Reducing the fluctuations of the outbound planning

An analysis of the auto-TOBT mechanism

Thesis

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Preface

Based on the need of a less fluctuating outbound planning, experts have proposed to investigate a replacement of the current business rule in the auto-TOBT mechanism. The effect of proposing a new rule for the auto-TOBT mechanism might reduce the number of triggered TOBT updates and therefore the outbound planning will be less dynamic.

During 20 weeks, from February 2020 till June 2020, I have been working on understanding the auto-TOBT mechanism and analyzing different business rules to create this graduation thesis and provide a conclusion. After three years and a half studying at the Aviation Academy, being part of the Centre of Excellence of the Knowledge & Development Centre (KDC) was a great honor and an interesting end of my study. I gained a lot of new knowledge about Airport Collaborative Decision-Making (A-CDM) and especially about the Target Off-Blocks Time. At the Aviation Academy, A-CDM is part of the curriculum but is not in much detail and therefore I was more than happy to have the opportunity to learn more about this principle.
Even though I worked from home for almost the complete duration of the graduation and visits to different departments was not possible due to the COVID-19 pandemic, it was an interesting period. In this period, I have improved my research, analyzing and writing skills by doing this research and I am proud of the final work I have produced.

First, I would like to thank Hans Kelder for being my supervisor throughout the whole period and for his valuable time. During this period, Hans helped me a lot with answering questions and providing feedback on my work based on his expertise during our weekly meetings. Moreover, I would like to thank Catya Zuniga for being my supervisor lecturer and for giving me the possibility to be able to perform my research at KDC. During this period, Catya was available to give weekly feedback on my work and being available for weekly meetings.

Hopefully, this thesis will be interesting to read, and you will enjoy reading!

Marc Out

Volendam, 27 May 2020.

Summary

At Amsterdam Airport Schiphol (AAS), the outbound planning is fluctuating which is a result of a dynamical pre-departure sequence and results in a loss of capacity. The fluctuations are caused by frequent updates of the Target Off-Block Time (TOBT), which is the main input to create the outbound planning. One of the manners of updating the TOBT, is done by a mechanism which updates the target off-blocks time automatically, which is referred as the auto-TOBT mechanism.

This research aims to reduce the number of automatically triggered TOBT updates while maintaining the accuracy and predictability of the off-blocks time. Therefore, the following research question is created:

"Which business rule(s) could reduce the number of auto-TOBT updates at AAS and therefore reducing the dynamical impact on the outbound planner, without losing accuracy and predictability of the TOBT?".

A business rule is an algorithm in the auto-TOBT mechanism which has conditions deciding if an update will be triggered.

To answer the research question, two new business rules will be compared with the current rule. This comparison is made based on different research topics which helped with analyzing the accuracy and predictability of each business rule. Besides the information about accuracy and predictability, the research topics provided an overview when in time, or in other words, how close to the actual in-blocks time of an aircraft, an accurate TOBT is calculated. The results of the research topics are retrieved from datasets in which inbound and outbound flight information of week 29 in 2019 was provided. With help of descriptive statistics, the results of the research topics are compared with each business rule. Based on the results of the analyzed research topics, it could be concluded that the second business rule provides the most predictable target off-block times, while the number of triggered updates were reduced as well. Therefore, the fluctuation on the outbound planning is reduced.

The second business is the best rule to replace the current business rule based on the performed analysis. However, this analysis did not include cargo operations, due to the lack of information. Moreover, the interests of airport partners are not considered with means of determining when in time an update must be accurate and what is an acceptable accuracy per airport partner.

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List of Abbreviations

Abbreviation	**Definition**
AAA	Amsterdam Advanced ATC System
AAS	Amsterdam Airport Schiphol
ABI	Advanced Boundary Information
A-CDM	Airport Collaborative Decision Making
AIBT	Actual In-Blocks Time
ALDT	Actual Landing Time
AMAN	Arrival Manager
AO	Aircraft Operator
AOBT	Actual Off-Blocks Time
ASAP	Advanced Schiphol Arrival Planner
ATC	Air Traffic Control
CDM	Collaborative Decision-Making
CISS	Central Information System Schiphol
CoE	Centre of Excellence
CPDSP	Collaborative Pre-Departure Sequence Planner
CTOT	Calculated Take-Off Time
EIBT	Estimated In-Block Time
ELDT	Estimated Landing Time
EOBT	Estimated Off-Block Time
EXIT	Estimated Taxi-In Time
EXOT	Estimated Taxi-Out Time
GH	Ground Handler
KDC	Knowledge & Development Centre
KLM	Royal Dutch Airlines
LVNL	Dutch Air Traffic Control
MTTT	Minimum Turnaround Time
NMOC	Network Manger Operations Centre
RWY	Runway
SIPOC	Supplier Input Process Outcome Customer
SOBT	Scheduled Off-Block Time
Std	Standard Deviation
TOBT	Target Off-Block time
TSAT	Target Start-Up Approval Time

List of Definitions

Term	**Definition**
Airport Partners	All stakeholders at AAS which are involved with CDM. These are: airport operator, aircraft operators (AO), ground handlers (GH), ATC (LVNL), and the Network Manager (NM).
Calculated Take-Off Time	A calculated take-off time issued by the air traffic flow management unit of EUROCONTROL, as it results in a tactical slot allocation, at which a flight is expected become airborne.
Current business rule	New TOBT: EIBT + MTTT > SOBT (Eq. 2.1) New TOBT: EIBT + MTTT <> previous TOBT (Eq. 2.2) New TOBT: AIBT + MTTT <> SOBT or previous TOBT (Eq. 2.3)
EIBT	EIBT = ELDT (or ALDT) + EXIT (Eq. 1.1)
First business rule	New TOBT: EIBT + MTTT ≥ SOBT+10 (Eq. 2.4) New TOBT: EIBT + MTTT > SOBT+5 ***or*** EIBT + MTTT <> previous TOBT +/- 5 (Eq. 2.5) New TOBT: EIBT + MTTT > SOBT ***or*** EIBT + MTTT <> previous TOBT (Eq. 2.6)
Second business rule	New TOBT: EIBT + MTTT > SOBT+5 (Eq. 2.7) New TOBT: EIBT + MTTT <> previous TOBT +/- 5 (Eq. 2.8) New TOBT: AIBT + MTTT <> previous TOBT (Eq. 2.9)
SIPOC	With help of a SIPOC-diagram, processes could be expressed in a more detailed level. It provides a summary of a process where the Supplier, Input, Process, Output, and Customer are provided. This creates an overview who is involved and what is required.
TOBT	The time that an AO/GH estimates that the aircraft is ready for pushback as all doors are closed and boarding bridge / stairs are removed. This time reference is calculated as: TOBT = EIBT (or AIBT) + MTTT (Eq. 1.2)

Introduction

This research is performed at the Centre of Excellence (CoE), which is the research center of the Knowledge Development Centre (KDC). KDC is founded by Amsterdam Airport Schiphol (AAS), Royal Dutch Airlines (KLM), and the Dutch Air Traffic Control (LVNL), Ministry of Infrastructure and Water Management and provides a platform for universities and colleges to find innovative and sustainable solutions for Mainport Schiphol (Knowledge & Development Centre, 2019). A cooperation with colleges and universities is established and have different focus points within the KDC. The Aviation Academy of the Amsterdam University of Applied Sciences focusses on the Capacity Management whereas the university TU Delft focusses on different topics within the CoE such as: air traffic management, aircraft noise, weather forecasting, air transport operations, and user interfaces (2019).

This research is focusing on the automatic Target Off-Block Times (auto-TOBT) update mechanism, and especially on the business rules within this mechanism. Those business rules have conditions deciding if the Target Off-Block Time should be updated automatically. This is only done when different operating conditions of this mechanism are met. This auto-TOBT mechanism is part of the Airport Collaborative Decision-Making System (A-CDM) which is implemented at Amsterdam Airport Schiphol.
Since May 2018, A-CDM is fully implemented based on the concept elements advised by EUROCONTROL to implement (Figure 1). EUROCONTROL is the founder of the A-CDM principle which aims to improve the efficiency of airport operations by improving the predictability of air traffic and optimizing the usage of available resources (EUROCONTROL Airport CDM Team, 2017).
At Amsterdam Airport Schiphol, improving the predictability of air traffic is done by making use of different systems of which the auto-TOBT mechanism is one of them. The concept elements which are advised by EUROCONTROL influence this mechanism and therefore on the predictability of air traffic and improving resource planning. To create an accurate Target Off-Block Time, it is from great importance to receive accurate and reliable information of different time references. Therefore, information sharing is fundamental in the A-CDM principle.
By having the milestones approach, the progress of a flight is monitored and creates common situational awareness. Based on the sixteen milestones in this approach, the overall aim of A-CDM could be achieved. Different essential time references, such as the expected arriving time at the parking position and the Target Take-Off Time are calculated based on the taxi time. Therefore, having accurate variable taxi times between runway and parking position and vice versa, the accuracy of the mentioned time references increases.
At Amsterdam Airport Schiphol, the outbound planning is created by making use of a Collaborative Pre-Departure Sequence Planner. This planner aims to make an outbound planning without losing outbound capacity. By having the TOBT as reference for the algorithm, it is important to have an accurate TOBT. This is achieved with help of the previous explained concept elements (Figure 1).
The airport capacity, as well as local airspace capacity, could be reduced by predicted and unpredicted events. Those events could be caused by adverse weather conditions which affects the complete airport operations. An assigned team of representatives of airport partners will manage the reduction of the capacity by making collaborative decisions.
A-CDM is completely implemented once the airport is connected to the Network Manager Operations Centre (NMOC). Once connected, arrival and departure information are sent by the NMOC to the applicable CDM-airports and involved air traffic control units. Via this way of sharing information, everyone involved receives the information in the same way. Based on the received information, the airport and airspace capacity could be regulated and time references are distributed on which the resource planning could be created.

Figure 1 Airport CDM Concept Elements advised by EUROCONTROL (EUROCONTROL Airport CDM Team, 2017).

Problem statement

At Amsterdam Airport Schiphol, the outbound planning is dynamical which has negatively impact on the outbound capacity and planning of resources. This dynamical outbound planning increases the chance of having additional delays caused by a regulated outbound flight by the Network Manager Operations Centre. One of the factors influencing the dynamics of the outbound planning is the Target Off-Blocks Time (TOBT). This time is used as a reference to create the departure planning. This TOBT could be calculated via two manners, which is manually or automatically. In this research, the focus will be on the automatically triggered TOBT updates. Those updates are triggered when conditions of the business rule are met. This business rule is part of a mechanism which is called: “auto-TOBT update mechanism”. This mechanism calculates the TOBT based on modifications of different time references, while considering the conditions of the business rule. This auto-TOBT mechanism is not active throughout the complete inbound flight, but only during a specific operating window and when multiple conditions are met. To reduce the dynamical impact on the outbound planning, prevent losing capacity, and improve resource planning, different predefined business rules for the mechanism will be analyzed. By analyzing those business rules, the aim is to have a rule creating less updates of the TOBT while maintaining the same predictability and therefore reducing the dynamics on the outbound planning.

Research objective

Analyzing two newly formulated business rules based on reducing the number of TOBT updates triggered by the auto-TOBT mechanism while maintaining the same, or almost the same, predictability.

Research questions

In this research, multiple questions will be answered. The main research question for this report will be:

“Which business rule(s) could reduce the number of auto-TOBT updates at AAS and therefore reducing the dynamical impact on the outbound planner, without losing the accuracy and predictability of the TOBT?”

To answer the main research question, multiple sub-questions are defined. Those sub-questions are:

1. What is the number of TOBT updates received?
2. How many minutes do the TOBT updates differ between each other?
3. What is the predictability of the TOBT at AIBT-40, AIBT-20, and AIBT-10, compared with the TOBT at AIBT?
4. How many minutes before AIBT does a TOBT update occur?
5. What is the difference in time between the TOBT at AIBT and TOBT at AOBT?

Research scope

In this research, the scope must be clearly defined to be able to completely focus on the actual problem statement. This research is scoped by different categories, which are:

- Historical inbound and outbound flight data of week 29 2019
- Inbound and outbound flights in week 29 2019
- Milestones 4, 5, 6, 7/8
- Helicopter operations are excluded
- General Aviation is excluded
- Cargo operations are excluded

Week 29 of 2019 is used, as this specific week represents an average week in the summer schedule which is used by KLM as reference to plan required resources for the summer schedule. The milestones which are within the scope of this research are milestones: 4, 5, 6, and 7/8 as those milestones are the start and end point of the auto-TOBT mechanism. These milestones are not based on the actual turnaround process, which is important to express because this research focusses only on the auto-TOBT mechanism and is not focusing on the actual turnaround process.

In this research, general aviation and helicopter operations are not considered as required information for the auto-TOBT mechanism, such as minimum turnaround time and scheduled in-blocks and scheduled off-blocks time, are not available. Furthermore, cargo operations are excluded as well. This is because cargo operations are often at ad-hoc basis. Moreover, there are no CDM flight states available for cargo operations which help to determine if a TOBT must be updated or not. By having a lack of useful information during the turnaround of a cargo aircraft, this operation will be excluded in this research.

Assumption

Besides the set scope, an assumption has been made as well. As the auto-TOBT mechanism is deactivated when the TOBT is adjusted manually (by the aircraft operator or main ground handler), an assumption for this research is made. This assumption is that all recorded inbound flights which triggered an update were not manually adjusted in the inbound flight phase. Therefore, all flights are triggered by this mechanism until the moment the aircraft arrived in-blocks.

Problem relevance

The relevance of this research is to investigate two different business rules to reduce the dynamics on the outbound planning. Currently, the auto-TOBT mechanism triggers an update of the Target Off-Block Time with any difference in the estimated landing and estimated in-blocks time, which therefore creates fluctuations in the outbound planning. Any business rule which increases the stability and maintains almost the same predictability of the auto-TOBT mechanism is an improvement for the outbound planning.

Research deliverables

The final document will have a detailed analysis of different research topics for each sub-question. Based on those results, the conclusion is given which provides advice on which business rule could replace the current business rule used in the auto-TOBT mechanism. A stakeholder analysis (Appendix I –) is performed to determine the audience for this research and results. Based on this analysis, the audience will be the CDM airport partners at Amsterdam Airport Schiphol.

Thesis structure

The structure of this thesis will be explained in this section. The first chapter is the methodology, which explains the approach to how the problem will be solved, by answering the main research question and sub-questions. Afterwards, the background of the problem will be discussed. In this chapter, an explanation about the Target Off-Block Times (TOBT) will be given as well as the auto-TOBT mechanism. Different information systems will be discussed, to create a better understanding of how time references are retrieved and shared.

