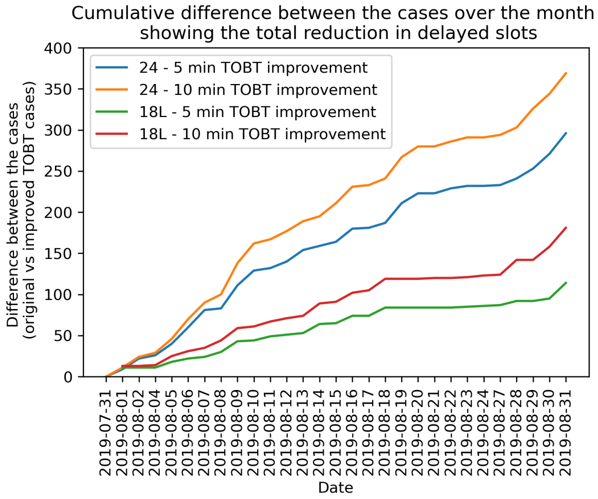


Figure 4: *Cumulative delay reduction of a month in 10 minute slots*

Aside from the improvement in difference in absolute shift, the volatility of the model is deemed to be of interest. The previous departure managing tool was perceived to be unstable by airlines and handlers. Earlier TOBT updates should therefore not lead to more instability of the model. It can be seen that for most days, there is a reduction in the total slot shift. During the example month, one outlier on the negative axis shows an increase of 17 slot shifts; however, this increase dissolves for a TOBT improvement of 10 minutes indicating that a 5-minute improvement is not sufficient on this day. For most days, the total number of shifts reduces, as is to be expected, creating more stability in the runway schedule.

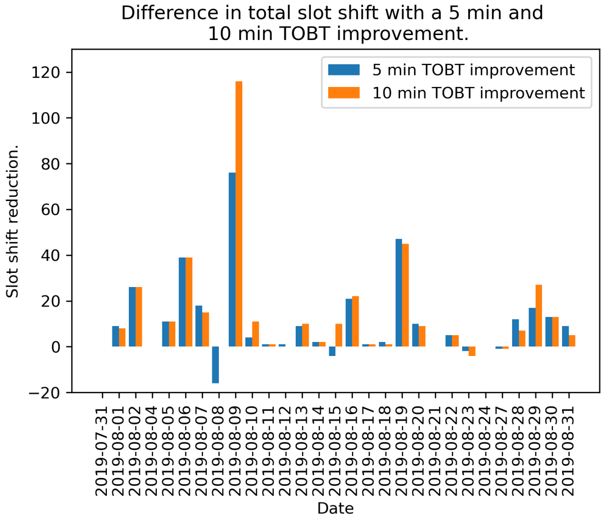


Figure 5: *Difference in total slots shifted per day*

The research question originated by observing that the runway was not used to its full capacity. The used runway capacity was observed to be lower than the capacity declared by the Air Traffic Control. It was hypothesised that earlier TOBT updates would lead to a higher runway capacity, as delays are communicated earlier and the runway use, therefore, would become more predictable in periods with more demand than capacity. In such a scenario, a late TOBT update communicating a delay leads to a gap in runway planning. In Figure 6, the difference in slot usage is visualised for a runway capacity of 7 flights per 10 minutes. It can be seen that with earlier TOBT updates up to 4 additional aircraft can depart during a period in which demand exceeds capacity. On half of the days, no gaps on the runway are present, or the improvement in TOBT setting is not enough to prevent a late TOBT update.

The runway capacity at Schiphol Airport varies depending on the weather conditions and the expected demand. The simulation was therefore run for three runway capacity conditions: 30 flights/hour, 36 flights/hour and 42 flights/hour. This corresponds to 5 flights/10 minutes, 6 flights/10 minutes and 7 flights/10 minutes respectively. Normal operation is considered to be 42 flights/hour, which is used in the initial planning and take-off slot assignment. By reducing the number of flights per slot, the delay and thus the total slot shift increases; however, the effect of timely TOBT updates also increases, as there are more slots with higher demand than capacity.

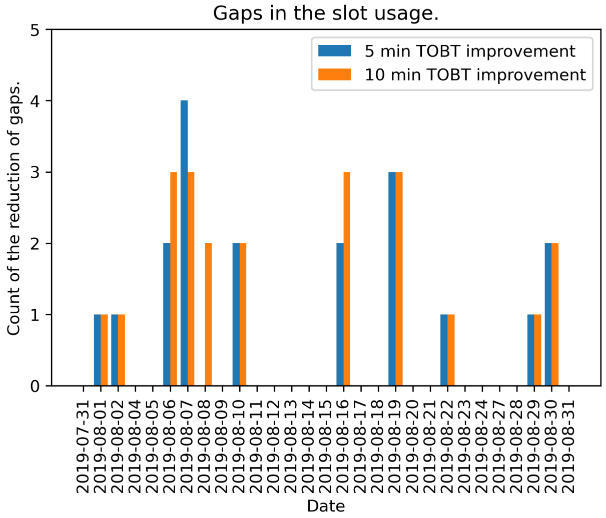


Figure 6: *Difference in runway usage when demand exceeds capacity*

6 Discussion

In this section, the results presented in section 5, that followed from the experiment, will be discussed. The limitations & assumptions of the used methodology and the research process are also presented.

6.1 Experimental results

The results obtained from the experimental model show a clear improvement in the runway schedule. The number of slots in delay assigned to flights per day is reduced, which can solely be attributed to the earlier TOBTs, as no other variables were altered between the simulations. It is expected that the experimental model only provides an altered runway schedule for cases in which last-minute delays or late TOBT improvements were communicated. In other cases, the Departure Manager did not change the priority of flights. A stable and fair priority runway schedule does not change if information is communicated earlier.

An independent t-test was used to test if there would be a significant difference between the experimental model with the original Target Off-Block Time updates (M= 0.3594, SD= 0.7568) and 5-minute earlier Target Off-Block Time updates (M= 0.3354, SD= 0.7301). Results indicate that, for the month of August, there is a significant difference between the two scenarios (t(12319)=2.5356, p=0.0112). Similar statistical significance values were found for the other months, which are tabulated in Table 3 in Appendix A. For the summer months, July and August, almost all differences are found to be significant. For January and February not all cases present significant differences. Besides the 5-minute earlier TOBT updates, also 10-minute earlier Target Off-Block Time updates were used as input for the simulation. The observed differences between the original output and the 10-minute improvement were even larger.

Looking at the total slot shift over all flights per month, no significant difference was found between the three cases. Looking at the net effect per day, a significant difference was found, which was expected by looking at Figure 5.

6.2 Limitations & assumptions

The turnaround and runway scheduling are two complex processes at an airport, due to the many factors that may affect a smooth operation. The stakes in the process are high as delays can be costly for airlines, handlers and an airport. For this simulation, it is assumed that all Target Off-Block Time updates can be communicated 5 minutes or 10 minutes earlier, although this might not be possible for all flights/updates in reality. Various studies have been done on the estimation of Target Off-Block Time updates; however, including this in the model was not feasible for this study. The feasibility of earlier Target Off-Block Time updates at Schiphol Airport is recommended to be studied further, to quantify the improvement in more detail.

As mentioned previously, this study assumed that predicting the TOBT earlier is feasible. As unexpected events occur, this can not always be feasible. It is however expected, that in more than 50% of the cases, a conservative earlier prediction of the TOBT can be realised by increasing turnaround analysis and increased monitoring. It should not occur that a TOBT expires before updating.

The assumptions made in the used approach may have influenced the observed results, but quantifying the effect of these assumptions is difficult without modelling multiple systems at various stakeholders and their connections. By choosing a comparative analysis, the aim is to isolate the assumptions to the extent possible. The assumptions made for this study are listed below:

- Historic data including behaviour
- Interaction with the network manager
- Interpretation of priority rules
- Fixed Taxi-Out time
- Weather conditions
- Penalties DMAN not considered

Historic data including behaviour:
Historic data from 2019 are used for the simulation of the new Departure Manager (DMAN). The new DMAN is, however, not yet operational, so the data are collected using the old runway scheduler. The previous runway scheduler was perceived to be unstable, therefore gaming by airlines and handlers was applied to prevent frequent changes in the assigned slot. This gaming will be present in the data and might produce some noise. The advantage of historical data, however, is that the new Departure Manager cannot be gamed, as the historical data are already recorded.

Interaction with the network manager:
The data contain Calculated Take-Off Times, which are slots assigned by the Network Manager (NM) to control the European airspace. The CTOTs assigned in the historical data are considered in the experimental model. Upon changing the moment of updating the Target Off-Block Times, the CTOTs are assumed to be constant, as it is not feasible to model the behaviour of the Network Manager. It can be expected, however, that the Network Manager could also optimise the use of the airspace.

Interpretation of priority rules:
The priority rules are specified in the Functional Specification of LVNL [3]. To simulate the model in an isolated environment, these priorities have been translated to matching variables in the available data. The priority rules have to be checked by the operational Departure Manager upon taking it into operation.

Fixed Taxi-Out Time:
In the operational scenario, the Estimated Taxi-Out Time is used to calculate the Target Take-Off Time based on the Target Off-Block Time. The Estimated Taxi-Out Time is calculated by an LVNL system taking into account the departing ramp, departure runway, and operational taxi routes. To simplify the model, a standard taxi time of 15 minutes is used for the simulation.

Weather conditions
The runway departure capacity varies based on the weather conditions, such as visibility and rainfall. As the weather conditions in the simulated months varied, this needs to be taken into consideration. The experimental model, however, was built for a fixed runway capacity as no declared capacity was available from historic data. The experimental model has therefore been applied for 7, 6, and 5 flights per 10-minute runway slot, ranging between 42 and 30 flights per hour, covering a complete range of possi-

bilities. Applying a lower capacity in the model than the realised capacity, however, causes large delays as flights will not be cancelled by the model. These delayed flights accumulate at the end of the day which proves that the simulation also operates well under sudden weather changes.

Penalties DMAN not considered
The new Departure Manager (DMAN) follows the best-planned-best-served principle, stimulating airlines and handlers to timely give updates of the Target Off-Block Time (TOBT). Failing to timely update the TOBT (such as expired TOBTs) will result in a penalty. Due to the historical origin of the data, no gaming or late TOBT updates were inserted in the data on purpose. The penalties were therefore not applied in the experimental model.

7 Conclusions

This article presents the findings of a study investigating the effects of a positive change in behaviour regarding earlier Target Off-Block Time (TOBT) updates on desired results in capacity, predictability and reduced delay based on historical data. An experimental model was used to simulate a new Departure Manager (DMAN), which uses a set of priority rules to assign flights to the runway slot in which they depart. The research question is formulated as: "What is the effect of the current behaviour regarding setting and updating of the Target Off-Block Time (TOBT) by airlines and handlers on the departure capacity of Schiphol Airport?". To answer this question, it should be mentioned that the simulation did not find an overall significant result for all cases, runways and months. Due to the number of flights scheduled on time, these results are insignificant overall, as the averages are influenced by the size of the data. However, a trend can be seen, indicating that earlier TOBT updates lead to a better runway schedule. One can not schedule better than on time, but late TOBT updates accumulate like a snowball effect throughout the planning.

Several steps could be taken to extend the presented study. The first step is to expand the model by including the behaviour of the Network Manager (NM) in the simulation. The Departure Manager (DMAN) is dependent on the traffic around Schiphol Airport. If TOBT updates are provided earlier, the resulting Calculated Take-Off Times (CTOTs) are likely to change, creating more improvement opportunities for flights that are bound to their CTOT.