The second chapter is called “Problem modelling” and provides theoretical information about each business rule which will be analyzed. Besides the detailed information about the business rules, information about the data will be explained.

Chapter three is the actual data analysis. In this chapter, five sub-questions (research topics) will be answered for each business rule by analyzing the results.

The second last chapter provides the conclusion and discussion. In the conclusion, the result will be presented. In the discussion, more information about how the researcher could approach the problem differently will be explained.

Finally, the last chapter will express recommendations for further studies on this research topic.

Research methodology

The research methodology provides an explanation of how the results will be achieved. Moreover, answering the main and sub-questions will be done with the help of the methodology, which explains the methods in order to answer those questions. When the same research will be done by others, following this methodology step by step will create almost identical results (Benders, 2019). This methodology is divided into three different phases of which a flow diagram is shown in Figure 2. For each phase, the objective is provided. Those three phases describe the general structure of this report.

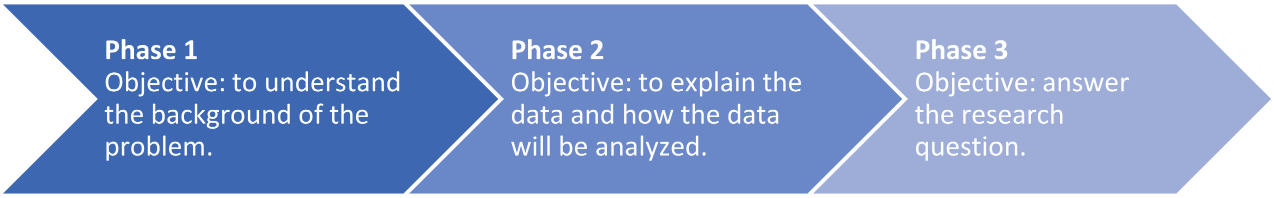


Figure 2 Flow diagram showing phases which must be succeeded throughout the project.

Phase 1

The first phase is desk research and will help with gaining more background information about the problem. In this phase, the topics expressed in Figure 3 will be explained. First, it is required to understand Airport Collaborative Decision Making (A-CDM), where is it used for, and which elements are required for implementing A-CDM. This information is retrieved from the implementation plan of EUROCONTROL, which is the main founder of A-CDM (EUROCONTROL Airport CDM Team, 2017). As this research is about the target off-blocks time and the mechanism which updates this time automatically, those topics will be discussed as well. As the auto-TOBT mechanism is different for each airport, this information will be retrieved from the A-CDM operational manual of Amsterdam Airport Schiphol (AAS) (Schiphol Airport, 2019), as Schiphol is the airport on which will be focused in this research.
Step three of understanding the background of the problem is to understand how time references are retrieved. This will be discussed by explaining the information systems which are used at AAS, by different airport partners.

Once understanding CDM, the importance of the TOBT, the auto-TOBT mechanism, and the information systems, a stakeholder analysis could be performed. In order to define the stakeholders and understand their position, the stakeholder analysis is performed with the help of the Power / Interest matrix (Appendix I). Those stakeholders are identified via desk research in CDM manuals of EUROCONTROL and AAS. The stakeholders are prioritized by their power and interest in the reduction of the dynamical outbound planning. Based on the stakeholder analysis, the target group of this research could be determined.

Figure 3 Methodology topics in phase 1.

Phase 2

Once understanding the background of the problem, the required data could be retrieved and analyzed. The research will consist of a quantitative analysis based on the retrieved data of week 29 in 2019, as this is a representative week for KLM to plan their resources for the summer period. Based on the retrieved information from Phase 1, the required data could be derived and used. Analyzing the data will be done in different phases (Figure 4). The first step in order to analyze the data is to create a list of the required data. Afterwards, a suitable programming language must be defined which is suitable for the size of the retrieved data. Once a suitable programming language is defined and the required datasets are available, the data must be filtered based on the criteria of the auto-TOBT mechanism and the predefined scope. Datasets used for this analysis are flight information of inbound and outbound flights and minimum turnaround times. More information about the required datasets and how the data will be filtered is discussed in paragraph 2.2.

When the data is filtered, the procedure in order to analyze the business rules will be created. This procedure expresses how the required information will help to answer the sub-questions and main research question. Based on the sub-questions, research topics have been created which are used in the procedure to analyze each business rule. The following research topics are derived from the sub-questions:

- Frequency of TOBT updates
- Inter arrival time of TOBT updates
- Predictability of TOBT at AIBT-40, AIBT-20, and AIBT-10
- Time before AIBT
- Difference in time between TOBT@AIBT and TOBT@AOBT

When the results are retrieved from the research topics, descriptive statistics will be used to compare the results. Within descriptive, two measures could be defined which are: measures of central tendency and measure of variability. The measure of tendency describes how the center of the data set is distributed by making use of the mean, mode, and median. The measure of variability helps to understand how the data set is spread. The spread of the data is expressed by the standard deviation, variance, minimum and maximum values, kurtosis, and skewness (Sekaran & Bougie, 2016). In this research, the spread of the data will be analyzed based on the standard deviation, minimum, and maximum.

Finally, validating the output is done by presenting the results to a group of CDM business experts. The aim of this group of experts is to improve the quality of the A-CDM performance at Amsterdam Airport Schiphol (AAS). Improving the quality of the performance is done by connecting CDM to the demand of the sector while maintaining the quality requirements of EUROCONTROL and to connect with the KPIs of each airport partner. This group of experts consists of people representing each CDM Airport partner, such as AAS, LVNL, KLM, ground handlers (GH), and aircraft operators (AO). Based on the remarks of the experts, the results could be validated, and a conclusion could be made.

Once all the steps visualized in Figure 4 are completed, the third phase of the research could start, which is answering the main research question.

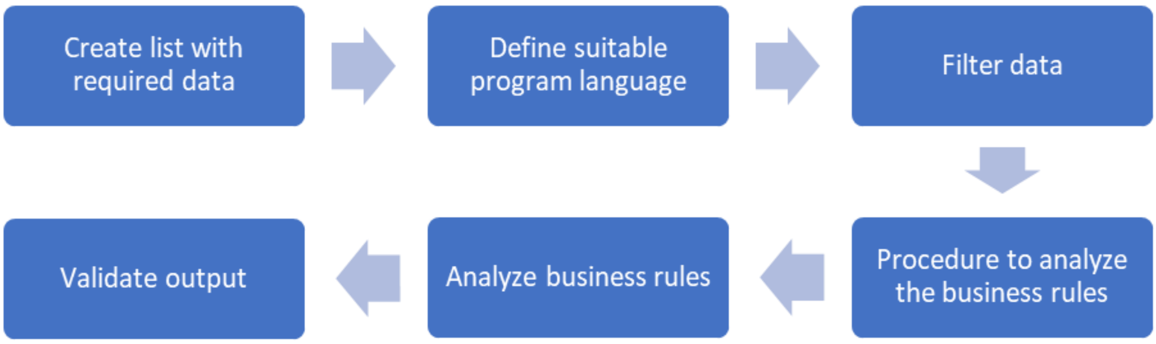


Figure 4 Steps to take when perform data analysis.

Phase 3

In the last phase, the main research question will be answered. As discussed in Phase 2, different research topics must be analyzed before answering the main research question. First, the validity is checked based on the frequency of updates and the inter arrival time between those updates. The frequency of TOBT updates gives an overview of how often a modification of the expected in-blocks and actual in-blocks time resulted in a calculation of the TOBT by the mechanism. For each business rule, the frequency of updates is different depending on the conditions of each business rule. Those conditions are discussed in paragraph 2.1. By analyzing this research topic, the first part of the main research question will be answered, which is: *"…reducing the number of TOBT updates…"*. Besides the frequency, the inter arrival time between updates will be analyzed. This inter arrival time provides the difference in minutes between the new calculated TOBT and the previous applicable off-block time.
In addition to the validity, the predictability of the TOBT is analyzed. This is done by comparing the target off-blocks time at three moments in time with the TOBT at actual in-blocks. Those moments in time are 40 minutes before actual in-block (AIBT-40), at AIBT-20, and AIBT-10. By analyzing the predictability, the second part of the main research question could be answered which is: *"…without losing the accuracy and predictability of the TOBT."*.
The time before AIBT is a research topic which provides an overview when in time, and how often, before actual in-blocks the TOBT is updated.
The comparison with TOBT@AIBT and TOBT@AOBT indicates the accuracy of the TOBT set at AIBT and the TOBT@AOBT. It expresses how much the TOBT@AOBT differs in minutes with the TOBT@AIBT and therefore the accuracy of the auto-TOBT mechanism could be checked. It gives an insight into the relevance to update a TOBT with any difference of one minute or more.

Based on the results of the described research topics, the main research can be answered and a conclusion could be made. Moreover, recommendations and further work could be established based on the findings of the results.

1 Background of the problem

In this chapter, background information about the problem will be explained. First, the two most relevant CDM elements, applicable for this research, will be explained. Those two elements are the milestones approach and the Collaborative Pre-Departure Sequence Planner (CPDSP). The remaining four elements: information sharing, variable taxi time, adverse conditions, and collaborative management of flight updates are not considered in this research. However, those elements are not less important. Moreover, the target off-blocks time will be explained, this is done by explaining how this reference time is calculated and updated at Amsterdam Airport Schiphol (AAS). Afterwards, different information systems are described. Those systems provide information which is the input to calculate different time references. Finally, an explanation of descriptive statistics is given, as descriptive statistics are used in order to analyze the results.

1.1 Elements of A-CDM

1.1.1 Milestones approach

This research focusses on the inbound phase of the milestones approach, which are milestones 1 to 7/8 (Figure 5). The first two milestones are about the exchange of flight plan data and route information. When all information is provided to EUROCONTROL and ground handling is finished, the aircraft takes off from the outstation (milestone 3). Once the flight arrives in the local airspace of the destination airport, the aircraft enters the Flight Information Region (FIR), which is milestone 4. When arriving in the FIR, the expected landing and in-blocks time are updated by ATC TWR. Milestone 5 is when the aircraft comes closer to the airport and is on final approach. Before the aircraft has landed, estimations of the landing time are triggered and are used in order to calculate different time references. When the aircraft touched down on the landing runway, the Actual Landing Time (ALDT) is provided to the airport CDM platform (milestone 6). The final part of the inbound phase is milestone 7 and 8, which indicates that the aircraft is in-blocks and ground handling starts. At AAS, not all sixteen advised milestones are implemented but a few of them. Those implemented milestones are marked red in Figure 5.
Information about the estimated landing time and in-blocks time will be provided to the Airport-CDM Platform via different information systems (paragraph 1.3). Throughout the complete inbound flight phase, the Estimated Landing Time (ELDT) will be updated. Updates of the ELDT triggers the calculation of time references such as the Estimated In-Block Time (EIBT) (Eq. 1.1).

$$ELDT\ (or\ ALDT) + EXIT = EIBT \ldots (1.1)$$

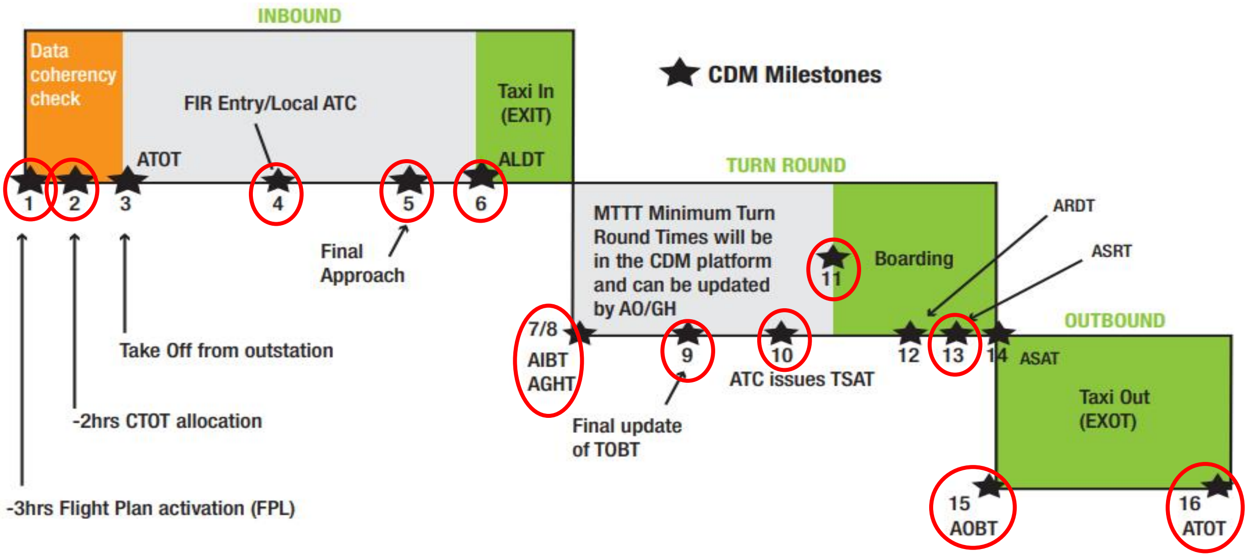


Figure 5 Overview of the milestone approach (EUROCONTROL Airport CDM Team, 2017).

1.1.2 Collaborative pre-departure sequence planner

The second element which is of importance in this research is the Collaborative Pre-Departure Sequence Planner (CPDSP). This planner is a module in the TWR-system and creates the outbound planning at AAS. The sequence in which the aircraft must depart is regulated by making use of the Target Start-Up Time (TSAT), which is the result of the CPDSP. The TSAT is calculated based on the Target Off-Blocks Time (TOBT) and an algorithm within the sequence planner (Figure 6). The algorithm checks on variables that influence the outbound flow of the airport. Variables on which will be checked are: Calculated Take-Off Time (CTOT), Standard Instrument Departure (SID), Wake Turbulence Category (WTC), and the capacity of the departure runway. Once all those variables are considered, the outbound sequence is made and regulated with the help of the TSAT. As shown in Figure 6, the TOBT is the main input for the outbound planning and once this fluctuates the outbound planning will fluctuate too, which is unlikely as this influences the utilization of the outbound capacity.

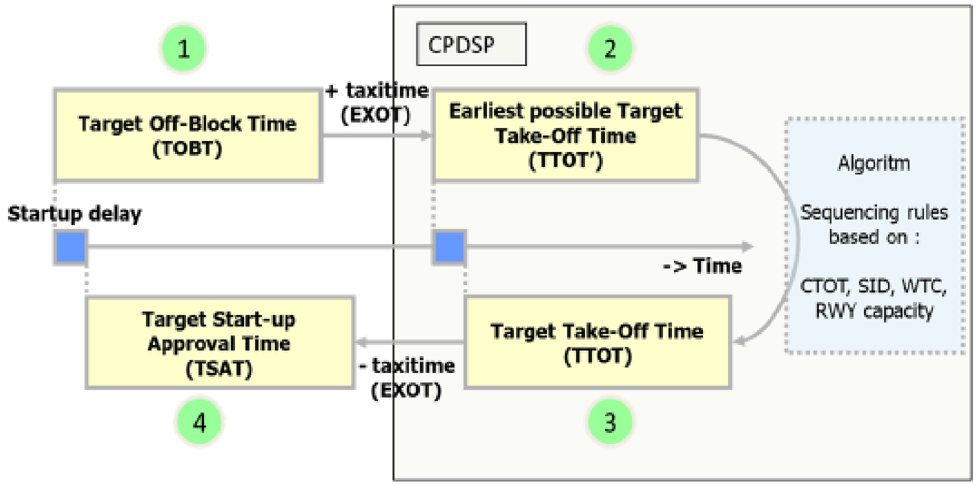


Figure 6 Collaborative Pre-Departure Sequence Planner mechanism (Schiphol Airport, 2019).

1.2 Target Off-Blocks Time

According to EUROCONTROL, the TOBT is a target time when all ground handling should be finished, all doors are closed and boarding equipment is removed in order to be ready pushback (EUROCONTROL Airport CDM Team, 2017). This timestamp is used as a reference point for the outbound planning and other planning reasons for airport partners. The aim of the TOBT is to provide all airport partners as timely, reliable, and accurate as possible the earliest possible off-blocks time (Schiphol Airport, 2019). The ground handling ready reference time is calculated beforehand by adding the Minimum Turnaround Time (MTTT) to the actual or estimated in-blocks time. TOBT is an important time as this time is the input in the CPDSP, which creates the outbound sequence and calculates the TSAT (2019) (Figure 6). When a TOBT is deleted or updated, a new TSAT will be provided, based on the most recent TOBT (Procedures Group LGW, 2014). In case a TOBT cannot be met, the TOBT must be updated or deleted as early as possible. If this is not done on time, outbound capacity is affected as the pre-departure sequence could not be changed.

1.2.1 Manners of updating the Target Off-Block Time

At Amsterdam Airport Schiphol (AAS), the TOBT can be updated in three different ways. Those three ways to update the off-blocks time are categorized in manual updates and automatic updates.

Manual updates

Manual updates of the TOBT is done by the AO or GH. Two different moments could be distinguished in order to update the TOBT manually. The first moment to update the TOBT manually is when it is known the current TOBT cannot be met, a difference of TOBT+5 or TOBT-5 is used as a reference. However, a manual update could be done with any difference as well. Those manual updates are based on the progress of the turnaround. When an update of the TOBT is required, the AO/GH should communicate

this through the Airport CDM-system as soon as possible and at the latest five minutes prior to the new TOBT (Schiphol Airport, 2019).
Secondly, the estimated off-block time (EOBT) should be updated when the TOBT differs with more than EOBT +/- 15. The EOBT is the off-blocks time according to the flight plan. When the TOBT is outside the +/- fifteen minutes window of the EOBT, the flight plan must be updated by the AO and filed again with an EOBT set equal to the most recent TOBT (2019).

Automatic updates

Besides the manual updates, the TOBT could be updated automatically as well. This is done by the auto-TOBT mechanism. This mechanism is implemented in the Airport CDM-platform and makes use of the information available on this platform (Schiphol Airport, 2019). In paragraph 1.3, more information about the Airport CDM-Platform and the resources of information are described.
The auto-TOBT mechanism is active when three conditions are met. First, the inbound flight has an assigned landing runway which is shared in the Airport CDM-Platform. Secondly, the inbound flight must be delayed because from this moment, the target off-block time will be later than the scheduled off-block time. Finally, the inbound aircraft should have a connected outbound flight. To stop this mechanism, two different conditions are applicable. The first manner is when the AO/GH updates the TOBT manually. Secondly, once the aircraft arrives at its final parking position the mechanism will stop (milestone 7) because, from this moment, the turnaround process will start (milestone 8). The operational window of the auto-TOBT mechanism is visualized in Figure 7.
Within the operational window of the auto-TOBT mechanism, a business rule decides if the TOBT must be updated automatically or not. The TOBT is calculated by adding the Estimated In-Blocks Time (EIBT) or Actual In-Blocks Time (AIBT) to the minimum time required to finish ground handling for the aircraft (MTTT). This results in the following equation (Eq. 1.2):

$$EIBT \ or \ AIBT + MTTT = TOBT \ldots (1.2)$$

Throughout the flight, the estimated time in-blocks is updated continuously based on updates of the expected landing time (ELDT). However, modifications of the EIBT will be considered only when those modifications take place within the operational window of the auto-TOBT mechanism. By making use of a business rule, the mechanism will check if the TOBT will be automatically updated. More information about those business rules is provided in paragraph 2.1.
As mentioned, the auto-TOBT mechanism stops when a manual input of the TOBT is received. However, in this research, an assumption (page 12) is made that no manual adjustments were made. All delayed inbound flights are triggered by this mechanism and have had automatic TOBT updates.

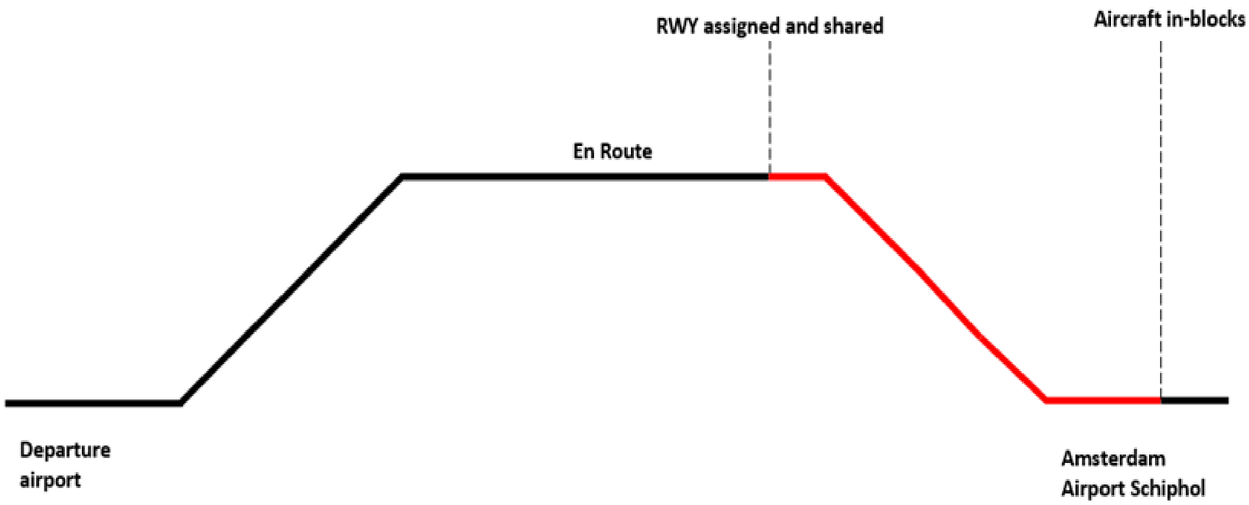


Figure 7 Operational window of the auto-TOBT mechanism indicated in red.

1.3 Information systems

Within the inbound flight phase, different systems are used to handle all flights and to retrieve and share the available inbound flight data. Those different information systems share the required information for the auto-TOBT mechanism. The information systems are mainly ATC systems such as Amsterdam Advanced ATC system (AAA), Advanced Schiphol Arrival Planner (ASAP), and TWR-system, as they provide updates of the ELDT and EIBT. All retrieved information from those ATC systems will be available for all airport partners via the Airport CDM-platform.

1.3.1 Central Information System Schiphol (CISS)

The Airport CDM-platform at AAS is called: Central Information System Schiphol (CISS). This platform gathers all information for flights in three flight phases which are: inbound, turnaround, and outbound. This information is retrieved from different resources such as ATC-systems (1.3.2), AO systems, and GH systems. The “best” available time reference is provided based on business rules within CISS. Those business rules describe the hierarchy of the resources and share the best information (Schiphol Airport, 2019). The information which is available in CISS is open for all airport partners connected to the A-CDM system. The following information is shared via CISS (N.V. Luchthaven Schiphol, 2019):

- Date of flight
- Local time of landing and arrival on the gate, as well as departing from gate and take-off
- Inbound and outbound destination and indicates if the flight is Schengen or non-Schengen
- Flight number
- Type of flight (Passengers, Freight or General Aviation)
- Aircraft type, WTC category, and aircraft registration
- Number of passengers
- Airline and ground handler
- Assigned landing and departure runway
- Parking location of aircraft
- Towing movements
- Which baggage belts and check-in desks
- Special information such as diverting, returning or calamity

All the described types of information are used for planning and operational reasons, analysis, and statistics (N.V. Luchthaven Schiphol, 2019). Once all this information is known, the airport partners could plan and allocate their resources. Besides CISS, the CDM portal is another Airport CDM-platform used at AAS. This makes use of the information provided in CISS.

1.3.2 ATC systems

Different ATC systems provide important information about the ELDT which is used for calculating different time references. The information provided by those systems triggers for example the EIBT (Eq. 1.1). To create a better understanding how the different ATC systems correlate with each other, and how information is finally shared with CISS, a cross-functional flowchart is provided in Appendix V – Flowchart enhancement between different ATC-systems. In this flowchart, the relation between different ELDTs are retrieved and how they are shared between different ATC systems and CISS. This flowchart is created by T. Scheffers, who performed an analysis of the ELDT. For further information and explanation of the provided cross-functional flowchart, his work could be consulted.

Amsterdam Advanced ATC system (AAA)

All air traffic controlled by the Dutch Air Traffic Controllers is done by making use of the system called Amsterdam Advanced ATC system (AAA). AAA is developed specifically for LVNL in the 1990s and entered service in 1998 (Scheffers, 2020). AAA is connected to other systems used by air traffic controllers, such as the Advanced Schiphol Arrival Planner (ASAP)-system and TWR-system.

Based on specific preferences of the air traffic controllers, AAA has been further developed internally. With the help of AAA, the air traffic controllers have an overview of all expected and actual regulated flights to and from airports within the Dutch airspace. This information is provided by the Central Flight Management Unit of EUROCONTROL, which is the main input for the AAA database. This database consists of all flight plans for the upcoming five hours (2020).

AAA is used by LVNL which processes retrieved information from different sources into usable ATC information and shares this information with different ATC-units within LVNL. The most important functions of AAA are to show the Secondary Surveillance Radar information, process flight plan information, and sending the required information to the next responsible Air Navigation Service Provider (LVNL, n.d.).

Advanced Schiphol Arrival Planner (ASAP)

Since November 2015, AAS implemented Advanced Schiphol Arrival Planner (ASAP), which is a specified arrival manager software (Knowledge & Development Centre, 2015). ASAP starts when an Advance Boundary Information (ABI)-message is retrieved by AAA. The first ABI-message is on average retrieved around 38 minutes before arriving at the Initial Approach Fix (Scheffers, 2020). When AAA retrieves the information, ASAP will start. The arrival planner assigns for all inbound flights at AAS an inbound runway, based on retrieved information in the ABI-message (LVNL, 2018). The approach planner optimizes the generated arrival sequence by ASAP as early as possible. Adjusting the arrival sequence could only be done to recover and/or prevent having delays, add additional flights, and when the sequence is unrealistic (LVNL, 2018). Trajectory prediction is a process that delivers estimated landing times for a specific flight at points such as the initial approach fix, Terminal Maneuvering Area, or runway threshold. The ELDTs are based on factors such as arrival order and information retrieved from the ABI-message.

TWR-system

All flights on final approach, as well as outbound flights at the runway and shortly after take-off, are handled by the tower controllers. When a flight is at final approach, AAA is not updating the ELDT anymore because the TWR-system is the system in use from that moment and shares the ELDT and Actual Landing Time (ALDT). This system is used by the tower controllers and contains track data, weather data, and plan data. All tracking data is retrieved from multiple radar sources. Tower controllers could monitor all ground movements and airborne traffic flying with a distance up to a maximum of sixty nautical miles around AAS. Ground movements are aircraft taxiing or being towed, as well as vehicles in the responsibility zone of ATC. All traffic movements, either aircraft or vehicles, which crosses the big red line at the apron are in the responsibility of ATC (Scheffers, 2020).

The input for plan data is flight plans (provided by AAA), tow plans, and other information about vehicle movements. The last two mentioned types of data are provided by AAS. The ELDT and ALDT information provided by TWR-system is shared with CISS (Scheffers, 2020).

Within the TWR-system, the CPDSP is implemented which creates the outbound planning used by the air traffic controllers. In this system, the TOBT is considered as well for the departure sequence.

2 Problem modelling

This chapter provides information about three business rules which will be analyzed. Those different business rules are the current business rule and two predefined business rules which could be the replacement of the current rule. Those rules will be discussed in the first paragraph. Each business rule is expressed with the help of a formula. In order to visualize those formulas, a visualization is created which shows the results of the formulas. Moreover, a flowchart for each rule is created, which gives an overview of the operation of the auto-TOBT mechanism with the correlated business rule. Processes within the flowchart are explained in more detail by making use of the SIPOC-diagram. With this diagram, it is understandable who is involved in the process and when as well as information about requirements for the specific process is explained. In addition to the explanation of the business rules, information about used databases is provided. The research topics which are discussed previously in Phase 3 of the Methodology, will be explained in this chapter as well. Finally, an explanation of three terms, accuracy, predictability, and stability will be provided as these terms will be used frequently.

2.1 Business rules

A business rule in the auto-TOBT mechanism is used which has a condition deciding when to trigger a TOBT update automatically. The aim of this business rule is to predict the TOBT beforehand, which will be used for the outbound planning and helps airport partners to allocate their resources earlier in time. The conditions of each business rule will be explained separately. Besides the differences in each business rule, they have similarities as well. Those similarities are the operating window of the auto-TOBT mechanism (Figure 7) and the minimum target off-block time. Every update of the TOBT cannot be earlier than Scheduled Off-block Time (SOBT). Therefore, the minimum time will be the SOBT, which results that an update of the TOBT will only occur when the triggered TOBT is later than the SOBT, or when the new TOBT is earlier in time and equal to the SOBT.
As mentioned in paragraph 1.2, the Target Off-Blocks Time is calculated based on the minimum time required to complete the ground handling (MTTT) and the expected or actual in-blocks time (Eq. 1.2).