Another step that can be taken is to include the dynamic runway capacity. The dynamic runway capacity was not available for the historic data but can be obtained at LVNL by looking at current data. The simulation is, as described in section 4, executed for three runway capacities: 42 flights/hour, 36 flights/hour and 30 flights/hour. The experimental model, however, takes these runway capacities as a constant for the entire month, which is not realistic due to constantly changing weather conditions. By considering the dynamic runway capacity, the model can be exactly tailored to the operational conditions, leading to more accuracy.

In this study, the Target Off-Block Time is seen as the input of the Departure Manager (DMAN), which constructs the departure runway schedule. The TOBT follows from the airlines/handlers, based on the turnaround process. It is assumed that with better turnaround monitoring, and a more conservative approach, the TOBT updates can be communicated 5 minutes and 10 minutes earlier. The feasibility of this timeframe is assumed in this study, by observations made in practice. To increase the accuracy of the experimental model, future research can model the turnaround itself, to identify in which cases earlier TOBT updates are feasible. This research could also indicate guidelines for TOBT update behaviour which airlines/handlers can use in the operations.

Lastly, the experimental model built for this research solely focused on the departure runway scheduling at Schiphol Airport. It would, however, be interesting to study how this model behaves at other airports, assuming the Target Off-Block Time behaviour and runway capacity will be different.

It is unknown whether the effect presented in this paper would be present in the operational situation, as the experiment is conducted in an isolated environment using various assumptions. However, it is expected, based on the observed trends, that earlier Target Off-Block Time (TOBT) updates lead to a higher capacity, higher predictability, and reduced delay.

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A Appendix

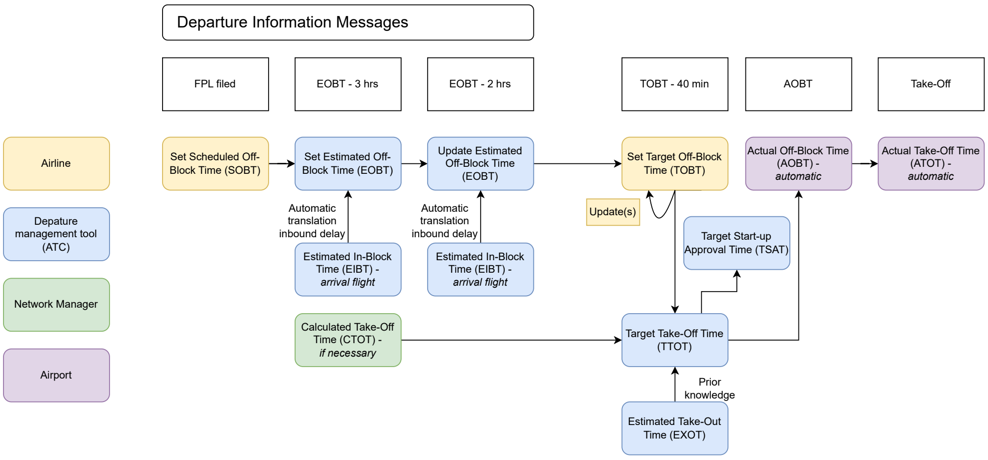


Figure 7: *Flow departure information messages*

Table 3: *Results statistical tests*

RW	Month	Slot size	Mean org	SD org	Mean 5min	SD 5min	Mean 10min	SD 10min	DOF	T-stat	P-value
24	08	7	0.3595	0.7568	0.3354	0.7302	-	-	12319	2.5357	0.0112
24	08	7	0.3595	0.7568	-	-	0.3295	0.7276	12319	3.1665	0.0015
24	08	6	0.7980	1.2659	0.7624	1.2294	-	-	12315	2.2362	0.0253
24	08	6	0.7980	1.2659	-	-	0.7482	1.2225	12315	3.1383	0.0017
18L	08	7	0.1324	0.5226	0.1128	0.4709	-	-	5803	2.1270	0.0334
18L	08	7	0.1324	0.5226	-	-	0.1013	0.4230	5803	3.5334	0.0004
18L	08	6	0.2785	0.7677	0.2469	0.7126	-	-	5803	2.3056	0.0212
18L	08	6	0.2785	0.7677	-	-	0.2291	0.6746	5803	3.6859	0.0002
24	07	7	0.2409	0.6182	0.2211	0.5909	-	-	7054	1.9489	0.0513
24	07	7	0.2409	0.6182	-	-	0.2129	0.5806	7054	2.7792	0.0054
24	07	6	0.4848	0.9540	0.4626	0.9311			7054	1.4021	0.1609
24	07	6	0.4848	0.9540	-	-	0.4505	0.9363	7054	2.1553	0.0311
18L	07	7	0.1523	0.5469	0.1208	0.4102	-	-	3871	2.8676	0.0041
18L	07	7	0.1523	0.5469	-	-	0.1084	0.3865	3871	4.0789	>0.001
18L	07	6	0.3044	0.7535	0.2719	0.0433	-	-	3871	2.0208	0.0433
18L	07	6	0.3044	0.7535	-	-	3.0376	0.0024	3871	3.0376	0.0024
24	01	7	0.1683	0.8293	0.1569	0.8133	-	-	6042	0.7641	0.4448
24	01	7	0.1683	0.8293	-	-	0.1525	0.8001	6042	1.0604	0.22890
24	01	6	0.3442	1.0398	0.3255	1.0222			6041	0.9970	0.3188
24	01	6	0.3442	1.0398	-	-	0.3197	1.0065	6041	1.3156	0.1883
18L	01	7	0.2791	0.6836	0.2642	0.6477	-	-	4051	1.0008	0.3170
18L	01	7	0.2791	0.6836	-	-	0.2581	0.6428	4051	1.4229	0.1548
18L	01	6	0.5184	1.0472	0.5046	1.0260	-	-	4051	0.6000	0.5485
18L	01	6	0.5184	1.0472	-	-	0.4954	1.0156	4051	1.0014	0.3167
24	02	7	0.2819	1.5208	0.2706	1.5037	-	-	7878	0.4688	0.6392
24	02	7	0.2819	1.5208	-	-	0.2640	1.4974	7878	0.7442	0.4568
24	02	6	0.5783	1.7174	0.5635	1.7022	-	-	7878	0.5451	0.5857
24	02	6	0.5783	1.7174	-	-	0.5527	1.6939	7878	0.9434	0.3455
18L	02	7	0.3514	0.7598	0.3205	0.7136	-	-	6463	2.3863	0.0170
18L	02	7	0.3514	0.7598	-	-	0.3098	0.6988	6463	3.2410	0.0012
18L	02	6	0.6709	1.1865	0.6367	1.1592	-	-	6463	1.6645	0.0902
18L	02	6	0.6709	1.1865	-	-	0.6261	1.1479	6463	2.1848	0.0289

II

Preliminary Report - Already Graded

1

Introduction

Schiphol is one of the largest airports in Europe. On a daily basis, many flights use one of its five runways for take-off and landing. To operate these flights, numerous supporting systems and procedures are required. The focus of this study is the take-off runway capacity, since increasing the runway and peak hour capacity is crucial for the future of Schiphol. The increase of capacity is not so much driven from the perspective of volume growth but is necessary from the perspective of network quality, reduction of delay, and reduction of noise pollution. Increasing runway capacity allows more aircraft to be handled from noise-preferred (primary) runways, and reduces the duration of peak periods. As a result, the need for runways to be used for longer periods of time decreases, creating longer periods of rest for the surrounding area.

The turnaround process takes place between arrival and departure of an aircraft and is conducted by an aircraft handler. This process starts when the blocks are placed around the wheels of the aircraft (Actual In-Block Time) and ends when these blocks are removed (Actual Off-Block Time). During the turnaround, data on the status of the process and departure planning are shared via Airport Collaborative Decision-Making (A-CDM) system. Involved parties such as the airline, aircraft handler, airport, and air-traffic organisation have access to these data in real-time, ensuring that each party has the most accurate data at all times and is able to communicate with the same information.

The most important parameter during the turnaround process with respect to the runway capacity is the Target Off-Block Time (TOBT). The Target Off-Block Time is the best estimate of when the blocks on the platform can be removed, indicating that the complete turnaround process is finished. This target time is used by the Air-Traffic control to schedule aircraft on the runway as part of the outbound traffic process. The runway scheduling is done based on scheduled capacity of the runway, actual available traffic, and current runway conditions such as weather. The Target Off-Block Time can therefore also be seen as the interface between the turnaround process and the outbound planning.

During a single turnaround, a strict timeline is set out for all required steps. Despite having a detailed planning, unexpected events and delays occur during the process. The delays are communicated by the airline or handler via a Target Off-Block Time update. Timing and accuracy of these updates are essential for a smooth process and are the subject of study in this research. This research aims to show the effect of an increase in knowledge sharing on the runway capacity. It is expected that having a better estimate of the Target Off-Block Time in terms of update frequency, update times, and behaviour of involved parties leads to an improved runway capacity for all stakeholders.

The research question for this study is formulated to study: the effect of the current behaviour regarding the **setting** and the **moment of updating** of the Target Off-Block Time (TOBT) by airlines and handlers on the **realised departure capacity** of Schiphol Airport? By varying the initially set Target Off-Block Time it can be observed whether the duration of turnarounds should initially be estimated with a longer or shorter duration. By modelling the moment of updating the effect of updating the Target Off-Block Time 'earlier' on the runway capacity can be investigated. It is hypothesised that 'earlier' updates could lead to more stability of the outbound planning and a higher realised runway capacity.

The study is started by briefly describing the turnaround process and describing the Target Off-Block Time in more detail in chapter 2. Thereafter, a literature review will be presented on studies on the duration of a turnaround, Target Off-Block Time updates and the construction of a departure schedule in chapter 3. In chapter 4, Schiphol airport is looked at more closely by describing the information position of the turnaround controller, elaborating on the working of the outbound planning and evaluating airlines and handlers' current Target Off-Block Time behaviour. Knowing the specific situation at Amsterdam Airport Schiphol, a research question is formulated, the working of the new outbound planning tool is described and the research proposal is provided in chapter 5.

2

Turnaround process and Target Off-Block Time

In this chapter, the turnaround is briefly described and an example block diagram is provided of a common turnaround. In section 2.2, the construction and use of the Target Off-Block Time are elaborated upon. The importance of this specific time element is emphasised.

2.1. Turnaround process

A turnaround occurs when two scheduled consecutive flight are operated with one aircraft, and is defined as the time between the actual in-block time (AIBT) and the actual off-block time (AOBT). The Actual In-Block Time is the moment when wheel blocks are placed after an aircraft arrives at the gate/stand and at the Actual Off-Block Time these blocks are removed again, leaving the aircraft ready for taxiing to the runway. During the turnaround, all after-landing processes and checklists are concluded and the aircraft is prepared for its next flight. A turnaround can occur either at the gate or at a remote position, also referred to as the apron.

There are multiple involved parties in the turnaround process of an aircraft. The most important ones are listed below [16].

- Airlines
- Ground handlers
- Airport operator
- Air Navigation Service Provider

Each aircraft belongs to an airline, often operating a fleet of aircraft. The airlines contract one or multiple ground handlers to execute the turnaround process at the gate or stand. The ground handlers need to know when their services are required and at which stand/gate the aircraft will be positioned. The airport operator is responsible for the scheduling of gates and stands, and the Air Navigation Service Provider (ANSP) facilitates the travel to/from the gates or stands. The airport operator and ANSP need to be kept up-to-date on the progress of the turnaround as their schedules are changing over time.

Besides the four most important stakeholders, also indirect stakeholders are involved. For example meteo providers, fuel providers, airport security, emergency services, and the Central Flow Management Unit (CMFU) are also indirectly part of the turnaround operation [16].