2.1.1 Current business rule

Currently, the auto-TOBT mechanism triggers automatically an update of the target off-block time when the EIBT is modified within the operational window. The first modification of the EIBT which could trigger an update of the TOBT is to check if the calculated TOBT is greater than the SOBT (Eq. 2.1).

$$Update\ TOBT: EIBT + MTTT > SOBT \ldots \textit{(2.1)}$$

Once the TOBT is updated automatically, the remaining updates of TOBT will be compared with the previous set target off-blocks time (Eq. 2.2).

$$Update\ TOBT: EIBT + MTTT <> previous\ TOBT \ \ldots \textit{(2.2)}$$

When the inbound flight arrived at the final parking position, the auto-TOBT mechanism will stop. Before the mechanism stops, a final check is done based on the AIBT (Eq. 2.3).

$$Update\ TOBT: AIBT + MTTT <> SOBT\ or\ previous\ TOBT \ldots \textit{(2.3)}$$

The flowchart represented in Figure 8 gives an overview when the auto-TOBT mechanism starts and when a TOBT update will be triggered based on the conditions of the current business rule (Eq. 2.1, Eq. 2.2, and Eq. 2.3). Within this flowchart, an orange connector (A) is used which indicates this process continues until the mechanism will stop. In addition to this flowchart, Figure 9 is created which visualizes the process in the flowchart based on the conditions of the current business rule. The color of the aircraft in this figure matches the TOBT with the same color. A SIPOC-diagram is created to understand who is responsible for each process within the flowchart and what is required in order to complete the process (Appendix II –

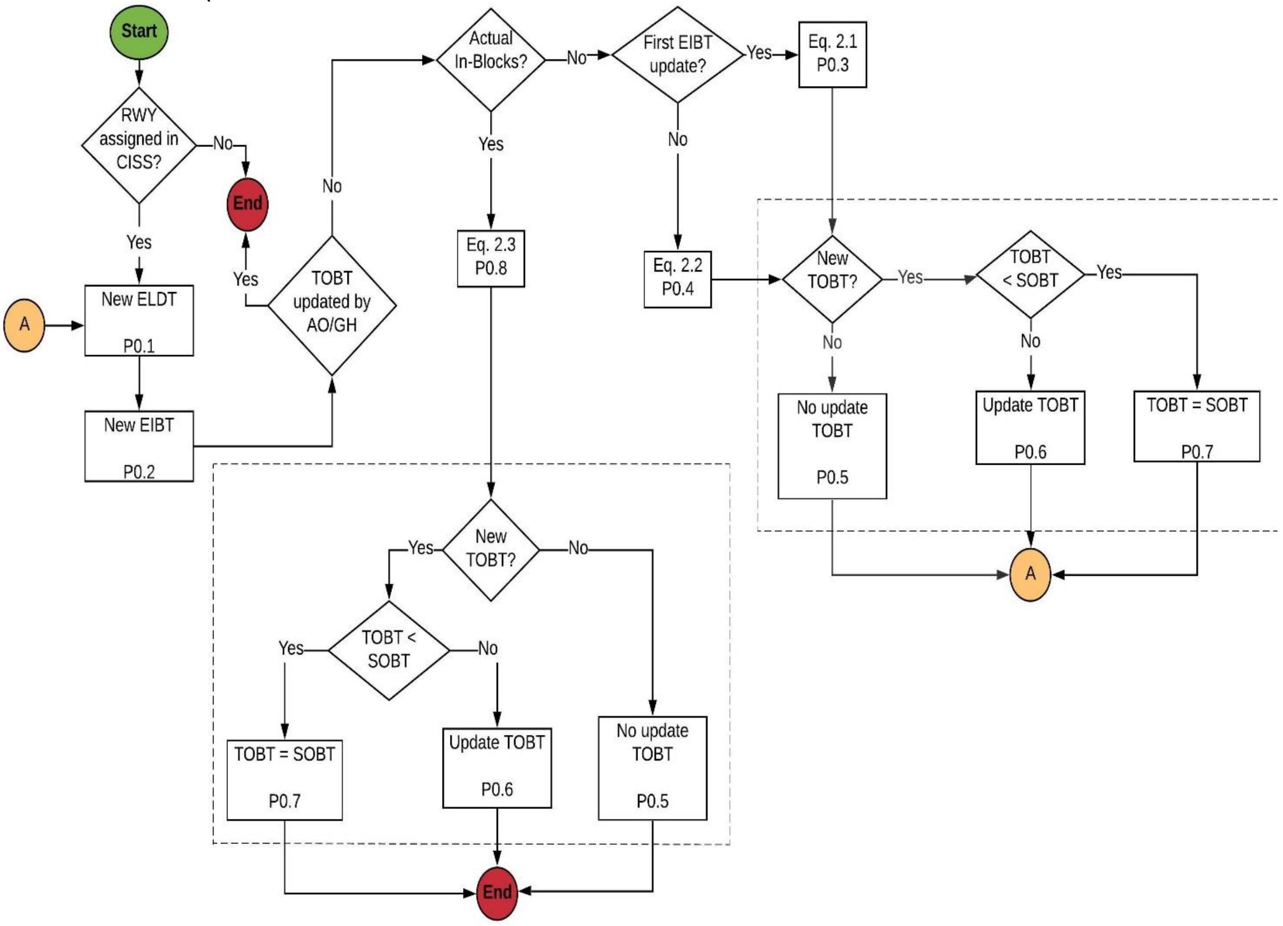


Figure 8 Flowchart showing the process of the auto-TOBT mechanism based on the conditions of the current business rule.

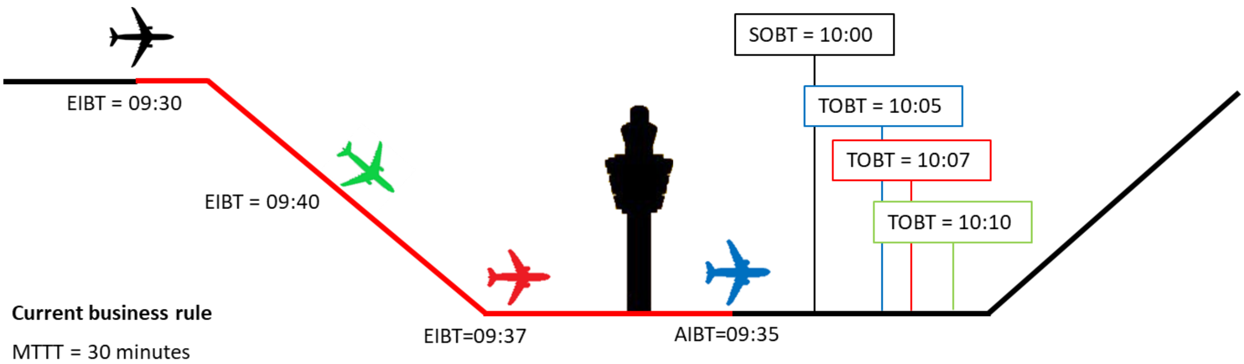


Figure 9 Inbound flight which is active in the operational window of the auto-TOBT mechanism.

2.1.2 First business rule

The first business rule which will be analyzed has three specific moments in time at which the EIBT is evaluated. If the result of this evaluation is true, automatic update of the TOBT will occur. Between those moments, the mechanism will not check for updates of the TOBT, even though the expected in-blocks time is updating.
The first moment in time is to check when the auto-TOBT mechanism is active. When the mechanism starts, it will be checked if the TOBT (Eq. 1.2) is ten or more minutes later than the Scheduled Off-Blocks Time (Eq. 2.4). This moment is chosen because it is the start of the auto-TOBT mechanism. The condition of SOBT+10 is based on the experience of the business experts. Ten minutes will be a good buffer because between the first moment the auto-TOBT mechanism is active and in-blocks different factors may influence the EIBT.

$$Update\ TOBT: EIBT + MTTT > SOBT + 10 \ldots \textit{(2.4)}$$

The second moment is when the aircraft landed (ALDT). At this moment the TOBT could be better predicted as fewer influencing factors are present during taxiing to the final parking position. The EIBT which is applicable at this moment is used in order to calculate the TOBT and to check if the condition is met. This condition is when the TOBT (Eq. 1.2) differs from SOBT+5 or is five minutes earlier or later than the TOBT resulted from the previous moment (Eq. 2.4). A difference of plus or minus five minutes at ALDT is set because from this moment fewer factors could influence the estimated time in-blocks. Moreover, those five minutes are derived from the manual updates, where the TOBT should be updated when this will differ with plus or minus five minutes compared to the current TOBT (sub-paragraph 1.2.1). The condition related to the second moment of checking if an update of the TOBT is necessary is written in the equation below (Eq. 2.5).

$$Update\ TOBT: EIBT + MTTT > SOBT + 5\ \boldsymbol{or}\ EIBT + MTTT <> \ previous\ TOBT +/-5 \ \ldots \textit{(2.5)}$$

Finally, the auto-TOBT mechanism checks when the aircraft is in-blocks. This is the last moment before the mechanism will stop operating and therefore a final check of the TOBT will be done. When the AIBT is known, the TOBT will be calculated based on this actual in-blocks time and will be updated with any differences between the calculated TOBT and previous set TOBT (Eq. 2.6). This condition will update with any difference because it provides a better prediction of the target off-blocks time as no other factors could influence the predicted TOBT which is updated automatically.

$$Update\ TOBT: AIBT + MTTT <> SOBT\ \boldsymbol{or}\ AIBT + MTTT <> \ previous\ TOBT \ldots \textit{(2.6)}$$

In order to understand the auto-TOBT mechanism with the three different moments and conditions to check for an update of the TOBT, a flowchart is created (Figure 10**Fout! Verwijzingsbron niet gevonden.**). In Figure 11, the process flow is visualized which will help with reading and understanding the flowchart. The colors of the aircraft are matching with the colors of the target off-block times. The aircraft in grey did not trigger an auto-TOBT update. Each of the processes in the flowchart is described in more detail by making use of the SIPOC-diagram which could be found in Appendix III – SIPOC-diagram processes flowchart first business rule .

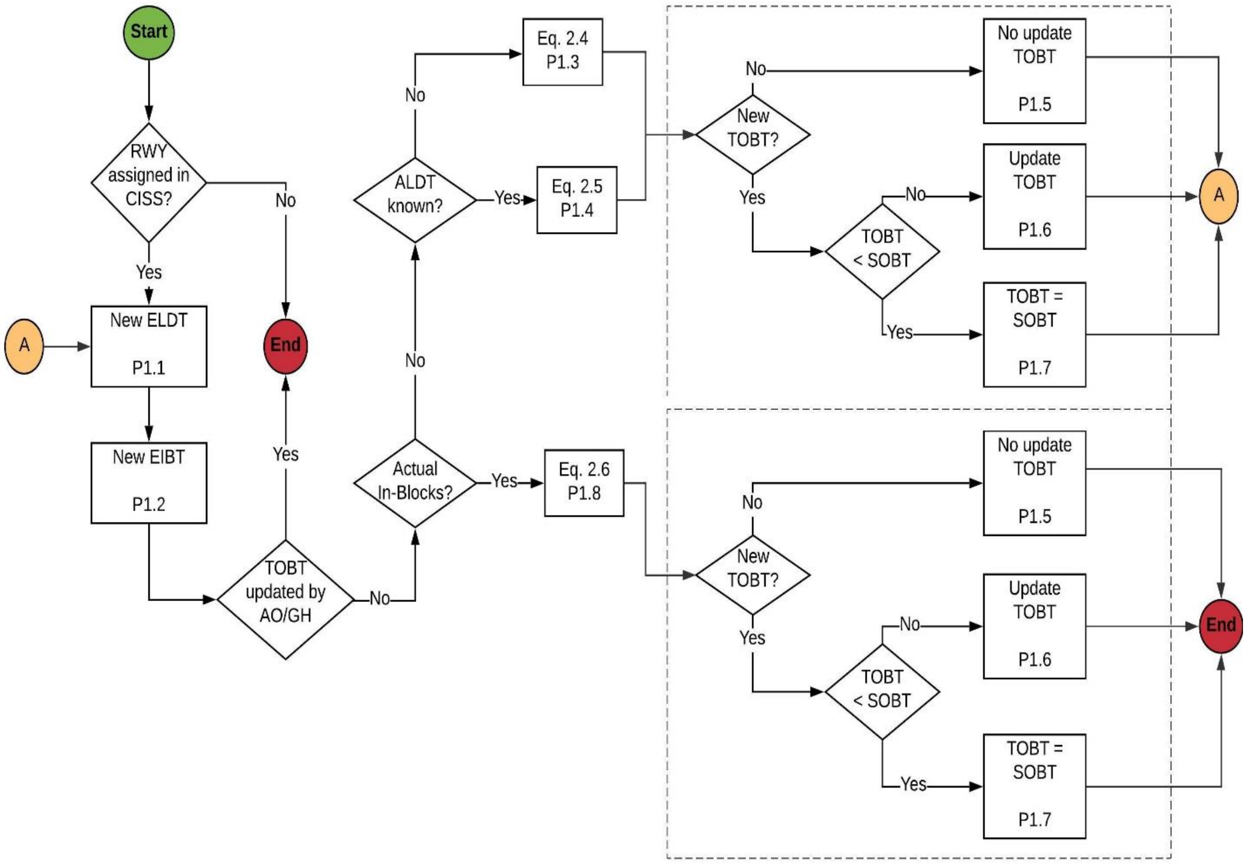


Figure 11 Flowchart showing the process of the auto-TOBT mechanism based on the conditions of the first business rule.

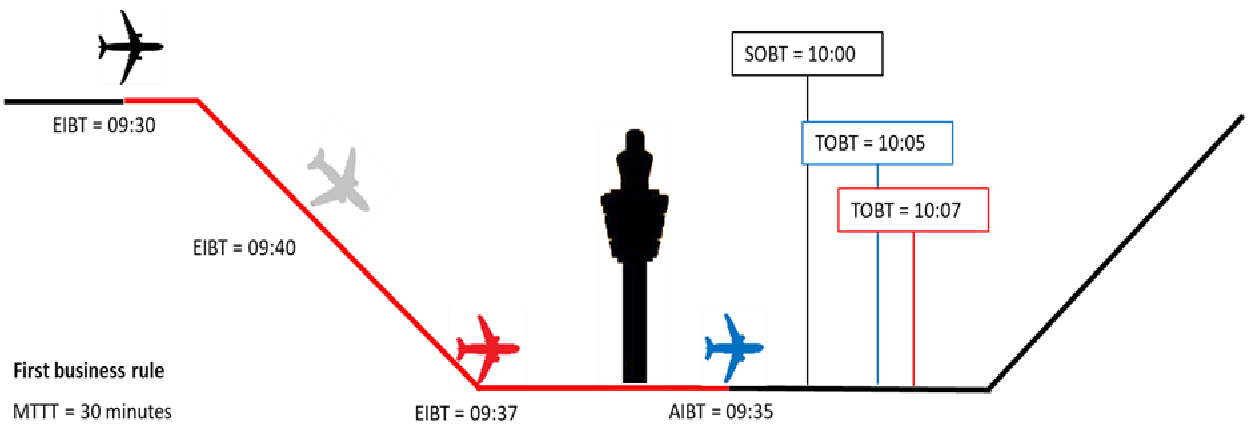


Figure 10 Inbound flight which is active in the operational window of the auto-TOBT mechanism visualizing the conditions of the first business rule.

2.1.3 Second business rule

The second, and final business rule which will be analyzed, is almost similar to the current business rule. The only difference is with the condition to update the target off-block time when this time differs five minutes or more with the SOBT (SOBT+5). Moreover, the second rule will update when the difference between the new TOBT and the previous TOBT is plus or minus five minutes (TOBT+/-5). The five minutes value is, as mentioned previously, derived from the moment to update the TOBT manually.
The first time an EIBT is updated when the auto-TOBT mechanism is active, the TOBT will be updated when this target time differs five minutes or more than the SOBT (Eq. 2.7).

$$Update\ TOBT: EIBT + MTTT > \ SOBT + 5 \ldots \text{(2.7)}$$

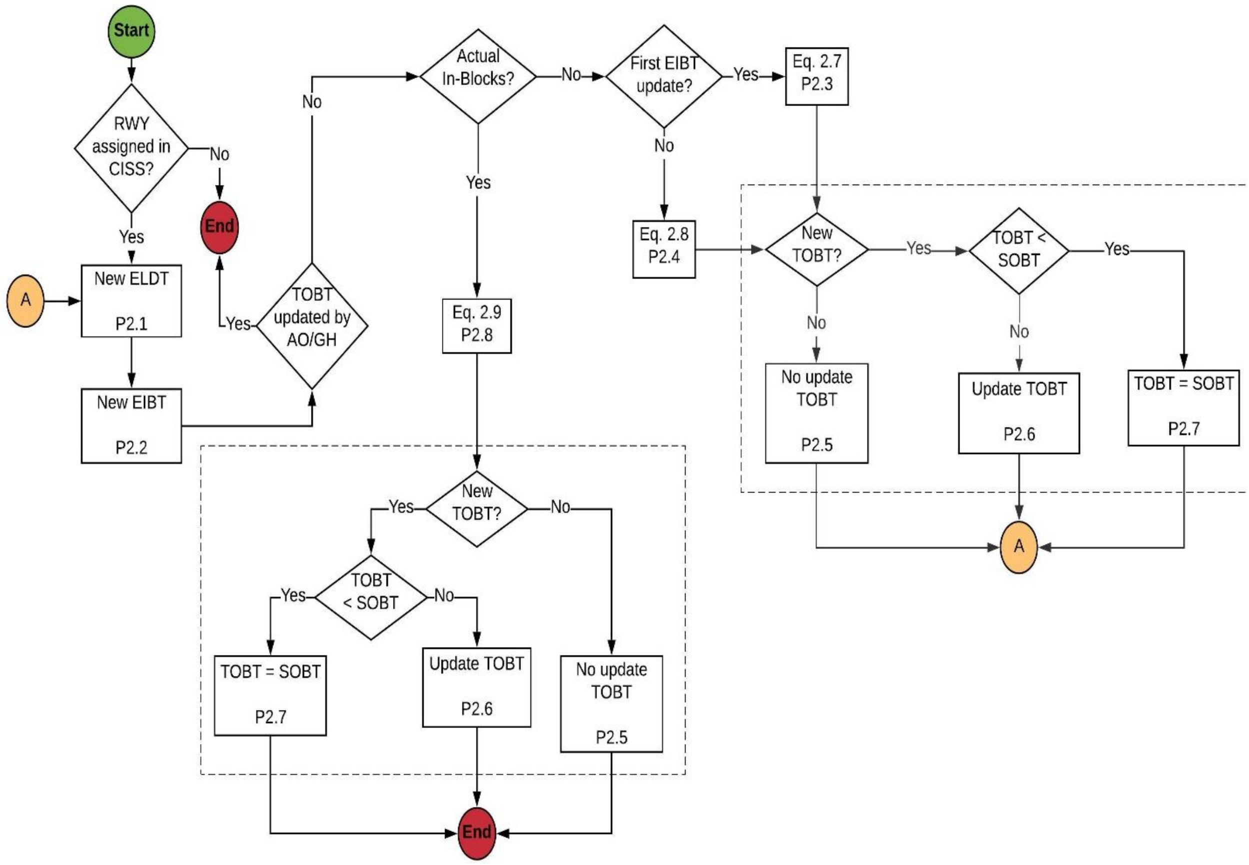
Once the first TOBT update occurred, the remaining calculated target off-blocks time will be compared with the previous TOBT. For this comparison, the TOBT will be updated automatically when there is a difference of plus or minus five minutes (Eq. 2.8).

$$Update\ TOBT: EIBT + MTTT <> previous\ TOBT +/-5 \ldots \text{(2.8)}$$

The final check if the TOBT must be automatically updated is, as with the first and current business rule, with any difference between the calculated TOBT and previous TOBT (Eq. 2.9).

$$Update\ TOBT: AIBT + MTTT <> previous\ TOBT \ldots \text{(2.9)}$$

To create a better understanding of the above-mentioned conditions, a flowchart (Figure 12) is made which expresses the complete flow of the auto-TOBT mechanism when the conditions relating to the second business rule are implemented. Moreover, a visualization of the auto-TOBT mechanism is made in Figure 13 in order to create a better understanding. In Appendix IV – SIPOC-diagram processes flowchart second business rule, a SIPOC-diagram is created which gives a detailed explanation of each process in the flowchart.



-Figure 12 Flowchart showing the process of the auto-TOBT mechanism based on the conditions of the second business rule. —

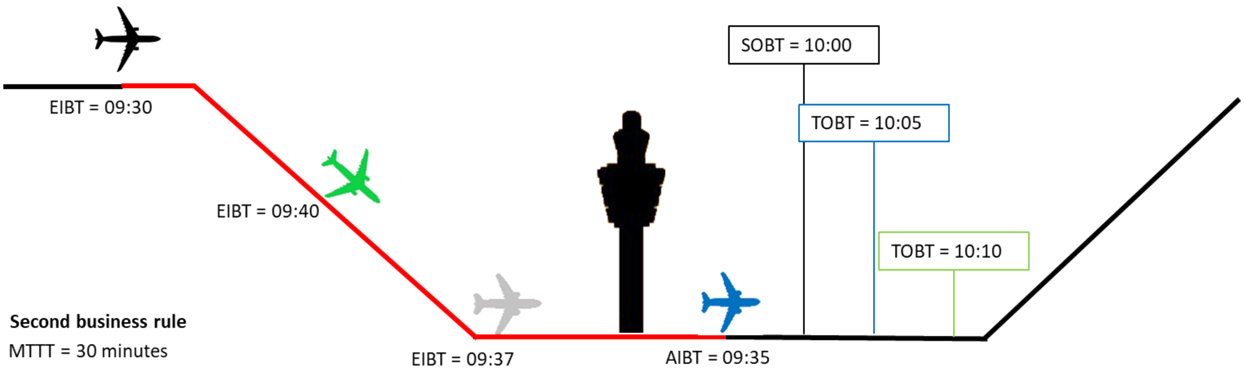


Figure 13 Inbound flight which is active in the operational window of the auto-TOBT mechanism.

2.2 Information about the data

2.2.1 Retrieval and filtering of data

To perform the data analysis, three different datasets are required. Those datasets are retrieved from AAS, who owns the flight information from all flights to and from the airport. The three different datasets which will be used in this research are:

- Inbound flight data at AAS
- Outbound flight data at AAS
- Table with Minimum Turnaround Times (MTTT)

The auto-TOBT mechanism is active based on inbound flights operated by aircraft with a connected outbound flight (sub-paragraph 1.2.1). Therefore, both the inbound and outbound flight data at AAS is required. In the inbound flight dataset, information about the moment when the runway is assigned and shared in CISS is provided, as well as any modification of the estimated landing time, actual landing time, estimated in-block time, actual in-blocks time. The outbound flight dataset contains the Scheduled Off-Block Time (SOBT), the TOBT and the Actual Off-Blocks Time (AOBT). The SOBT is necessary to decide if the off-block time should be updated by the mechanism and the TOBT and AOBT is required for analyzing the business rules. Information of the inbound flights and outbound flights is retrieved and based on week 29, 2019.
In order to calculate the TOBT, the minimum turnaround time (MTTT) is required (Eq. 1.2). Therefore, an overview with MTTTs per airline and type of aircraft is required. This minimum time is the time required for the GH to perform a quick turnaround for the specific airline and type of aircraft (Schiphol Airport, 2019).

Once all the datasets are retrieved, the data will be filtered based on the scope as discussed at page 12. With the filtered data, a dataset is created with all required data required for the research topics, as discussed in phase 3 of the methodology. The final dataset is discussed in the next sub-paragraph.

2.2.2 Explanation of dataset

As discussed in the previous section, three datasets are combined into one final dataset. With the information of the retrieved datasets, the research topics could be analyzed. In Figure 15 an extraction of the final dataset is shown which is used to analyze the research topics.

To be able to derive the different timestamps used to calculate the predictability and to know how many minutes before actual in-blocks, the first column “FLTDATA_MODIFIED” is used. This indicates when in time the modification of the second column is recorded. Those modifications are filtered on the estimated in-blocks time (EIBT) and actual in-blocks time (AIBT). A modified EIBT is caused by a modification of the estimated landing time (ELDT) as they are relating to each other (Eq. 1.1). The SIBT refers to the Scheduled In-Blocks Time which is the planned time the aircraft should be at the final parking position. “FLTNR” refers to the flight number on which all the information is based. The columns with the “EIBT” and “ALDT” are referring to the estimated in-blocks time and actual landing time. For the first business rule, the ALDT as well as “ALDT_TIME_MODIFIED” are required (Eq. 2.5). “ALDT_TIME_MODIFIED” is the time when the landing time was modified.

As discussed previously, one of the conditions to trigger the auto-TOBT mechanism is to have a connected outbound flight, this flight is shown in the “CONNECT_FLTNR” column. The outbound flight has a planned off-block time which is shown in the column “SOBT”. To calculate the target off-block time, the minimum turnaround time is required (Eq. 1.2) and this is expressed in the column “MTTT”. The outcome of Eq. 1.2 is shown in “TOBT”. “TOBT_AT_AIBT” and “TOBT_AT_AOBT” are the target off-blocks time applicable at the actual in-blocks time and actual off-blocks time (Figure 14). Those times are necessary to analyze the final research topic. Finally, the actual arrival time at the parking position is shown as this is the final moment the auto-TOBT mechanism is active and the last condition the TOBT could be updated (Eq. 2.3, Eq. 2.6, and Eq. 2.9).

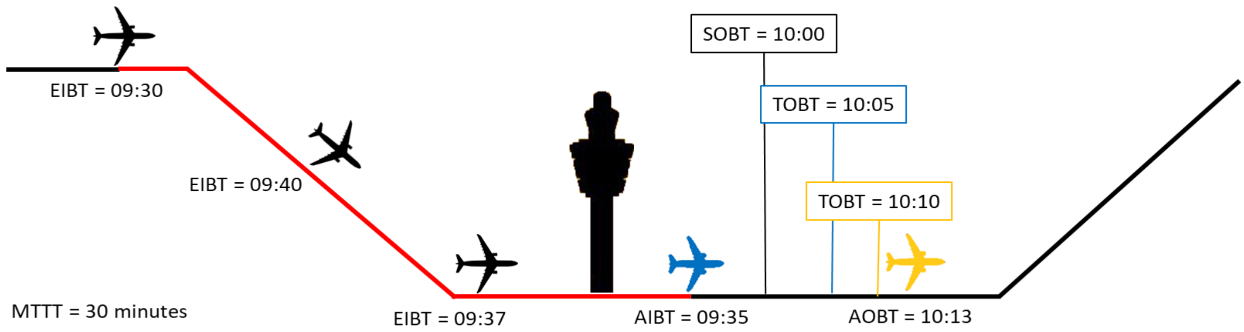


Figure 14 Difference between TOBT at AIBT (blue) and TOBT at AOBT (orange).

FLTDATA_MODIFIED	MODIFICATIONS	SIBT	FLTNR	EIBT	ALDT	ALDT_TIME_MODIFIED	CONNECT_FLTNR	SOBT	MTTT	TOBT	TOBT_at_AIBT	TOBT_at_AOBT	AIBT
15-7-2019 06:30	EIBT	15-7-2019 07:25	KL1866	15-7-2019 07:15			KL1071	15-07-19 8:00	00:35	15-07-19 7:50	15-7-2019 08:00	15-07-19 8:00	15-07-19 7:18
15-7-2019 06:31	EIBT	15-7-2019 07:25	KL1866	15-7-2019 07:14			KL1071	15-07-19 8:00	00:35	15-07-19 7:49	15-7-2019 08:00	15-07-19 8:00	15-07-19 7:18
15-7-2019 06:35	EIBT	15-7-2019 07:25	KL1866	15-7-2019 07:16			KL1071	15-07-19 8:00	00:35	15-07-19 7:51	15-7-2019 08:00	15-07-19 8:00	15-07-19 7:18
15-7-2019 06:35	EIBT	15-7-2019 07:25	KL1866	15-7-2019 07:14			KL1071	15-07-19 8:00	00:35	15-07-19 7:49	15-7-2019 08:00	15-07-19 8:00	15-07-19 7:18
15-7-2019 06:41	EIBT	15-7-2019 07:25	KL1866	15-7-2019 07:16			KL1071	15-07-19 8:00	00:35	15-07-19 7:51	15-7-2019 08:00	15-07-19 8:00	15-07-19 7:18
15-7-2019 07:08	EIBT	15-7-2019 07:25	KL1866	15-7-2019 07:17			KL1071	15-07-19 8:00	00:35	15-07-19 7:52	15-7-2019 08:00	15-07-19 8:00	15-07-19 7:18
15-7-2019 07:13	EIBT	15-7-2019 07:25	KL1866	15-7-2019 07:17	15-7-2019 07:13	15-7-2019 07:15	KL1071	15-07-19 8:00	00:35	15-07-19 7:52	15-7-2019 08:00	15-07-19 8:00	15-07-19 7:18
15-7-2019 07:18	AIBT	15-7-2019 07:25	KL1866	15-7-2019 07:17			KL1071	15-07-19 8:00	00:35	15-07-19 7:53	15-7-2019 08:00	15-07-19 8:00	15-07-19 7:18

Figure 15 Overview of the procedure how the data is analyzed. In this overview, the first business rule is expressed.