Listed below are the general steps taken during a turnaround [17], which are tailored per aircraft and type of flight. A general turnaround schedule is often provided by the aircraft manufacturer and can be tailored by the airline. Long-haul flights might require different turnaround processes than short-haul flights. For short-haul flights, an airline might for example choose to only resupply the catering every other flight. The duration of the sub-processes changes over time and depends on multiple factors, such as for example the comprehensiveness of the sub-process, the current progress during the sub-process, and the number of scheduled staff. During the turnaround process, applicable regulations and guidelines should be strictly followed [29]. For instance, the regulations state that aircraft crew should be present in the cabin if passengers are onboard while ground operations take place or that an aircraft may not be fuelled during boarding and deboarding. In Figure 2.1, the common blocks within a turnaround are shown, wherein the critical path is indicated in red [8].

Steps during a turnaround:

- Aircraft arrives (IB)
- Ground power connection (ACC)
- Flight administration (ACC)
- Passengers deboarding (DEB)
- Baggage unloading (UNL)
- Crew change (DEB/BOA)
- Resupply catering (CAT)
- Aircraft cleaning (CLE)
- Aircraft refuelling (FUE)
- Water service (CLE)
- Passenger boarding (BOA)
- Baggage loading (LOA)
- Ground power disconnection (FIN)
- Optionally: de-icing and/or anti-icing (OB)
- Aircraft departs (OB)

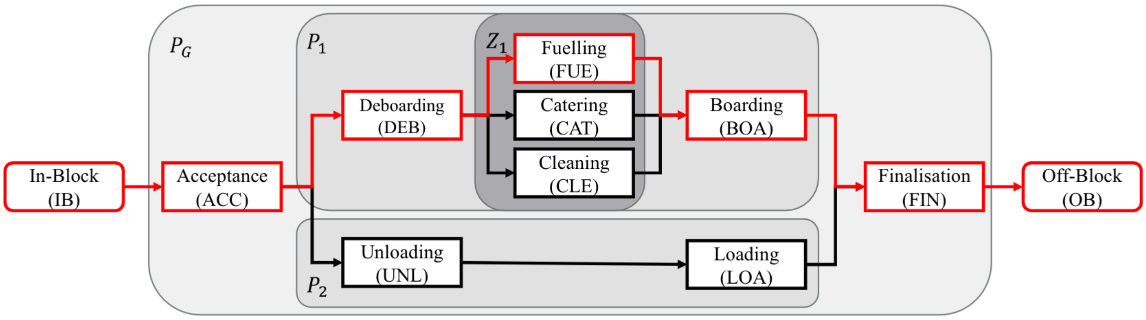


Figure 2.1: Common block in a turnaround process [8]

2.2. Target Off-Block Time

During the aircraft turnaround, which is described above, a milestone approach is used to create common situational awareness for all parties involved in the turnaround [1]. Information is shared between these parties using airport-CDM. Figure 2.2 shows the milestones recommended by EUROCONTROL to keep the involved parties informed during the turnaround.

The Target Off-Block Time (TOBT) serves as the main means of communication between the Air Traffic Control (ATC) system, and the flight process, as it is used as a trigger for the ATC to calculate the Target Start-Up Approval Time (TSAT) [14]. It thus operates on the interface of the turnaround process. The Target Start-Up Approval Time is used to inform all involved parties when the aircraft is expected to start-up and push back. Adding the Estimated Taxi-Time to the Target Start-up Approval Time leads to a Target Take-Off Time (TTOT). The Target Start-Up Approval Time is determined by the departure management tool (DMAN) that, aside from the Target Off-Block Time, takes the following inputs: the allocated runway, the variable estimated taxi time, the Calculated Take-Off Time (CTOT), and the runway capacity. In the determination of the Target Take-Off Time and the Target Start-up Approval Time, not only the current air traffic situation around the airport is taken into account, but also the Air Traffic Flow Management (ATFM) along the scheduled route of the flight is considered, sometimes resulting in a Calculated Take-Off Time. A Calculated Take-Off Time is only given to a flight if on-route congestion is expected for a flight and if it, therefore, needs to take-off within a specific window. All these time estimates are of influence to the Target Off-Block Time, which is therefore considered an important milestone to achieve an efficient and reliable flight operation. Milestone (nr. 9) lies on the interface between the ground processes and the flight process and is of influence on both processes. This milestone therefore has the highest number of connected resources, stressing its importance.

Timely updating of the Target Off-Block Time is essential. This will be demonstrated by using an example [14]. A flight is constrained in its Calculated Take-Off Time (CTOT). This is done by the Central Flow Management Unit (CFMU), which calculates the airspace sector load throughout a flight prior to take-off. The Central Flow Management Unit delays a flight or imposes restrictions if a sector overload occurs during the flight. The Calculated Take-Off Time requires a flight to take-off within a 15-minute window, 5 minutes prior and 10 minutes after the provided Calculated Take-Off Time. The Calculated Take-Off Time is based on the Target Off-Block Time that airlines send via the Central Flow Management Unit (CFMU) as part of the Departure Planning Information (DPI). DPI messages are used to provide all involved parties with the most recent information containing: which Standard Instrument Departure routes a flight uses, an estimation of the take-off time, the Target Off-Block Time, the Target Start-up Approval Time, and an Estimated Taxi-Out Time. An inaccurate or late update of the Target Off-Block Time can cause the aircraft to fail to depart within the take-off window (Calculated Take-Off Time window), causing a redundant reservation of the airspace this flight was going to occupy. At that point, the reservation cannot be assigned to another flight anymore, for example to a flight that had been delayed previously. This example shows the importance of accurate and timely updates of the Target Off-Block Time on the optimal use of the airspace and the runway.

During a turnaround, unanticipated events occur all the time. The turnaround process itself is laid out prior to its start; however, the process requires continuous monitoring and controlling, which is done by a turnaround controller either remotely or on the platform. The turnaround controller oversees the turnaround and makes decisions based on available data and delays. This requires simultaneous monitoring of the critical path as a whole as well as monitoring the sub-processes for every turnaround. These decisions result in an update of the Target Off-Block Time that is entered into the system, and thereby the delay information is shared with the other involved partners.

Each airline uses its own monitoring system, generating real-time data on the turnaround processes either manually or automatically, for example by using an Aircraft Communication Addressing and Reporting System (ACARS) or by using sensors placed at the gate/apron [14]. The sensors are able to identify the current status at the gate/apron in detail; however, transposing this detailed monitoring to the effect on the critical path is not studied and is mostly done manually. Examples of tools that are used to process information, by airlines in Airline Operation Centres (AOCs) are *Allegro* and *HubStar* [14]. These tools process the information aiming to create a cohesive picture for the turnaround controller.

After each TOBT update, the outbound planning of the airport has to be revised by air traffic control to accommodate all outgoing traffic. Late Target Off-Block Time updates can cause disruptions, of which one example was provided earlier, explaining that runway slots cannot always be assigned to other flights if their Target Off-Block Time is changed late. It also has implications for other places at the airport. Pushback trucks already at the gate need to wait if the Target Off-Block Time is pushed last minute, and if no other gates are available, landing traffic also experiences a delay, which can potentially propagate to connecting flights.

Number	Milestones	Time Reference	Mandatory / Optional for Airport CDM Implementation
1	ATC Flight Plan activation	3 hours before EOBT	Highly Recommended
2	EOBT – 2 hr	2 hours before EOBT	Highly Recommended
3	Take off from outstation	ATOT from outstation	Highly Recommended
4	Local radar update	Varies according to airport	Highly Recommended
5	Final approach	Varies according to airport	Highly Recommended
6	Landing	ALDT	Highly Recommended
7	In-block	AIBT	Highly Recommended
8	Ground handling starts	ACGT	Recommended
9	TOBT update prior to TSAT	Varies according to airport	Recommended
10	TSAT issue	TOBT -30 mins to -40 mins	Highly Recommended
11	Boarding starts	Varies according to airport	Recommended
12	Aircraft ready	ARDT	Recommended
13	Start up request	ASRT	Recommended
14	Start up approved	ASAT	Recommended
15	Off-block	AOBT	Highly Recommended
16	Take off	ATOT	Highly Recommended

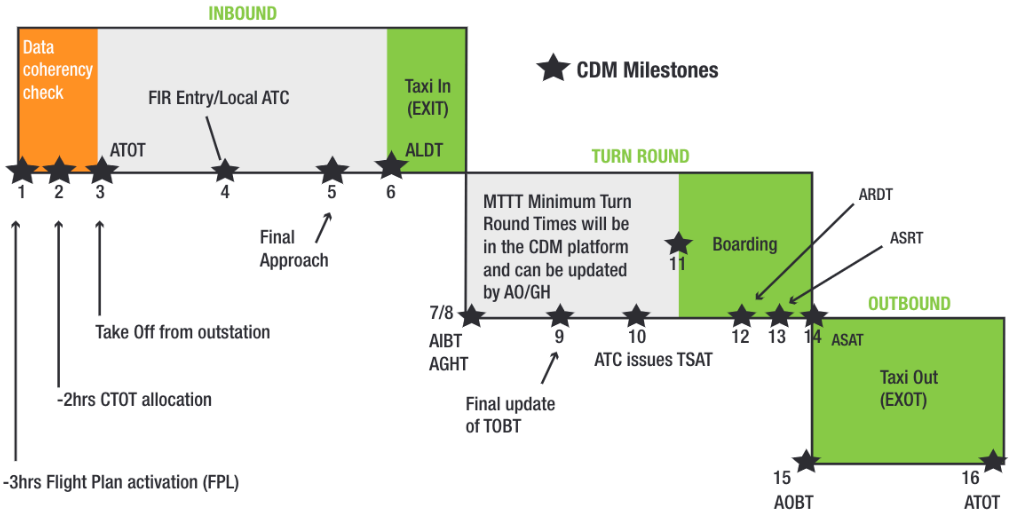


Figure 2.2: Milestone approach turnaround process [1]

In this chapter, a brief look at the turnaround process is taken. Identifying the critical process results in the minimum duration of the turnaround. The expected duration of the turnaround is communicated by means of the Target Off-Block Time. The place of this TOBT in the airport-CDM process is elaborated upon to provide insight into the complete process and stress the importance of the Target Off-Block Time. Insight into the turnaround process is required to analyse the initial setting of the Target Off-Block Time. In order to study the implications of the Target Off-Block Time updates information on the departure runway scheduling is required.

3

Literature review

Multiple studies have focused on the prediction of the Target Off-Block Time, which is done by estimating and monitoring the duration of the turnaround. These studies will be reviewed in this chapter.

3.1. The duration of the turnaround process

Multiple studies in predicting the target off-block time have been done. Predicting the Target Off-Block Time is done by estimating and monitoring the duration of a turnaround. In practice, airlines determine them based on their need. The specific situation at Schiphol airport is looked at more closely as part of the case study in chapter 4.

In most studies, the critical path method (CPM) is used to determine the minimum time between arriving at the gate and the desired departure [29]. The critical path method identifies which sub-processes constrain the complete duration of the turnaround; however, the method does not take punctuality or uncertainties into account. The fuzzy critical path method, a variation of the critical path method, was used in [7]. This is a combination between CPM and fuzzy set theory. Fuzzy set theory is able to also consider task duration, punctuality and uncertainties in addition to the features described for the critical path method.

Besides critical path modelling, Agent-Based Simulation (ABS) can be used to monitor the turnaround process which uses a microscopic view, as individual agents are able to make autonomous decisions following programmed rules. This results in interactions between the agents, which can also be evaluated on a macro level by evaluating the system as a whole, which is done in techniques such as discrete event simulation (DES) and object-oriented simulation [29].

Anderson et al. [5, 6] developed a model aiming to simulate airline decision making during a turnaround, by using an integer programming model. The model can be used for prediction of turnaround or evaluation of current practises. The model simulates decisions regarding pushback times taking into account the outbound planning, the gate assignment, gate scheduling, and ground support scheduling/operations while minimising delay on passenger level. As part of this study, two additional models representing taxiing to and from the gate/apron and the runway were developed using a simple queuing technique. The three models combined were used to evaluate the complete system of airport operations.

Wu & Caves [33, 35, 34] conducted several studies in turnaround simulation with a focus on uncertainties in the process. A Markovian model was used and state transition flows were identified and presented [34]. The main advantage of using a Markovian model is the ability to model the transition between activities conducted by different ground service providers in a stochastic manner. The model also incorporates disturbances in aircraft turnaround. Aside from solely looking at process optimisation during a turnaround, flight punctuality has been studied. Factors of influence on flight punctuality that have been identified based on a limited number of flights using a Monte Carlo Simulation are scheduled buffer time and operational efficiency. In a subsequent study, the use of buffer times is further investigated entailing a trade-off between schedule punctuality against aircraft utilisation with the aim to minimise costs [35].

Mujica Mota et al. zoomed in on the turnaround process and created a discrete-event simulation (DES) model for Lelystad airport to model individual handling processes of a turnaround [22]. The model requires a detailed platform layout and uses predefined constant time values for the sub-processes. Norin et al. closely looked at the optimisation of the de-icing process [23]. The effect of applying different optimisation strategies on one turnaround sub-process on the complete airport logistics is studied. Therefore, the complete turnaround from landing to take-off is modelled. In the complete model, some dependencies between sub-processes are neglected. Tian et al. studied ground handling of future and unconventional aircraft configurations aiming to improve the ground processes for new aircraft types [31]. The latter study uses a 3D aircraft model as input for the aircraft configuration.

In [15], the Target Off-Block Time is predicted based on an LSI-CNN model, which stands for latent semantic index (LSI) and convolution neural network (CNN). The model only uses time data of the turnaround that are coupled with the Target Off-Block Times and inserted in a CNN. The LSI method determines whether the information in the time data influences the critical path of the turnaround process. It is found that the accuracy of the LSI-CNN model is higher compared with a model that uses a fully-connected neural network, as is done in [13]. In this study, neural networks are applied to predict flight turnaround times based on seven factors; however, these factors do not change over time and therefore produce a static turnaround time [13]. In [36], Back Propagation (BP) neural networks are used, but instead of predicting the turnaround time, used neural networks to predict the off-block time directly. This study used optimised the neural network by using a genetic algorithm [36]. The off-block time is predicted on multiple instances. A higher accuracy of the estimated off-block time is achieved once the flight is in-block compared to prior to the arrival of the flight.

In [21] it is argued that using a distribution is preferred over using a Target Off-Block Time prediction, as the TOBT often changes over time. The author argues that having frequent updates reduces the reliability of a TOBT, as it then might as well change again. Based on the historic updates of the TOBT, a distribution is estimated by a neural network. The distribution is assumed to follow the Johnson-SU distribution. Using a distribution the reliability can be incorporated directly in the standard distribution. According to [21], this could also reduce delay in the assignment of the Target Start-up Approval Time.

3.2. Updating the Target Off-Block Time

Once a flight arrives at the gate/apron, the flight is referred to as In-Block. During the turnaround process, the Target Off-Block Time is updated according to the status of the turnaround process. Studies into the effect of Target Off-Block Time updates or information disruptions in general, are discussed in this section.

The effect of information disruptions and disturbances in the Airport Collaborative Decision Making (A-CDM) system with respect to the accuracy of the off-block time are studied in [24]. Their research is twofold in first analysing the impact of information disruption on the Target Off-Block Time and second by simulating the pushback and taxiing process. The effect of the Target Off-Block Time changes on the take-off performance was also analysed. The study started by identifying the information flow in the A-CMD process and identified which parties use the Target Off-Block Time and at what instance with respect to the time itself. Using an experiment, the Actual Off-Block Time is compared to the Target Off-Block Time, showing at which milestone a disturbance occurs. A limitation of this study is that the variability in the duration of the service processes in the turnaround is not considered. The impact of the found disturbances is studied using an Aircraft Flow and Process Simulation tool, developed by the Airport Research Center, called CAST. Two scenarios are used as a case study. For scenario 1 the nominal Target Off-Block Time is used whereas for scenario 2 the data including the disruptions in the Target Off-Block Time were used. The latter scenario shows a higher average taxi delay and a shift of delay towards evening hours due to a domino effect.

As part of [10], the effect of uncertainty in the Estimated Off-Block Time on the departure performance was studied. When departure metering is applied, waiting times are assigned at the gate such that aircraft have a lower taxi time (which includes the waiting time) while making sure the runway is used optimally. Uncertainty in the Target Off-Block Time can impact the departure metering twofold: less accurate taxi time predictions and loss of a runway slot. The degree of successful departure metering is measured in the following key performance indicators: taxi times, required fuel, and departure queues [10].

3.3. Departure runway scheduling

Each airport has its own system and algorithm to conduct its departure scheduling. Therefore, research is often connected to a specific airport. In [11], the general problem is described as a desire for increased punctuality, a reduction in costs and fair prioritisation of flights that are critical for an airline's network. Previous studies on Collaborative Decision Making focused on ground and departure processes identify the absence of coordination as the main problem [11]. This problem is visible at airports with fluctuating taxi times, and large queues due to outbound traffic peaks. This study argues that the complex optimisation process aims to find a balance between punctuality requirements and planning constraints while fulfilling the separation requirements in case of overcapacity.

In [30], an analysis was conducted aiming to show the potential savings that could be obtained if a tool was used for departure runway scheduling. A departure manager uses virtual queuing rather than physical queuing on a taxiway, creating the advantage that aircraft can remain at the gate for a longer period of time while also reducing the complexity of the field and increasing the flexibility for air traffic control. Previous work to this study neglected limited gate capacity, so this was taken into account, leading to a more realistic improvement in expected delay and financial benefit [30].

Generalised dynamic programming has been applied to the runway scheduling problem on simulated traffic levels at Dallas/Fort Worth International airport using three basic heuristics [20]. The study considers four constraints when building the sequence: Departure Wake Vortex Separation, Departure Area Navigation Separation, Runway Crossings Separation, and Miles-in Trail Separation. [20] builds on the work of [25] and [26]. [25] explained how to apply dynamic programming by imposing additional constraints limiting the position shifting. This is done by comparing the shifted position with an initial reference position. [26] applied the limit in position shift to a runway scheduling problem taking into account both delay and throughput, resulting in a fast solution on a simplified model with limited constraints. In [12], dynamic programming has also been used to reduce the number of position shifts by imposing a maximum, as a reduced number of shifts leads to a higher runway capacity. Linear programming is also used by [19] but this study aims to tackle three problems at once by optimising the arrivals, departures, and ground movements all in one. This optimisation, however, is not tested for changes in the target off-block time. It follows a three-step approach by first calculating the shortest route on the ground to and from the runway, then calculating the arrival and departure times, and lastly merging this into a schedule without conflicts on all fronts.

In [4], a system was developed to assist controllers in scheduling the departing aircraft for Boston Logan, focusing on ground traffic and minimising delays. Their initial solution was one-stage, mainly solving objectives and constraints while taking the aircraft-specific characteristics into account [4]. In a later paper, a two-stage heuristic algorithm is presented, in which slots are sequenced during the first-stage departure class and runway crossings are generated by a departure class sequencer based on the variable departure runway capacity. In the second stage thereafter, the sequenced slots are connected to specific flights that are available for departure. The latter is done by using a Branch & Bound algorithm solving for the constraints that are not solved in the first-stage [2]. The main purpose of separating into two stages is the degree of uncertainty, as there is less uncertainty in the demand based on aircraft weight classes compared to specific aircraft characteristics [3].

Another study [9] that takes ground movement into account, created a decisions support tool for departure runway controllers at London Heathrow to assist in take-off sequencing. A decisions support tool was created for departure runway controllers at London Heathrow to assist in take-off sequencing. For Heathrow specifically, it was deemed important to consider constraints regarding overtaking in the holding area. Constraint techniques were previously applied on inbound traffic, resource constraints (e.g. runway, SID, exit point), order constraints, timeslot constraints, separation constraints based on weight class, and airport layout topology constraints [32].

At the National Aerospace Laboratory of the Netherlands (NLR), the outbound punctuality sequencing was studied by applying the information available as part of Airport Collaborative Decision Making (A-CDM) in a new Departure Management tool (DMAN), which is called the Outbound Punctuality Sequencer (OPS) [11]. The paper proposes a solution that is based on three operational changes: requiring timely updates of the estimated off-block times from the flight deck, ground traffic being accommodated on time, and following a detailed departure planning with a new procedure. The tool accommodates a multi-runway airport in mixed-mode operations but is specifically designed for Stockholm Arlanda airport [11].

In this chapter, common methods are described that are used for the prediction of turnaround duration. For this study, the critical path method will be applied and assumed operational at Schiphol Airport as no detailed information on the sub-processes is available. The effect of continuous and timely information sharing will be studied by applying it to a new model which will be implemented at Schiphol Airport. Lastly, how such a model is implemented at other airports was investigated such that important model parameters are not forgotten. A case study regarding Schiphol Airport is presented in the next chapter.

4

Case study Schiphol

In this chapter, the working of the turnaround at Schiphol is looked at. It highlights the available information at the position of the Duty Area Managers in section 4.1 and the working of the current and new outbound planning system in section 4.2. In section 4.3, the Target Off-Block Time data of Schiphol are looked at, showing the previous behaviour of airlines and handlers.

4.1. Turnaround specifics at Schiphol

The largest airline that operates on Schiphol is KLM. Their operations are controlled by KLM Ground Services from the Hub Control Center (HCC). At the HCC, three Duty Area Managers (DAMS) monitor all flights operated by KLM from a remote position, each having their own area: Intercontinental flights, European flights and flights operated by subsidiary KLM Cityhopper. The Duty Area Managers rely on the information provided to them to assess the status of a particular flight. This information as well as the decisions made, will be elaborated upon below.

Each flight has two turnaround controllers on the side of the airline in charge of the turnaround process: one is responsible for processes above the wing (for the cabin and gate) and the other is responsible for processes below the wing (on the platform). These turnaround controllers provide information on the status of the flight and report on issues interfering with the scheduled tasks to the Duty Area Managers. The information is not provided on standardised points during the turnaround process, but is presented by the turnaround controllers as deemed necessary via verbal communication. The Duty Area Manager can also take the initiative by requesting information.

At the Hub Control Centre all turnaround process tasks are scheduled by the planning department. This is done based on internal information and available staff and equipment. As aircraft handlers track the progress accurately, the Duty Area Managers can see in one overview, for each process during a turnaround, if staff/equipment has been scheduled, if staff has arrived at the platform, if the task has started including at what time, and if the process is finished. On the same overview the Duty Area Managers can see how many passengers already boarded the aircraft.

Each platform contains a camera system that can be operated remotely by the Duty Area Managers. This can not be counted as information available on an every turnaround as there are not enough displays available to create an overview of all flights that are monitored simultaneously. Looking up and adjusting the cameras to the desired angle in is also too labour intensive using the current system.

The Duty Area Managers change the Target Off-Block Times of their flights based on all available information. It is often hard to predict how much delay needs to be given to a flight, as it is often unclear exactly how much time is required to resolve an issue. The Duty Area Managers are experienced and trained in making educated estimations for each situation; however, there are no exact metrics. Not knowing how large the extent of a delay is, currently causes situations where delays are entered just before or even after the initially set Target Off-Block Time, leading to an expired Target Off-Block Time.

This will be shown in section 4.3.