2.3 Accuracy, predictability and stability

In this research, the terms accuracy, predictability, and stability are frequently used. In this paragraph, all three terms will be explained to point out the differences between each of them and to create a better understanding.

The definition of accuracy is according to the Oxford dictionary as follows: *"The quality or state of being correct or precise."* (Oxford University Press (OUP), 2020a). In other words, it expresses the degree to which a calculated value is correct compared to the standard value. This is expressed in a percentage. In this research, the accuracy of the value of the updated TOBT will be compared with the TOBT@AIBT, which is the final TOBT triggered by the auto-TOBT mechanism.

"The ability to be predicted." (Oxford University Press (OUP), 2020b), is the definition of predictability. In addition to this definition, the term predict is required. Predict is an estimation that something will happen in the future or will be a consequence of something (2020b). In this research, the predictability of a TOBT update is used to estimate the TOBT.

The terms accuracy and predictability seem quite similar but are used in different ways. As in this research, the value of TOBT resulted from the auto-TOBT mechanism will be compared with the TOBT@AIBT. The TOBT is a prediction of the final TOBT, which is the TOBT@AOBT.

Finally, stability is used to see if the TOBT is changing or not. According to the Oxford dictionary, the definition of stability is: *"The state of being stable."* (Oxford University Press (OUP), 2020c). To understand the term stability even better, the term stable must be described. Stable is when something is not likely to change or fail (2020c).

Now the terms accuracy, predictability, and stability are discussed, it will be easier to understand why the research topics, or sub-questions, will provide more information to answer the main research question. In the next chapter, the business rules will be analyzed based on the research topics.

3 Data Analysis

The actual data analysis will consist of comparing three business rules with five different research topics. Those research topics are derived from the sub-questions and the results will be discussed separately in each paragraph. The research topics which are analyzed are:

1. Frequency of TOBT updates
2. Inter arrival time of TOBT update in minutes
3. Predictability of the TOBT update
4. Time before AIBT
5. Difference in time between TOBT@AIBT and TOBT@AOBT

Three out of five research topics will be analyzed based on the same input. The input which will be used is 25,922 modifications of the EIBT and AIBT, triggered in week 29 of 2019. The research topics which make use of this input are the frequency of TOBT updates, inter arrival time of a TOBT update, and the difference in time between TOBT@AIBT and TOBT@AOBT. To have an overview when before AIBT a TOBT update occurred, a triggered TOBT update based on a modification of AIBT is not considered. Predictability of the TOBT update and the time before AIBT will make use of modifications of the EIBT only, as the comparison is made with the target off-block time at AIBT or the clock time at AIBT. When considering TOBT updates triggered by modifications of EIBT only, the same results will not be analyzed twice. As each business rule has different conditions (paragraph 2.1), the results between each business rule will differ.
The results of each research topic will be analyzed based on the measures of central tendency and measure of variability. With the measures of central tendency, the center of the data points is described by making use of the mean, median, and mode. Moreover, the measure of variability is used to understand how much spread the data is (page 15). To analyze the business rules which each other based on the results of the research topic, the Mean Absolute Deviation is used. With this absolute deviation, the deviation between the data point and the mean is expressed (Khan Academy, 2020). This is also known as the standard deviation (std), which expresses how close to the mean the data points are situated (Rumsey, n.d.). Therefore, each business rule will be compared based on the spread of the data and the mean.
The data is represented by making use of bar charts and boxplots which are based on the raw data which is provided in appendices for each business rule. Pivot tables with raw data are represented in Appendix VI (current business rule), Appendix VII (first business rule), and Appendix VIII (second business rule).

In phase 3 of the Methodology, those research topics are explained in detail (page 16). This chapter has the same structure as described in phase 3. Based on the interpretation of the results of the analysis of the research topics a conclusion could be made.

3.1 Validity of TOBT updates

3.1.1 Frequency of TOBT updates

The frequency of the TOBT updates indicates how often the TOBT will be updated automatically based on any modification of the EIBT or AIBT. The frequency of updates differs between each business rule as different conditions are applicable. Figure 16 visualizes the percentage of modifications of the EIBT and AIBT which resulted in an automatically updated TOBT. For example, with the current business rule, 17.61% of all modifications of the EIBT and AIBT resulted in a TOBT update. In other words, 4,565 TOBT updates were triggered. Based on those percentages, the number of updates, number of individual flights, and average number of updates per flight are expressed. Those numbers are represented in Table 1. As the information presented in this table shows, the number of TOBT updates is the highest with the current business rule and lowest with the first business rule. This is because the current business rule updates with any minute difference and the first business rule are only triggered at three specific moments. Therefore, the maximum number of updates for the first business rule is three updates. The current and second business rules have a maximum number of updates of fifteen and seven updates. Furthermore, the number of individual flights affected by an auto-TOBT update differs between each business rule. With the current business rule, 979 individual flights have had a TOBT update, whereas 880 and 893 individual flights have had an update for the first and second business rule.

Based on those results, it could be concluded that the first business rule triggers fewer TOBT updates and therefore the outbound planning will be updated less frequently. Moreover, the first business rule triggered fewer individual flights compared with the other two business rules.

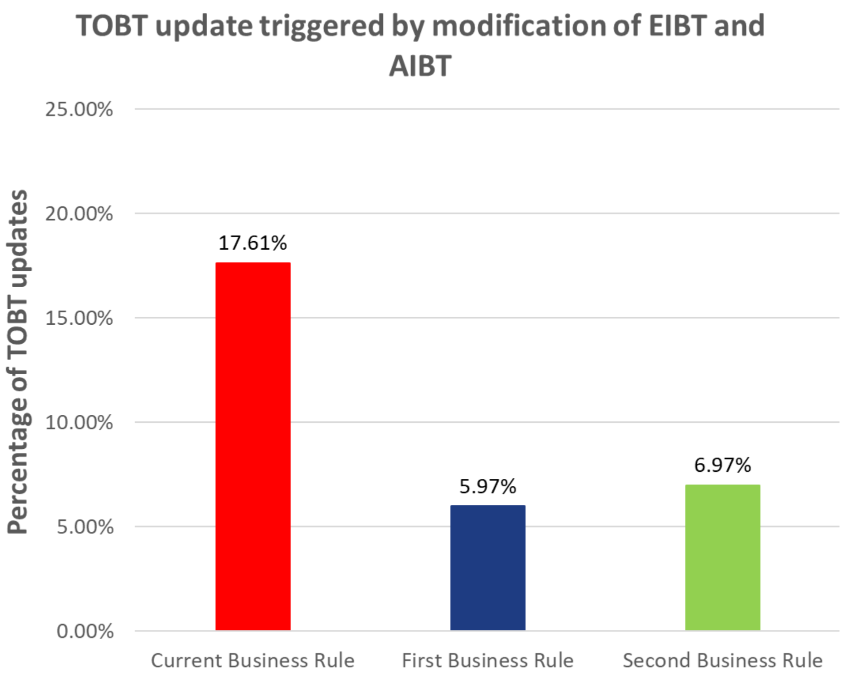


Figure 16 Percentage of modifications resulted in a TOBT update per business rule.

Table 1 Overview of results per business rule based on the number of TOBT updates.

Number of TOBT updates			
	Current	First	Second
# of updates	4565	1547	1807
# of individual flights	979	880	893
Median (per flight)	5	2	2
Mean	4.7	1.8	1.95
Min	1	1	1
Max	15	3	7

3.1.2 Inter arrival time of TOBT updates

The inter arrival time of each update, or in other words, the difference in minutes between new TOBT and previous TOBT, gives more information about the stability of the updates of the TOBT. In Table 2, information for each business rule is presented. As shown, the minimum value is a minus number which indicates that the TOBT is changed to an earlier moment in time compared with the previous TOBT. For example, the minus eleven minutes means that the new triggered TOBT is eleven minutes earlier than the previous set TOBT. This could be caused by updates of the estimated landing time as the aircraft might be vectored or placed in a holding pattern by the air traffic controllers. The maximum value indicates that the new triggered TOBT is later than the previous TOBT. The maximum value of 1203 minutes (20 hours and 30 minutes), is because the inbound flight is delayed with 20 hours and 30 minutes. This difference is caused at the start of the auto-TOBT mechanism where the comparison is made with the SOBT (Eq. 2.1, Eq. 2.4, and Eq. 2.7). On average, the inter arrival time between updates of the first business rule is higher than the average of the second business rule and current rule. The higher average size of a TOBT update of the first and second rule is based on the conditions related to those rules. Moreover, the value for the means are not close to the conditions of each business rule. For example, the second business rule gives an update when the TOBT differs with more than five minutes. The mean for the second rule is almost twelve minutes difference between each update. This high value for the mean is caused by the inbound delay. Inbound delay is when the inbound flight arrives with a delay and this delay is triggering the first shift of the TOBT when the comparison is made with the SOBT.
The high standard deviation (std) indicates that the inter arrival time is widely spread as shown in Figure 17. This widely spread of data is caused by the inbound flight delay which is based on the first triggered update which visualizes the difference between the TOBT and SOBT. This tells that the inter arrival time between 20 hours and 30 minutes and ten minutes is caused by an inbound flight delay. Most of the updates have an inter arrival time between ten and minus eleven minutes (Figure 17) which is based on the conditions of the business rules. In Appendix IX – Boxplot inter arrival time of TOBT update, the information is represented by making use of a boxplot.

With this analysis, the different conditions are clearly visualized and could be concluded that the current business rule has more updates of the TOBT with smaller changes and the first and second business rules will have fewer updates but when an update occurs the difference is greater.

Table 2 Results per business rule based on the inter arrival time of each TOBT update in minutes.

Inter arrival time (in minutes)			
	Current	First	Second
Mean	4.71	13.9	11.9
Mode	1	1	5
Median	1	5	5
Std	25.55	42.44	39.56
Min	-11	-9	-11
Max	1203	1203	1203

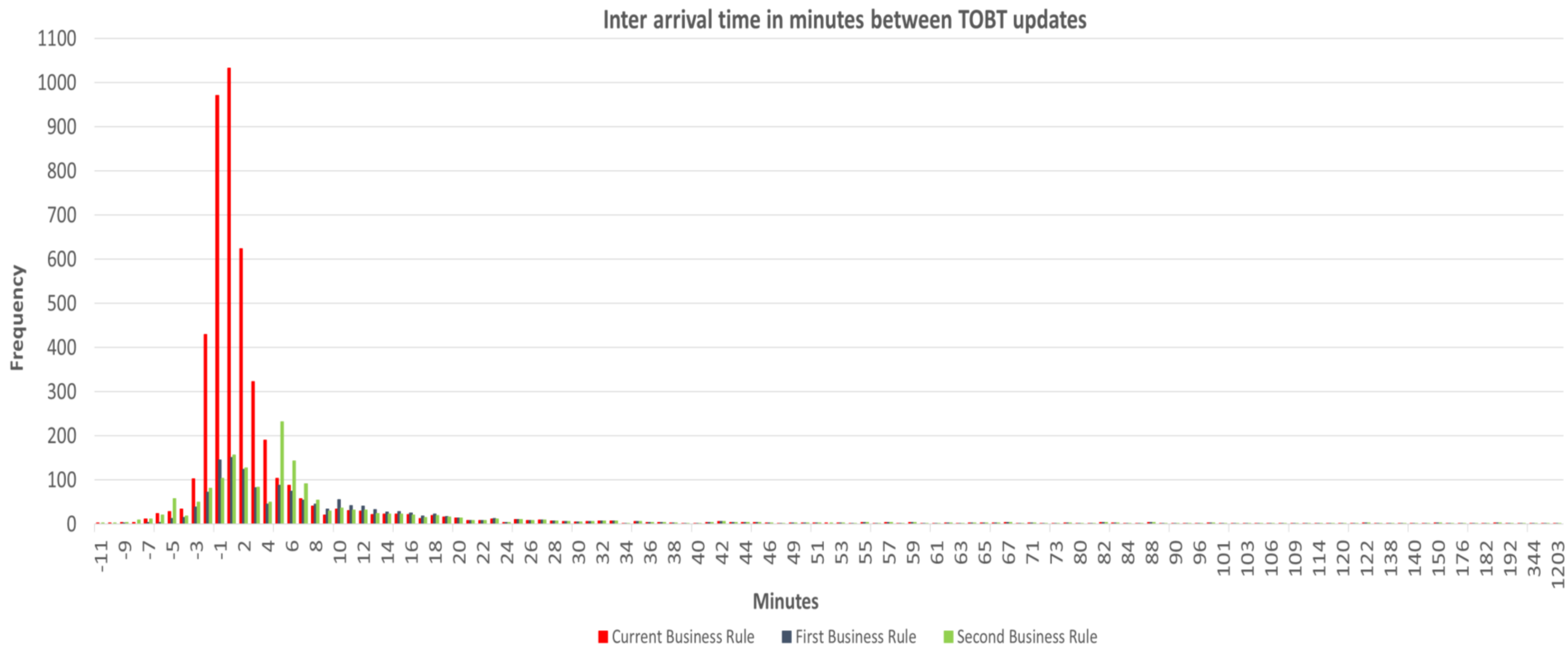


Figure 17 Visualization of the frequency of updates occurred per minute difference between each TOBT update.

3.2 Predictability of the TOBT update

The predictability of a TOBT update is expressed based on the difference between the triggered update and the TOBT@AIBT. It gives an estimation of how accurate the predicted TOBT is. Based on the predictability, the different business rules could be compared. To be able to compare each business rule equally, three timestamps are used. Those timestamps are at 40 minutes prior in-blocks (AIBT-40), twenty minutes (AIBT-20), and ten minutes (AIBT-10) before arriving at the final parking position. At each timestamp, the business rules are compared based on the standard deviation (std) and mean. As shown in Figure 18, boxplots per timestamp and per business rule are made. With each timestamp, the first business rule has a wider boxplot indicating a higher standard deviation compared with the second and current business rule. Therefore, the predictability of an updated TOBT, based on the conditions of the first business rule, is not as good as with the current situation and second rule. Furthermore, the second and current business rules do not have a big difference between each other. However, the current business rule has better predictability at each timestamp.

In Table 3, the statistical results per business rule categorized per timestamp is shown. As shown at AIBT-40, the predictability of the TOBT does not differ much between each business rule. Moreover, based on the spread of the data (std), it could be concluded that the target off-block times at AIBT-40 are less predictable compared to AIBT-20 and AIBT-10. Between AIBT-40 and AIBT-20, the average difference between the update of the TOBT and TOBT@AIBT is significantly less as well as the standard deviation (std). Between AIBT-20 and AIBT-10, this difference is less significant. Based on the big difference between AIBT-40 and AIBT-20 it could be concluded that in those twenty minutes different factors are influencing the TOBT.