Delays in the turnaround process are classified using the IATA delay codes, such that the cause of the delay can be traced and penalties can be assigned to the right stakeholder. Cockpit/Cabin crew arriving late at the aircraft, can cause the boarding to start late which causes a delay. In another case, the cleaning service arrived late, which caused the boarding to start late. Another phenomenon that was observed is the gaming of the Target Start-up Approval Time, which can best be explained by an example. A flight was observed where a delay of 15 minutes was expected, so the Target Off-Block Time was adjusted accordingly. This new Target Off-Block Time lead to a new Target Start-up Approval Time from +15 minutes with respect to the new Target Off-Block Time, imposing a total delay of 30 minutes. The Duty Area Manager consecutively adjusted the Target Off-Block Time again as if the initial delay was expected to be 10 minutes, leading to a new Target Start-up Approval Time of +10 minutes, leading to a total delay of 20 minutes. The Duty Area Managers of the airline are not to blame for this observation, as their job is to make sure that flights can depart as close to the desired time. The jumping Target Start-up Approval Time resulting from an unstable Departure Manager causes these issues. How the Target Off-Block Time is translated to a Target Start-up Approval Time is elaborated upon in the following section. In Figure 4.1, the timeline of flight is shown connected to all times in the turnaround process and the stakeholder responsible for updating it.

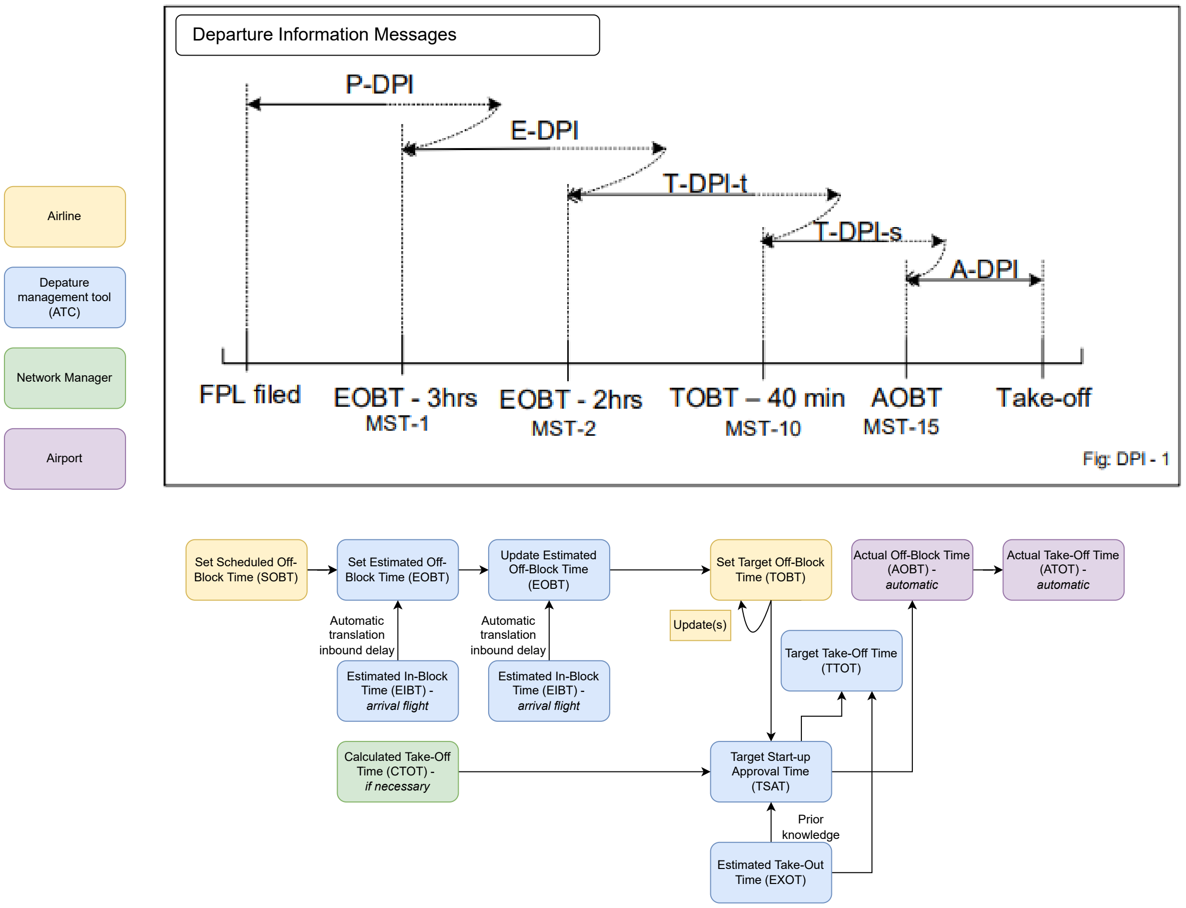


Figure 4.1: Overview of times during a turnaround.

4.2. Working outbound planning

The Departure Manager, also referred to as DMAN, is a planning system that helps to improve departure flows at an airport. The Departure Manager calculates the Target Take-Off Time and Target Start-up Approval Time (TSAT) for each flight, based on the Target Off-Block Time, the slot assigned by the Network Manager, and the Calculated Take-Off Time.

Before being able to build an accurate pre-departure sequence, the Target Take-Off Time needs to be accurate, as this represents the number of the particular aircraft in the take-off sequence. Once a Target Off-Block Time is known and the used runway is known, the Target Take-Off Time can be calculated by adding the taxi time (Estimated Taxi-Out Time (EXOT)) to the Target Off-Block Time. In combination with a potential slot, this leads to a Target Start-up Approval Time and a corresponding window during which a pilot can request start-up clearance. The Target Take-Off Time is thus used to help adhere to the Departure and Slot Tolerance window (DTW/STW) and the Calculated Take-Off Time (CTOT). Once the start-up clearance is provided and the aircraft is pushed-back from the gate, it starts taxiing to the runway to take-off within the Target Take-Off Time window. This process is visually shown in Figure 4.2. Should an aircraft not be able to comply with the Departure and Slot Tolerance Window, the Runway Controller (RC) needs to contact/inform the Network Manager (NM) that the aircraft will not make the slot window and either ask for an extension of the slot or request a new slot. Slots are used to prevent the congestion of aircraft on a route when it is on its way from A to B.

Whether the Target Start-up Approval Times and their spacing are relevant for the aircraft throughput is dependent on the airport. For Schiphol, the Target Start-up Approval Time sequence currently determines the achieved throughput which is maintained at the runway; however, in an ideal case it should solely be used to control the quantity of aircraft and not maintain the Target Start-up Approval Time sequence for the runway, as there are multiple runways and routes to the runway creating a complex system.

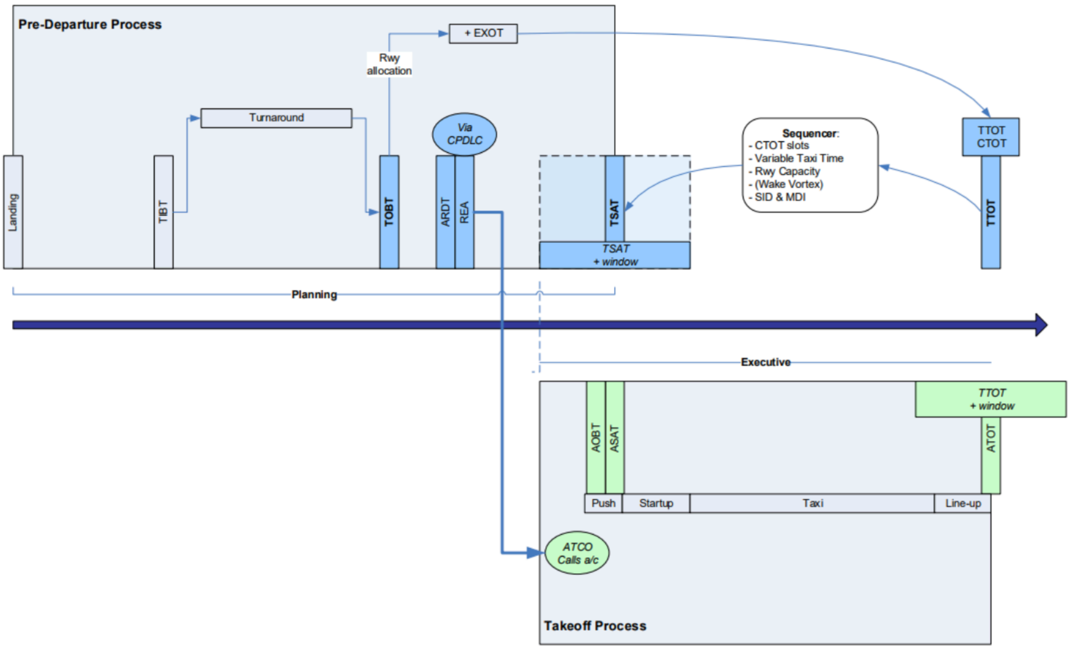


Figure 4.2: DMAN process overview [18]

The current Departure Manager system is perceived to provide unstable Target Start-up Approval Times, as it moves flights back and forward on the outbound planning [27]. Air Traffic Control The Netherlands (LVNL) is currently working on the implementation of a new Departure Manager following different rules, which aims at providing more stability in the Target Start-up Approval Time. This research will be based on the new Departure Manager tool. In the new situation, there will be a single runway & capacity planning that is used for a single outbound planning, compared to it now being done in two different systems. This outbound planning is presented to outbound planner (OPL) and shared with partners. The runway & capacity planning will be loaded in the system up to 24 hours in advance, based on the capacity forecast (which is developed in consultation with meteo, airport and hub carrier). The planning will be at least 3 hours in the future to create stable knowledge sharing for all stakeholders. The take-off runway & capacity planning will be entered and edited at the Schiphol tower, while the landing runway & capacity planning will be entered and adjusted at Schiphol Approach.

The runway & capacity planning uses runway planning periods containing a start time, take-off runway(s) including exit sectors, Standard Instrument Departures (SIDs), capacity, the landing runway(s) including stack preference, capacity, and type of procedure used for landing and approach. The outbound planning sequencer uses blocks of 10 minutes, which should preferably also be the case for the runway planning periods.

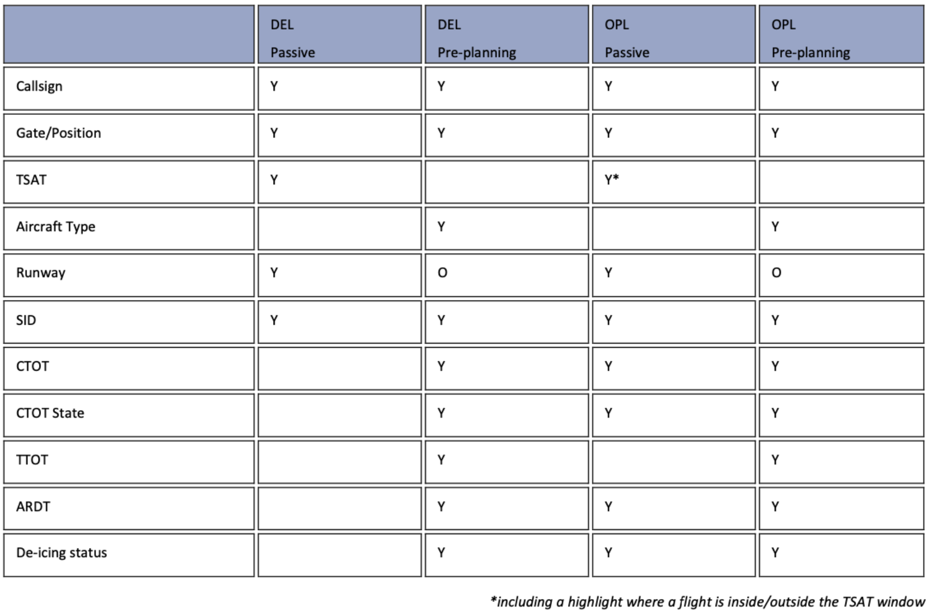
Using the runway & capacity planning, the Outbound Planning Sequencer assigns a planned runway to each flight and provides an outbound sequence per runway for the upcoming 3 hours. The Outbound Planning Sequencer schedules flights on 10 minute blocks. The numbers of flights being scheduled per block is dependent on the capacity in the runway & capacity planning. Within the 10 minute block the flights will be scheduled on a one-minute basis following their Target Take-Off Time or Calculated Take-Off Time (or block start time if TTOT or CTOT are not possible).

The Outbound Planning Sequencer assigns a Target Take-Off Time and runway to a flight. Flights in a new block (and potentially new runway configuration) will not be scheduled with a Target Take-Off Time earlier than the last flight from the previous block. Thereby, conflicts with Standard Instrument Departures between blocks are eliminated. Only pilots who call early/late in their Target Start-up Approval Time window might arrive early/late at the runway. This posed conflict then needs to be solved by the runway controller(s). Flights that are shifted to another 10 minute block, might need to depart from a different runway. If the flight has not received airway clearance, this will be communicated to the aircraft right away.

The Outbound Planning Sequencer uses variable taxi times such that the arrival on the runway can be predicted accurately from each gate to a particular runway taking into account various conditions. If the predicted taxi time is too short, the aircraft will not be on time to make the defined Target Take-Off Time. If the estimated taxi time is too long, flights will have to hold at their gate otherwise or arrive at the indicated runway too early. The variable taxi time is not solely determined by the route the aircraft needs to take between the gate and the runway, but is also dependent on operational factors such as visibility, snow, maintenance, and blockages. The taxi time in the system therefore should be adaptable. In order to accommodate this, multiple taxi tables are available for various operational conditions which can be selected by the outbound planner.

The new Departure Manager aims to connect the pre-departure phase with the runway capacity using the same time intervals. It creates a flow of outbound flights which is monitored and controlled making sure that enough, but not too many, flights receive start-up clearance and get to the runway. This balance between enough and not too many is vital to control the workload of the ground and runway controllers.

The outbound planning is operated through a Human Machine Interface (HMI). The Human Machine Interface provides a ground controller with an overview of both the pre-planned sequence as well as the flow from start-up/push-back until a flight is airborne. The Human Machine Interface supports both planning ahead and immediate decision-making. Ideally, a controller should not intervene, but adhoc changes should also be accommodated for such as a sudden runway change. The primary interface used is a touch interface containing information from the sequencer showing the departure sequence. In addition, the secondary interface shows information provided by the outbound planning system associated with the departure sequence, such as the runway capacity, runway planning periods, and key performance indicator monitoring. The touch interface at Schiphol is connected to the Electronic Flight Strip System, which allows for transferring a flight to other personnel at different workstations in the tower. The information available / required for the outbound planner is shown in Figure 4.3.



	DEL Passive	DEL Pre-planning	OPL Passive	OPL Pre-planning
Callsign	Y	Y	Y	Y
Gate/Position	Y	Y	Y	Y
TSAT	Y		Y*	
Aircraft Type		Y		Y
Runway	Y	O	Y	O
SID	Y	Y	Y	Y
CTOT		Y	Y	Y
CTOT State		Y	Y	Y
TTOT		Y		Y
ARDT		Y	Y	Y
De-icing status		Y	Y	Y

***including a highlight where a flight is inside/outside the TSAT window*

Figure 4.3: Information requirements for the delivery controller (DEL) and outbound planner (OPL) [18]

4.3. Airlines and handlers TOBT behaviour

As mentioned previously, airlines are responsible for updating their Target Off-Block Times. The current Target Off-Block Time behaviour is described in this section and initial observations are presented.

The Target Off-Block Time updates during the month October 2019 are visualised below in two figures. Figure 4.4 contains a histogram showing the time horizon between the moment the Target Off-Block Time update is entered in the system and the new ‘desired’ Target Off-Block Time. This thus shows how much in advance the Target Off-Block Time updates are done. An example of this axis is: an update of the TOBT that is communicated at 12:00 setting the new TOBT at 12:10 has an ‘horion’ of 10 minutes. Ideally, all Target Off-Block Time updates are done well in advance, on a large horizon, such that a stable outbound planning can be created and few last minute changes are required. Figure 4.4 shows that the majority of Target Off-Block Time updates are currently done last minute, with a horizon between 0 and 2,5 minutes prior to the new desired off-block time. The colours in the figure represent the size of the Target Off-Block Time update, with respect to its previous state. Negative change means that aircraft are ready ‘earlier’ than previously expected and positive change means a delay with respect to their previous Target Off-Block Time. The figure shows that it frequently occurs that aircraft suddenly decrease their Target Off-Block Time once the aircraft is almost at the end of their turnaround. Airlines thus often overestimate the time required for their turnaround. It can be seen that this eventually often leads to a large jump on the Target Off-Block Time from up to 60 minutes to the current time. This is not necessarily a problem for the outbound planning, as the aircraft can still depart in their originally assigned slot. In terms of airport logistics, however, it is not favourable to have an aircraft occupying a gate for this period.

Figure 4.5 shows the difference between the moment of the Target Off-Block Time update and the previous set Target Off-Block Time. It thus shows in how much time the previous Target Off-Block Time would have expired should it not have been updated. It can be seen on the bars on the left side of zero that it frequently appears that the Target Off-Block Time is already expired for a period of up to 30 minutes before a new Target Off-Block Time is set. This expiration causes a gap in the outbound planning, as the aircraft is expected on the runway but is eventually not able to make the scheduled runway slot. This slot is unlikely to be filled again with a flight that is ready to depart earlier than scheduled. The change between the previous and new TOBT are visualised using the same colour scheme, where positive change stands for a delay and negative stands for a new ‘earlier’ TOBT. Target Off-Block Times that are 0 - 10 minutes past expiration often get updated by the amount of 5 - 10 minutes, as is

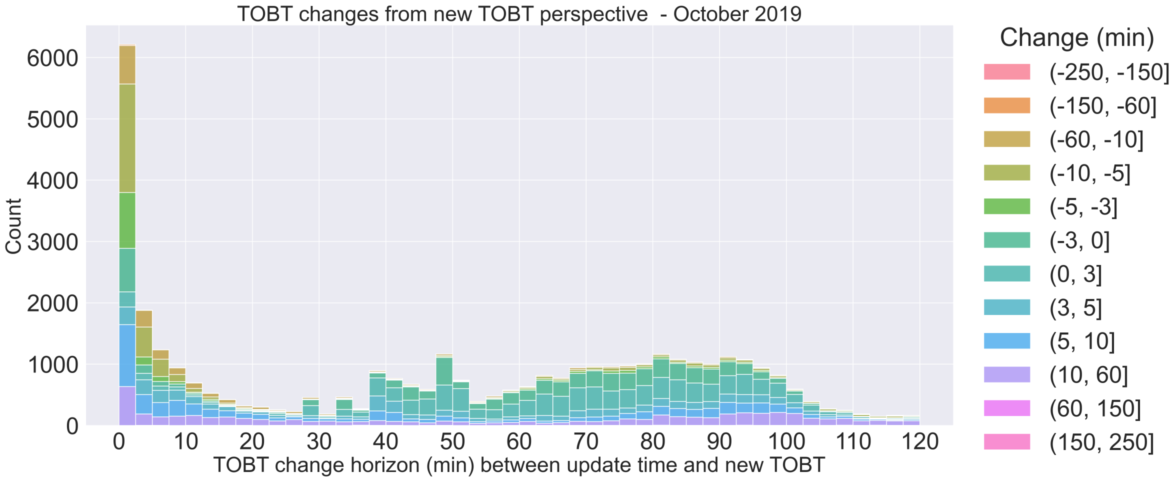


Figure 4.4: Target Off-Block Time horizon on the moment of updating

indicated in blue, which places the updated time just in the present. The figure also shows that between 10 - 30 minutes before expiration, the Target Off-Block Time is often decreased by this amount as well, indicating that a flight is thus ready right away after the update. As mentioned previously, this is not desired for logistical purposes.

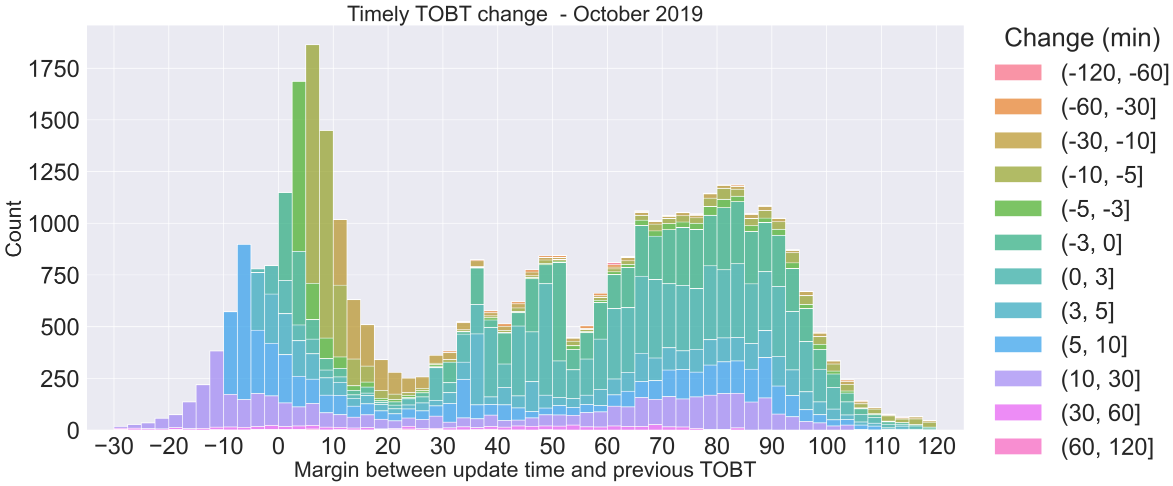


Figure 4.5: Late update TOBT

Figure 4.4 and 4.5 clearly show that between 30 - 90 minutes prior to the set Target Off-Block Time, mainly smaller updates are entered in the system ranging between +5 en -5 minutes. This shows that the turnaround controller, in that time frame, can quite accurately monitor the turnarounds by for example looking current status of the critical path of the complete turnaround. The sudden jumps at the end of the turnaround show that at the end of the turnaround, there is more uncertainty or that built-in buffers are not predicted accurately. The expired Target Off-Block Times could say something about the lack of information provided to, or communicated by, the turnaround controller in particular situations.

To gain more insight in the Target Off-Block Time behaviour on an airline level, the graphs can be presented per airline, as shown in Figure 4.6. Comparing for example KLM and EJU for the month October 2019, it can be observed that between 0 - 25 minutes prior to Target Off-Block Time expiration, KLM mainly conducts changes between -10 and +10. EJU in the same horizon provides changes between -30 and +10, from which the majority falls within the -30 to -10 range. The larger the changes, the higher the instability on the outbound planning.

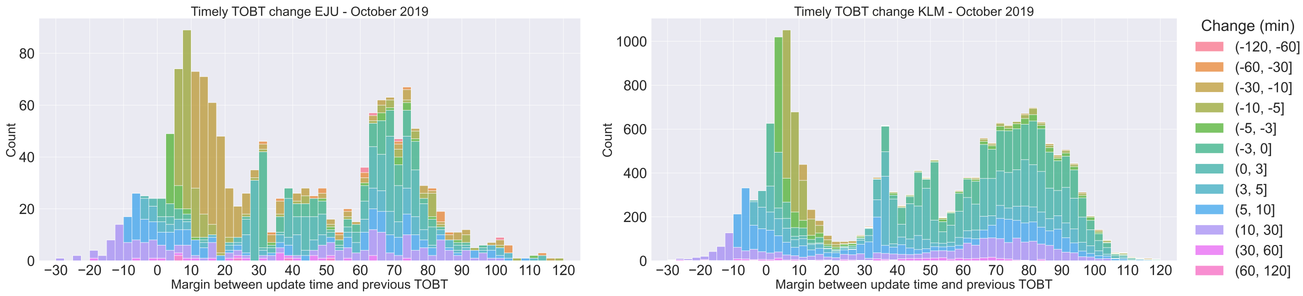


Figure 4.6: Comparison KLM and EJU - TOBT expiration updates - October 2019

In previous graphs, large jumps in Target Off-Block Time have been observed. It was indicated that these jumps regularly corresponded to buffer times that were eventually not required. Figure 4.7 shows that most aircraft depart later than the initially Schedule Off-Block Time (SOBT). Combined with the sudden jumps in the later stage of the turnaround, this shows that during the turnaround the Target Off-Block Time was set to a later time by the turnaround controller. Near the end of the turnaround, it was then most likely to be brought forward again.