Based on the results visualized in Table 3 and Figure 18, it could be concluded that the current business rule has the best predictability compared to the first and second business rule. However, the second rule does not differ much with the current rule, compared with the differences between the first and current, and therefore the second business rule could replace the current business rule better.

Table 3 Overview of the results of each business rule based on three different timestamps.

Predictability of TOBT at AIBT-40 (in minutes)			
	Current	First	Second
Mean	4.49	6.99	5.40
Mode	1	1	1
Median	2	4	3
Std	11.58	12.26	12.01
Min	0	0	0
Max	185	185	185

Predictability of TOBT at AIBT-20 (in minutes)			
	Current	First	Second
Mean	1.94	5.07	2.92
Mode	1	1	1
Median	1	4	2
Std	4.15	5.66	4.47
Min	0	0	0
Max	114	114	114

Predictability of TOBT at AIBT-10 (in minutes)			
	Current	First	Second
Mean	1.55	3.24	2.36
Mode	1	1	1
Median	1	2	2
Std	4.01	4.80	4.32
Min	0	0	0
Max	114	114	114

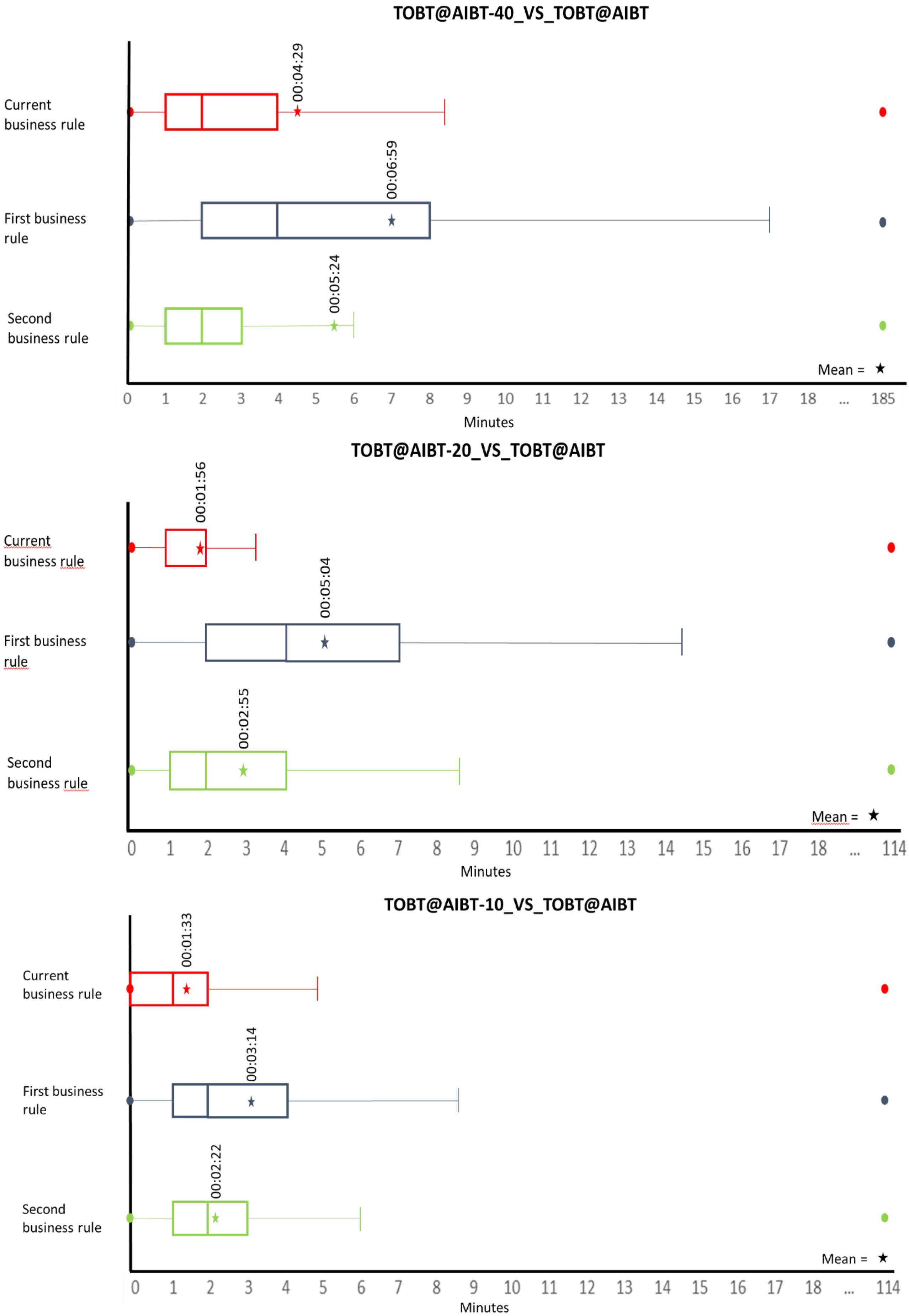


Figure 18 Visualization of the spread of the data per timestamp.

3.3 Time before AIBT

The time before AIBT indicates how many minutes a TOBT update occurred prior to AIBT. To analyze this research topic, the TOBT triggered at actual in-blocks is not considered. Based on the results, a bar chart (Figure 19) is created which gives an overview of how many minutes before arriving at the final parking position an update of the TOBT is triggered. Moreover, in Table 4 information about the results is shown. As the table visualizes, the first update has been triggered 72 minutes before in-blocks and the last update has been triggered between zero and four minutes before in-blocks. The zero minutes of the first business rule is resulted based on a late modification of the landing time which was shared with CISS at the same time the aircraft was in-blocks. On average, the second business rule has updated the earliest moment in time which could be beneficial if the predictability is good earlier in time as well. This might be beneficial as resources could be planned earlier in time.
As shown in Figure 19, most of the updates occurred between 55 and 36 minutes before in-blocks. The moment a TOBT update is triggered differs per business rule as different conditions are applicable. In Figure 19, the conditions of the first business rule (Eq. 2.4 and Eq. 2.5) are clearly visualized in this bar chart. Moreover, this figure shows that the frequency of updates reduces when the aircraft is closer to its final parking position. This indicates that most of the triggered TOBT updates will take place earlier in time.

Based on this analysis, it could be concluded that most of the updates occur 55 to 36 minutes prior to in-blocks and the second business rule have updates triggered on average earlier in time.

Table 4 Overview of the results of the analysed data for the time before actual in-blocks a TOBT was triggered.

Time before AIBT (in minutes)			
	Current	**First**	**Second**
Mean	33.83	29.01	40.23
Median	37	37	44
Min	2	0	4
Max	72	72	72

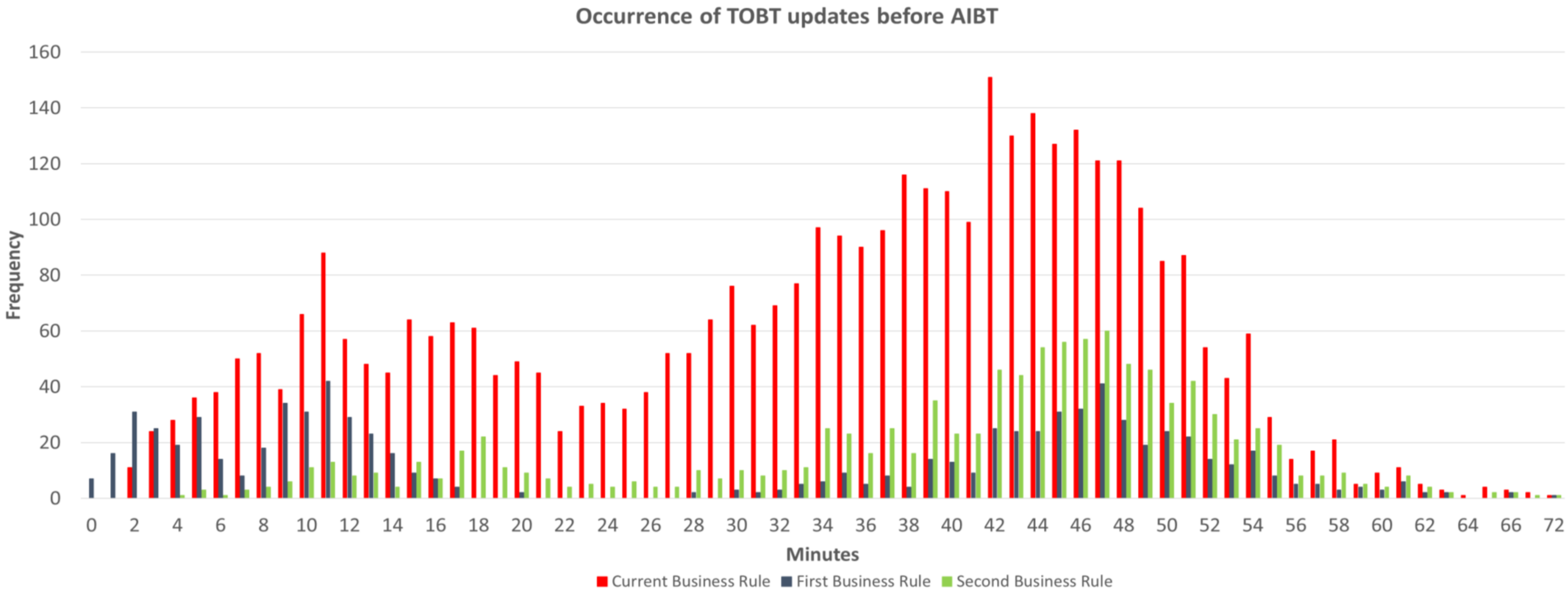


Figure 19 Overview of frequency of TOBT updates in minutes before actual in-blocks per business rule.

3.4 Difference in time between TOBT@AIBT and TOBT@AOBT

The difference between TOBT@AIBT and TOBT@AOBT is the final research topic which is analyzed and gives an insight into the predictability of the auto-TOBT mechanism. In order words, how accurate is the predicted TOBT by the mechanism compared with the TOBT when the aircraft leaves its parking position. For each business rule, the last trigger moment to have an update of the TOBT is the same (Eq. 2.3, Eq. 2.6, and Eq. 2.9) Therefore, the results as shown in Table 5 and Figure 20 represents each business rule. Based on the results shown in Table 4, the minimum value is -43 minutes this means that the TOBT@AIBT was 43 minutes later than the TOBT@AOBT. The maximum value, 300 minutes (five hours) indicates that the TOBT@AIBT was five earlier than the TOBT@AOBT. Because of the high standard deviation (std), the difference between the TOBT before the turnaround process started, and the TOBT when leaving the parking position is widely spread. This could be caused by multiple factors that happened during the turnaround process.

Based on the widespread of the data, it could be concluded that is it unnecessary to predict a TOBT as precisely as possible when the aircraft is in-blocks. This is because, during the turnaround process, different factors could influence the final TOBT at the actual off-block moment which requires manual adjustments of the TOBT.

In Appendix XI – Boxplot difference in minutes between TOBT@AIBT and TOBT@AOBT, the results of this research topic are represented differently by making use of a boxplot.

Table 5 Result rule showing the difference between the TOBT@AIBT and TOBT@AOBT.

Difference between TOBT@AIBT and TOBT@AOBT (in minutes)	
Mean	6.31
Median	2
Mode	0
Std	19.04
Min	-43
Max	300

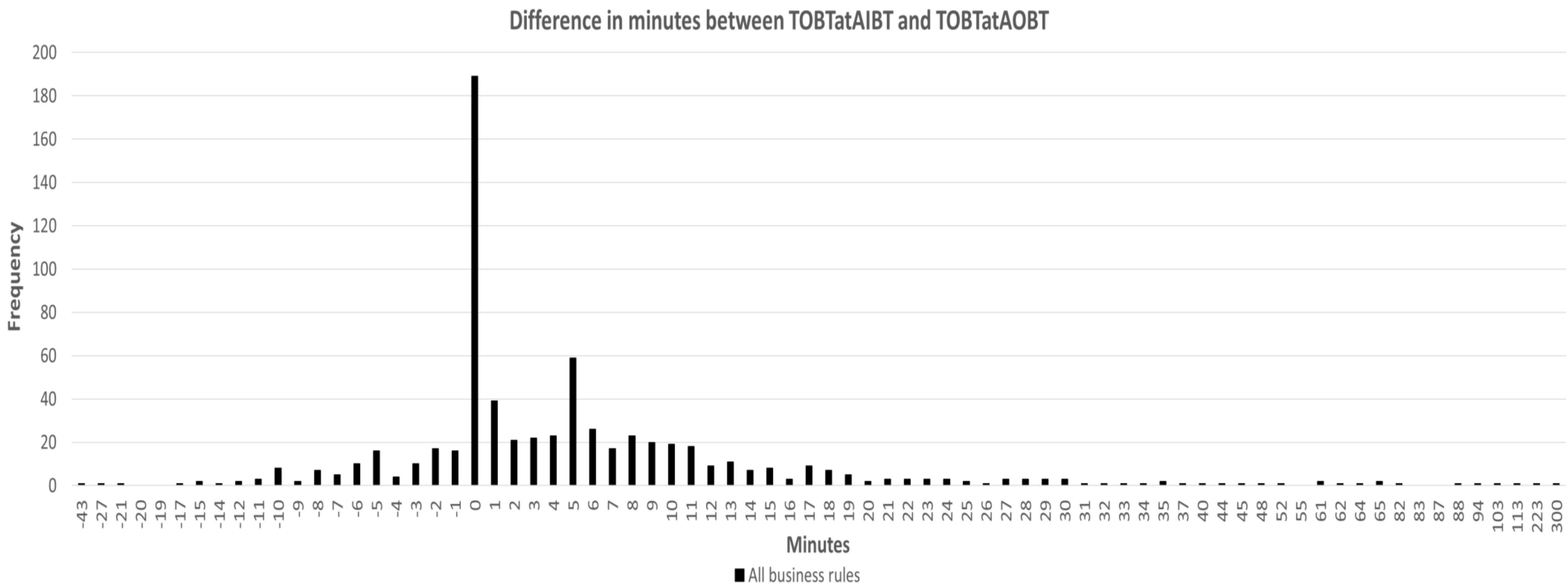


Figure 20 Overview of the frequency of the minutes difference between the TOBT@AIBT and TOBT@AOBT, which is for each business rule the same.