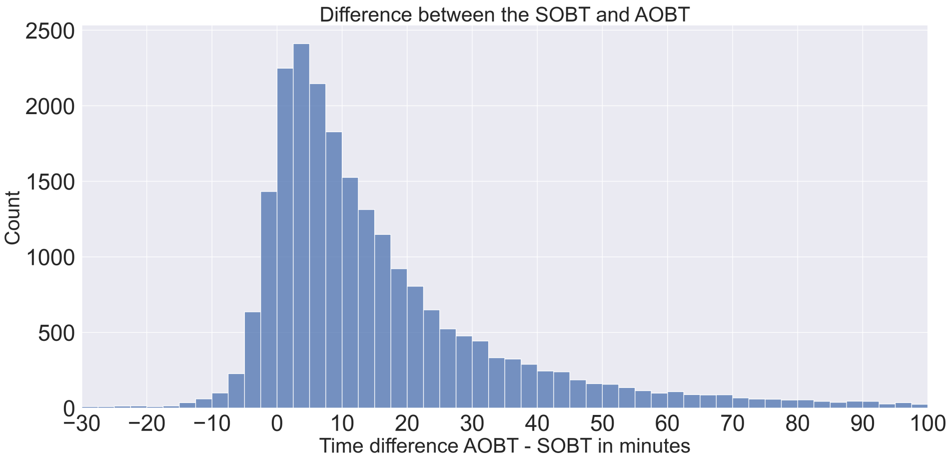
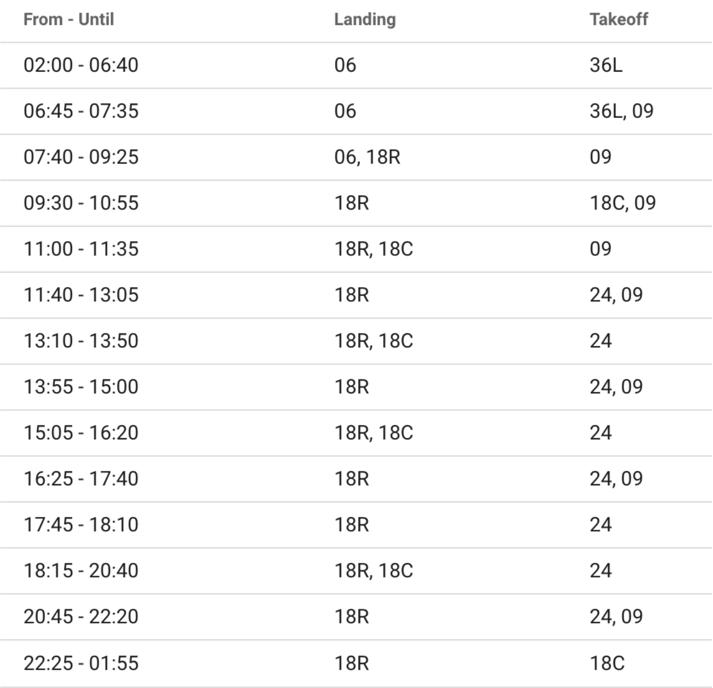


Figure 4.7: Difference between SOBT and AOBT - October 2019

4.4. Departure capacity Schiphol

Figure 4.10 shows aircraft that departed during the month October 2019. Each line represents a different day, showing the number of aircraft that departed per hour. During a regular day Schiphol changes between inbound and outbound peaks multiple times, as can be seen in Figure 4.8. During outbound peaks, two runways are used for departures, whereas for inbound peaks two runways are used for arrivals. Schiphol declares the capacity of both configurations in advance, as well as an off-peak and night capacity. The declared capacity translates into an initial planning combined with the slots provided to airlines by the network manager.

The scheduled off-block times of the month October 2019 are shown in Figure 4.9. It can be seen that the scheduled off-block time do not correspond one-to-one with the actual take-off times, shown in Figure 4.10. Logically, there is a slight offset, as taxi time is not taken into account in the scheduled off-block times. Apart from this, however, it can be seen that the peaks do not correspond. This shows that there is a difference between the flight plans and the realised outbound traffic. Multiple factors cause this offset such as weather, runway availability, and the target off-block time that follows from the turnaround process.



From - Until	Landing	Takeoff
02:00 - 06:40	06	36L
06:45 - 07:35	06	36L, 09
07:40 - 09:25	06, 18R	09
09:30 - 10:55	18R	18C, 09
11:00 - 11:35	18R, 18C	09
11:40 - 13:05	18R	24, 09
13:10 - 13:50	18R, 18C	24
13:55 - 15:00	18R	24, 09
15:05 - 16:20	18R, 18C	24
16:25 - 17:40	18R	24, 09
17:45 - 18:10	18R	24
18:15 - 20:40	18R, 18C	24
20:45 - 22:20	18R	24, 09
22:25 - 01:55	18R	18C

Figure 4.8: Runway changes Schiphol on 7-10-2019 [28]

It can be seen in the figures below that during the month there is a variable amount of flights departing per hour each day, although a trend can be observed. Peaks in outbound traffic consistently occur between 05:00 - 06:00, between 8:00 - 9:00, between 10:00 - 11:00, and between 19:00 - 20:00. During the month October, the number of flights departing between 19:00 and 20:00 range from 35 and 82, although most of the data points (days) fall in the range of 55 and 74.

In this chapter, a case study of Schiphol Airport was presented. The turnaround procedure and the working of the outbound planning have been described. The behaviour regarding Target Off-Block Times has been shown in various figures and various improvement opportunities have been highlighted. The departure peaks have also been indicated which need to be incorporated into the model. In the next chapter, the model and research will be elaborated upon and the research hypotheses will be presented.

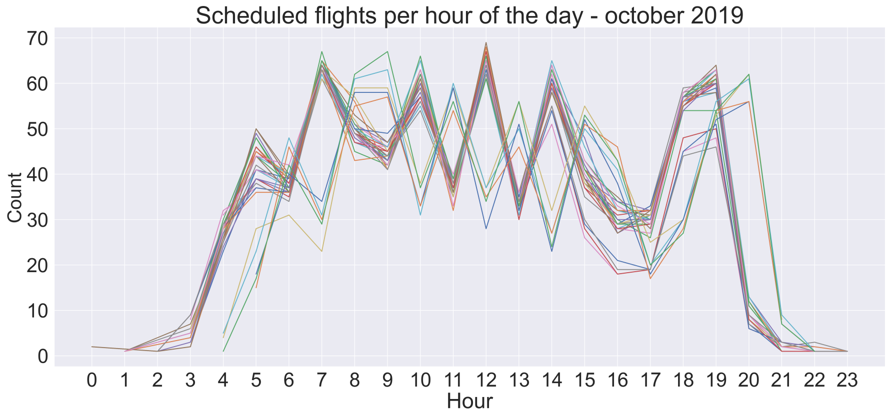


Figure 4.9: Flights per hour of the day - Scheduled Off-Block Time

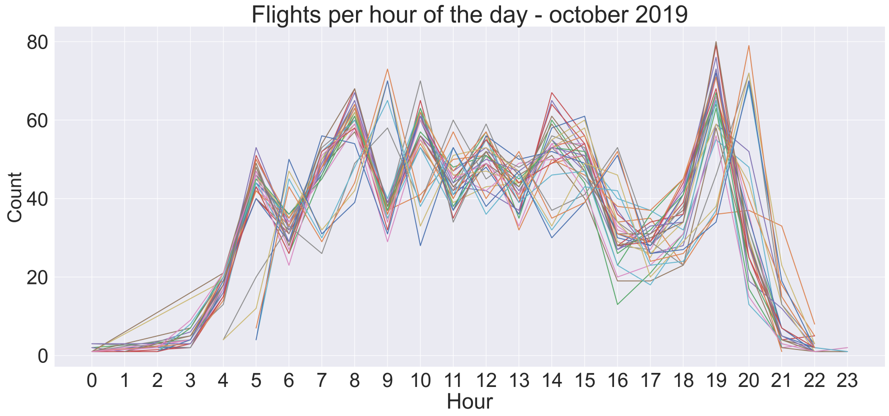


Figure 4.10: Flights per hour of the day - Actual Time of Departure

5

Research Proposal

In this chapter the research objective is elaborated upon in section 5.1. Following the research objective, the research question and sub-questions are presented in section 5.2. In section 5.3, the experimental approach for this research is presented and the model is explained. In section 5.5, the dependent and independent variables are tabulated and the research hypotheses are presented in section 5.4.

5.1. Research Objective

The main research objective of this thesis is:

> "To investigate whether a sub-optimal setting and updating of the Target Off-Block Time (TOBT) has an influence of the capacity of an airport where airport collaborative decision making (A-CMD) is used, such as Schiphol, by means of a data analysis on current practises and by creation of a model showing the effect of identified improvement opportunities regarding TOBT setting and updating in the outbound planning".

5.2. Research Question(s)

The research question is:

> "What is the effect of the current behaviour regarding the **setting** and **moment of updating** of the Target Off-Block Time (TOBT) by airlines and handlers on the **realised departure capacity** of Schiphol Airport?"

The research question in divided into sub-questions which are listed below.

- Are there differences and similarities in Target Off-Block Time usage between the various operators at Schiphol in terms of update frequency, update step size, and update horizon?
- Can 'earlier' Target Off-Block Time updates lead to a higher runway capacity at Schiphol?
- Can 'earlier' Target Off-Block Time updates lead to more stability in the outbound planning at Schiphol?

5.3. Experimental approach - model

The working of the new outbound planning system has been described in chapter 2. Using the priority rules defined for the new departure sequencer, the effect of Target Off-Block Time setting on the outbound planning will be analysed. By varying the update times in the known Target Off-Block Time data, the robustness and effectiveness of the priority rules will be investigated.

For this analysis, the outbound planning system has to be built in python following the priority rules, which are listed below. As a simulator is not readily available for testing, the simulation will project the data in a simplified matter. The communication between the different partners for example cannot be modelled and therefore will be considered stationary.

Priority rules Departure Manager:

1. Flights with more than 10 Calculated Take-Off Time updates.
   Within this list, priority is given in descending order.
2. Flights with more than 2 shifts.
   Within this list, priority is given in descending order.
3. Flights with a Calculated Take-Off Time that would violate the Slot Tolerance Window (STW) if shifted (and would therefore have to receive a new Calculated Take-Off Time).
   This condition is only applied if the flight is still in the Slot Tolerance Windows.
4. Flights with Calculated Take-Off Time or flights with cancelled Calculated Take-Off Time that would be planned later than the cancelled Calculated Take-Off Time if shifted.
   This condition is not applied in intervals before the cancelled Calculated Take-Off Time.
5. Flights with 1 or 2 previous shifts.
   Within this list, priority is given in descending order.
6. Flights with an earlier Target Off-Block Time get priority in ascending order.
7. Time between Target Off-Block Time and Scheduled Off-Block Time, taking into account Target Off-Block Time before Scheduled Off-Block Time situation sorting in ascending order.
8. Lastly, if flights are similar in all priority rules above, priority is given based on the flight sorted ID.

Flights receive a penalty if the Target Start-up Approval Time expires, meaning that engine start-up and pushback are not called for within the indicated window. A penalty is also received if the Target Off-Block Time is updated within five minutes of expiration or after the expiration of the Target Start-up Approval Time. The reduction in the number of shifts is still to be determined.

Based on the priority rules listed above, a model of the Departure Manager tool is built. The layout of the model is presented in Figure 5.1. The runway planning is created per day and data on runway capacity as well as Target Off-Block Time data in the form of Departure Planning Information messages (DPI) are used. An initial runway planning is created based on the Scheduled Off-Block Time, which is used as an inventarisation of the demand. Based on the demand the priority rules are used to dissipate the overflow to the adjacent intervals in the schedule. The runway planning is thereafter continuously iterated as new DPI messages with Target Off-Block Time updates come in. At the end of a modelled day, the data on actual used runway capacity is exported and grouped per month for analysis. The simulation is executed for varying timestamps of Target Off-Block Time updates in order to simulate whether timely updates help improve the realised runway capacity.

Limitations of this study can be found in the connections the systems usually have, compared to the simulation running on an isolated machine. In the current operational systems, all variables have a lot of connections and information is automatically shared between all involved parties. The timestep variation will for example be conducted in isolation, thus the increase in the window of uncertainty will not increase or change the corresponding Target Off-Block Time. This needs to be taken into account when interpreting the results as part of the analysis. Another limitation has to do with the data that were obtained in 2019. As the new outbound planning tool is not yet operational, these data were gathered using the old system. By establishing a baseline and doing a comparison with the baseline this limitation is expected to have a minor influence.

5.4. Research hypotheses

In this section, a number of research hypotheses will be presented that will be evaluated based on the experimental model described above.

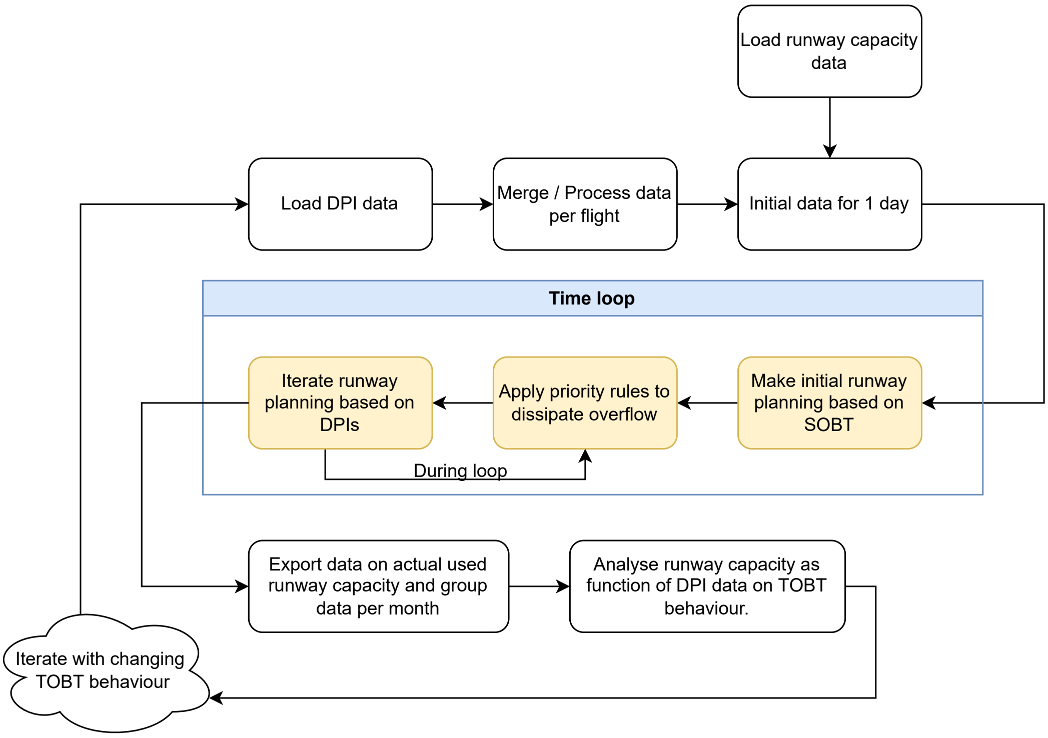


Figure 5.1: Diagram showing the layout of the model simulation

Hypothesis 1:
Earlier Target Off-Block Time updates lead to a higher ideal slot adherence. This hypothesis aims to evaluate whether more aircraft can depart during their ideal slot if Target Off-Block Time updates are communicated earlier while containing the same information. In order for the new outbound planning to be profitable for both the air traffic control and airlines, the slot adherence should and is expected to increase due to better anticipation.

Hypothesis 2:
Earlier Target Off-Block Time updates lead to a higher slot usage ratio during slots where demand exceeds capacity. This hypothesis aims to evaluate whether slots are used to their maximum capacity. Reducing the last-minute or late updates should reduce the frequency where runway slots can not be filled causing gaps on the runway It is expected that timely communication reduces the offset between the declared capacity (on paper) and realised (actual) runway capacity. This is expected as earlier communication of the Target Off-Block Time allows more time for better anticipation in the outbound planning process. To evaluate this hypothesis, the time stamp of the updates will be varied for a particular day by imposing a time stamp shift. The outbound schedule resulting from the experimental model is compared with the outbound schedule of the same day with a time stamp shift of zero.

Hypothesis 3:
Earlier Target Off-Block Time updates lead to a lower average and total shift. This hypothesis aims to evaluate whether the stability of the outbound planning increases if the Target Off-Block Time updates are communicated earlier. It is expected that timely communication improves the stability of the outbound planning and therefore also reduces the volatility of the assigned Target Start-up Approval Times. By providing timely updates, fewer last-minute changes are expected, which should lead to less volatility in the outbound planning. This needs to be tested as in the previous model the Target Start-up Approval Time was changing frequently for a particular flight.

5.5. Variables

In Table 5.1, the dependent and independent variables can be found. The dependent variables will be extracted for each generated outbound planning and will be evaluated for each day. The dependent variables will be elaborated upon below.

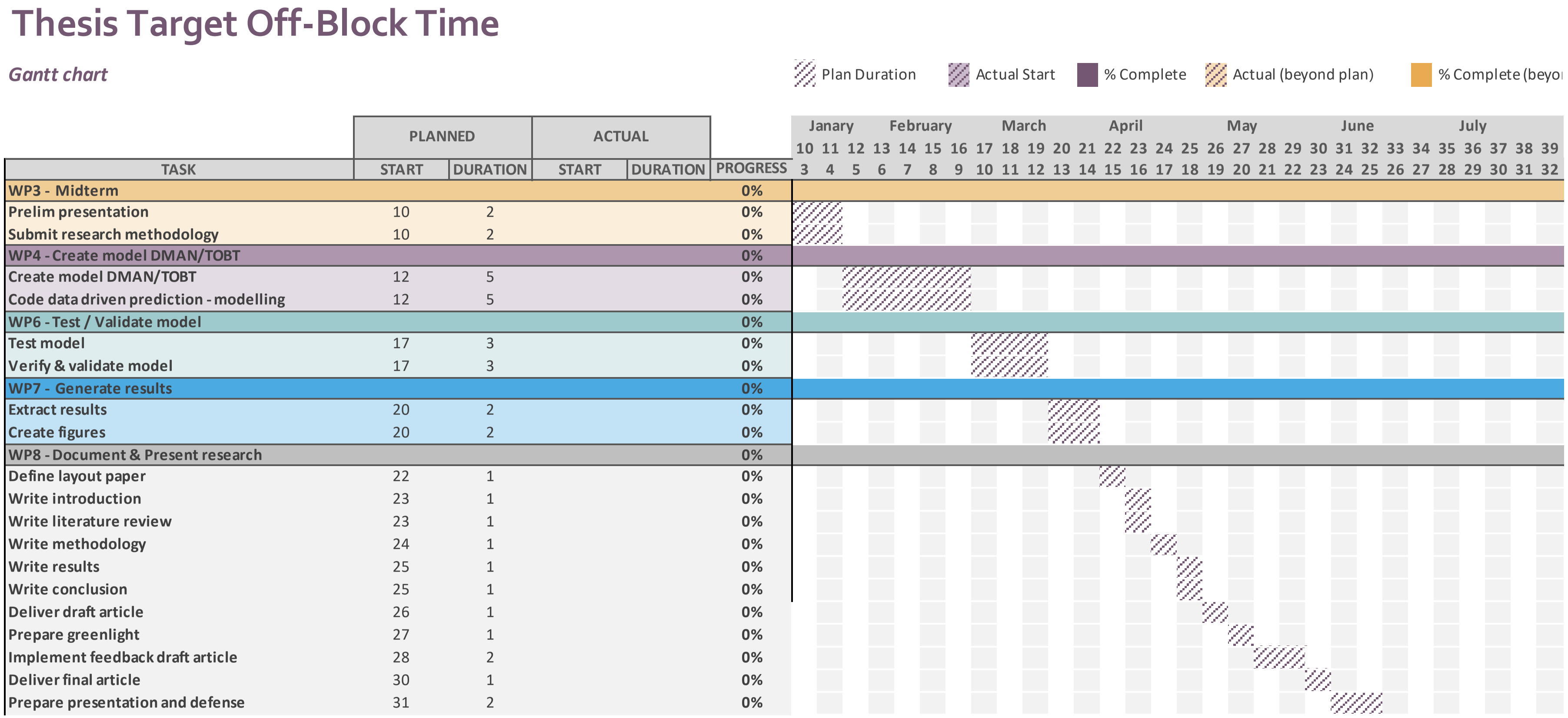
The **ideal slot adherence** will be a means to evaluate the desire of airlines, namely how many percent of aircraft can depart in their initially requested/optimal slot. The **slot usage** is a means to measure the use of the available spots in a runway slot. The outbound planning has a declared capacity based on many factors such as weather and runways available. Based on available traffic and scheduling this leads to a realised capacity. The difference between the realised capacity and the declared capacity can tell something about the operational efficiency. This can be observed by looking at the slot usage, as slots might not fully be used while demand exceeds capacity. The last two dependent variable **average shift** and **total shift** correspond to the number of slots that an aircraft has to shift with respect to the initially desired/scheduled slot to fit in the outbound planning.

Table 5.1: Variables used to construct and evaluate the outbound planning

Dependent variables	**Independent variables**
Ideal slot adherence	Timestamp update
Slot usage	Airline
Average shift	Target Off-Block Time
Total shift	# open runways
	Doors closed time
	Taxi time (average)
	Declared capacity

5.6. Project planning

A Gantt chart of the project planning can be found in Figure 5.2.



Thesis Target Off-Block Time

Gantt chart

	PLANNED		ACTUAL		
TASK	START	DURATION	START	DURATION	PROGRESS
WP3 - Midterm					0%
Prelim presentation	10	2			0%
Submit research methodology	10	2			0%
WP4 - Create model DMAN/TOBT					0%
Create model DMAN/TOBT	12	5			0%
Code data driven prediction - modelling	12	5			0%
WP6 - Test / Validate model					0%
Test model	17	3			0%
Verify & validate model	17	3			0%
WP7 - Generate results					0%
Extract results	20	2			0%
Create figures	20	2			0%
WP8 - Document & Present research					0%
Define layout paper	22	1			0%
Write introduction	23	1			0%
Write literature review	23	1			0%
Write methodology	24	1			0%
Write results	25	1			0%
Write conclusion	25	1			0%
Deliver draft article	26	1			0%
Prepare greenlight	27	1			0%
Implement feedback draft article	28	2			0%
Deliver final article	30	1			0%
Prepare presentation and defense	31	2			0%

Figure 5.2: Thesis planning

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