4 Conclusion and Discussion

This chapter discusses the conclusion and discussion. In the conclusion, an answer to the main research question is provided based on the results of the analysis. The interpretation of the research and what could have been done better is discussed in the discussion.

4.1 Conclusion

The aim of this research was to analyze different business rules of the auto-TOBT mechanism in order to create a stable and predictable TOBT to reduce the fluctuations in the outbound planning. This is done by analyzing two newly predefined business rules and compare those with the business rule which is currently in use in the mechanism. Based on the aim of this research the following main research question was created:

"Which business rule(s) could reduce the number of auto-TOBT updates at AAS and therefore reducing the dynamical impact on the outbound planner, without losing accuracy and predictability of the TOBT?"

Different research topics have resulted in an answer to this main research question. The first part of the research question is to reduce the number of automatically triggered TOBT updates at AAS. Based on this, the frequency of the triggered TOBT updates is analyzed and compared per business rule. In the current situation, 4,565 updates have been triggered in week 29, 2019 with an average difference of 4.7 minutes between each update. With this information, the first business rule and the second business rule were compared. The conditions of the first business rule triggered 1,547 TOBT updates with an average inter arrival time of 13.9 minutes and 1,807 updates with an average size of 11.9 minutes were triggered based on the conditions of the second business rule. To reduce the number of TOBT updates triggered by the auto-TOBT mechanism, the first business rule is better.
However, the second part of the research question is to maintain the same or almost the same, predictability and accuracy of the TOBT. The predictability of the updated TOBT is compared with the TOBT set at the actual in-blocks time (AIBT). In order to compare each business rule equally, the rules were compared based on different timestamps. The following timestamps have adhered to AIBT-40, AIBT-20, and AIBT-10. With this comparison, the predictability of the TOBT at each timestamp is derived as well as the predictability of each business rule. The first business rule had, at all timestamps, the highest spread of difference between the updated TOBT and TOBT@AIBT, which indicates that the first business rule creates a less predictable TOBT compared with the current and second business rule. The current business rule has the best predictability out of all business rules. However, the second business rule does not differ much with the current situation. Therefore, the second business rule triggers less good predicted TOBTs compared with the current situation but a better-predicted TOBT compared to the first rule.
In order to understand how accurate the TOBT should be, a comparison is made between the TOBT@AIBT and TOBT@AOBT. The result of this comparison showed a high spread of data, indicating it is not necessary to be as accurate as possible during the inbound flight phase.

Based on the results, it could be concluded that the first business rule creates the least amount of TOBT updates. However, it has less good predictability compared with the current and second business rule. Compared with the first business rule, the second business rule creates a little more TOBT updates but has better-predicted TOBT. However, the predictability is not as good as in the current situation. Although, the less good prediction of the TOBT in the second business rule is acceptable, because of the spread between TOBT@AIBT and TOBT@AOBT.

Based on the main research question and results of the data analysis it could be concluded that the second business rule is the best in order to replace the current business rule.

4.2 Discussion

The results which were analyzed did show the expected results. However, once analyzing it could be concluded that the results were in general and not into much detail which could be used in order to provide a good conclusion. Therefore, an additional research topic was created to give more meaning to the results which helped with getting a conclusion that is more useful for each airport partner. This additional research topic was created and analyzed close to the deadline. This could have been prevented by logical reasoning earlier in time.

The analyzed data and results of the research topics were based on commercial passenger flights only. Cargo flights were excluded from this research because of the lack of information about the minimum turnaround time. Therefore, the results are not representing the complete commercial flight operations at Amsterdam Airport Schiphol. In addition, general aviation has been excluded in this research as well. In order to have a complete insight into the effects of the business rules, cargo flights should be included. To include those flights, the minimum turnaround time is required for this category of air transport by making use of CDM flight states.

Within this research, the interests of different airport partners were not considered. Therefore, deciding if the TOBT had a good predictability, and used timestamps (AIBT-40, AIBT-20, and AIBT-10) were based on expertise. In order to make sure the results are useful for all airport partners, their preferences should be known. By knowing the airport partners' preferences, other timestamps might be useful to analyze. Moreover, the required accuracy applicable per airport partner could be analyzed when their preferences are known.

The research topic expressing the predictability at three different timestamps have shown that the predictability of the Target Off-Block Time at AIBT-40 was not as good as at AIBT-20 and AIBT-10. This indicates that the calculated off-block time at AIBT-40 triggered an update that was not good predicted and therefore triggered the outbound planning as well at that moment. This resulted in a dynamical outbound planning already earlier in time. Between AIBT-40 and AIBT-20 the biggest difference in predictability was shown, to increase the predictability at the first timestamp the process of the inbound flight between AIBT-40 and AIBT-20 should be analyzed. Another way to reduce the risk of having an unpredicted off-block time is to evaluate the start moment of the auto-TOBT mechanism.

5 Recommendation

In this chapter, the recommended further work which could be done on short notice will be discussed. Those recommendations are in addition to the ones mentioned in the discussion.

The Target Off-Block Time (TOBT) is calculated based on a variable time element, which is the expected or actual in-blocks time and a fixed element which is the minimum turnaround time. In order to evaluate the quality calculated TOBT, it is recommended to analyze if the list with minimum turnaround times per aircraft operator and aircraft type are still realistic.
In addition to aim for a better quality of the minimum turnaround time, continuing further research to the Estimated Landing Time (ELDT) is required. This further research is necessary as the ELDT is the basis for calculations of the estimated in-blocks time resulting in the TOBT. When the accuracy of the ELDT is not good, the related time references will be negatively influenced as well. Therefore, it is highly recommended to perform further research on the ELDT.

In this research, a comparison is made based on the Standard Off-Block Time (SOBT) at the first moment the auto-TOBT mechanism is triggered. In this case, the inbound delays influencing the results of the auto-TOBT mechanism and the calculated TOBT. To eliminate this inbound delay, a comparison should be made at the start of the mechanism with the TOBT which is applicable at that moment. When the TOBT is earlier than the SOBT, the SOBT still remains the reference for further updates. Updates after the start of the auto-TOBT mechanism will then be compared with the applicable TOBT. In this case, the inbound flight delays do not affect the results anymore. Therefore, it is recommended to adjust this in further work to assess the quality of the calculated TOBT better. In order to create a better quality of the TOBT, it would be useful to have an accurate EIBT/ELDT earlier in time. Therefore, it is possible to have a good quality of the estimated in-blocks time and target off-blocks time earlier in time and the auto-TOBT mechanism could make use of this. By knowing those times early, the inbound flight delay will be eliminated.

The results and conclusion are based on data of one specific week (week 29, 2019). It is recommended to perform this analysis based on other weeks in 2019 to be able to conclude if the advised business rule is showing the same results.

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Appendix I – Stakeholder analysis

To analyze the impact of the dynamical outbound planning, a stakeholder analysis is required to understand what the influences and impacts of the stakeholders are on the stability of the TOBT. With a Power / Interest matrix (Figure I), an overview will be created which stakeholder has influence on the realization of a less dynamic outbound planning and which stakeholder is interested. A stable TOBT influences the outbound planning which in the end has influence on the available capacity and resources for each involved stakeholder. However, each stakeholder influences the realization of a less fluctuating TOBT differently. With help of desk research, the following involved stakeholders are defined (Schiphol Airport, 2019):

- Aircraft operators [AO]
- Amsterdam Airport Schiphol [AAS]
- Air Traffic Control [ATC]
- EUROCONTROL [EC]
- Ground Handlers [GH]

Those stakeholders are all interested in a more stable TOBT as this time reference is important for their resource planning and capacity. In the Power / Interest matrix, the stakeholders are placed based on their power to influence the reduction of the dynamical outbound planning and their interest to have a less dynamic outbound planning. As shown in the matrix (Figure I), almost all stakeholders are interested in a more stable outbound planning. Most of the stakeholders have less influence on achieving a more stable TOBT as they are all limited to processes happening previously. The AO and GH as well as AAS have the highest power, compared to ATC and EC, in order to improve the stability of the TOBT. The aircraft operators and ground handlers should be managed closely as they are the two stakeholders which have influence on the stability of the TOBT as they can adjust this target time manually. AAS has high power as the airport is responsible for the auto-TOBT mechanism and could change the business rules if needed. Additionally, the airport could impose sanctions to the AO and GH when rules are not obeyed and can create regulations. Those stakeholders must be managed closely in order to achieve the stable TOBT and thus a less dynamic outbound planning.

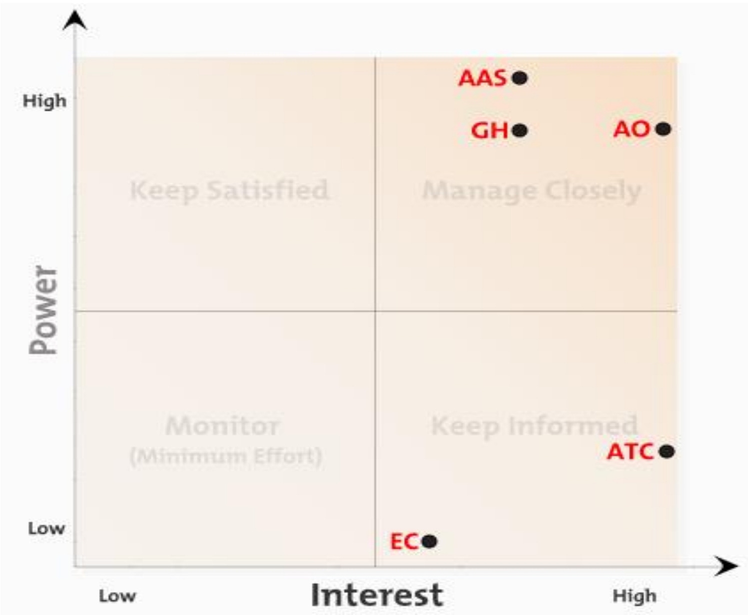


Figure I Power / Interest matrix with involved stakeholders on reducing the dynamical outbound planning.

Explanation of the stakeholders and their position in the power / interest matrix

AO – Based on the service level agreement made between AO and GH, one of them could update the TOBT manually. Those manual updates are based on the activities happening during the turnaround. As either the AO or GH could update the TOBT manually, they have high power in order to achieve a stable TOBT.
AO is interested in a stable TOBT as this will reduce the required update of the flight plan when TOBT has +/- 15 minutes difference with EOBT (Schiphol Airport, 2019). Flight crews are interested in a stable target off-block time as they could prepare themselves based on this time reference. TOBT updates as well as flight plan updates will increase the risk in a CTOT which leads to additional delays for the outbound flight. In addition to the reduction of delays, key performance indicators such as on-time performance will be positively influenced as the outbound flights could depart on-time more often as the departure sequence will be less fluctuating. Furthermore, passenger satisfaction will increase as flights departing on time more often (Groppe, 2011).

AAS – The airport has a high power of creating a more stable TOBT as the airport is responsible for the auto-TOBT mechanism and could adjust business rules. Moreover, AAS can impose sanctions on aircraft operators or ground handlers when necessary. Additionally, AAS is responsible for regulations at the airport. Besides the power of AAS, the airport is highly interested in a more stable outbound planning as resource planning could be improved. Therefore, resources such as aircraft parking positions could be planned better and resulting in higher utilization of available parking positions. Moreover, gate allocation to inbound aircraft could be improved with more stable TOBTs. Therefore, the inbound flight does not have to wait for an occupied parking position or gate (Groppe, 2011). Lastly, the available capacity of the runways could be used better the departure sequence could be planned better without having gaps in the sequence.

ATC – Air Traffic Control has no power in creating a more stable TOBT, ATC is not responsible for the turnaround process. However, they are highly interested in the stability of the TOBT. Once the TOBT could be better predicted and is more stable, the departure sequence will be better utilized, and no losses of capacity will occur. This is the result of the effects on the Collaborative Pre-Departure Sequence Planner (CPDSP) which is the responsibility of the LVNL.

EC – EUROCONTROL has no power on a more stable TOBT, as they could only influence the take-off time by providing a Calculated Take-Off Time (CTOT), which is based on the filed flight plan and the expected demand and capacity in a specific part of the European airspace. Based on the TOBT, time references such as the Target Take-Off Time and Target Start-Up Time are calculated by the CPDSP. Those time references are the basis to know the demand at a specific airspace at a specific time. When the demand is exceeds the capacity, a CTOT will be given. With a more stable TOBT, the TTOT and TSAT will fluctuate less often and therefore the number of CTOT updates will be reduced. With a more stable TOBT, the CTOT could be more accurate as well and therefore new regulated take-offs can be planned closer to each other. EUROCONTROL is highly interested in the less dynamical outbound planning as this would result in more flight departing as initiated and therefore no capacity in the European airspace is wasted due to delayed flights.

GH – GH are interested, as the fluctuating TOBT influences the utilization of their resources, such as staff and equipment. By having a more stable TOBT, resources could be planned with less time in between flights which increases the utilization of equipment and reduction of staff costs. As the outbound flight will be pushed back without delays, inbound traffic will not be delayed by holding at the ground. This results in no rippled effect of delays and reduces work pressure to absorb the delay during the turnaround.

Appendix II – SIPOC-diagram processes flowchart current business rule

The processes (P0.X) shown in the flowchart of the current business rule at page 23 are explained in detail in the SIPOC-diagram (Table I).

Table I SIPOC-diagram providing more detailed information about each process in the flowchart of the current business rule.

Supplier	Input	Process	Outputs	Customer
LVNL	Inbound data (AAA/ASAP)	P0.1 ELDT calculation	New ELDT	Airport partners Airport database / CISS
Airport database / CISS	ELDT	P0.2 EIBT calculation	New EIBT	Airport partners Airport database / CISS
Airport database / CISS	First EIBT update	P0.3 Eq. 2.1	New TOBT	Airport partners Airport database / CISS
Airport database / CISS	New EIBT	P0.4 Eq. 2.2	New TOBT	Airport partners Airport database / CISS
Airport database / CISS LVNL	No new TOBT	P0.5 No update of TOBT	Keep current TOBT	Airport partners Airport database / CISS
Airport database / CISS	TOBT later than SOBT	P0.6 Update TOBT	New reference TOBT	Airport partners Airport database / CISS
Airport database / CISS	TOBT earlier than SOBT	P0.7 TOBT set equal to SOBT	New TOBT is equal to SOBT	Airport partners Airport database / CISS
GH/AO Airport database / CISS	Aircraft in-blocks	P0.8 Eq. 2.3	New TOBT	Airport partners Airport database / CISS

Appendix III – SIPOC-diagram processes flowchart first business rule

The processes (P1.X) shown in the flowchart of the first business rule (page 25) are explained with help of the SIPOC-diagram below.

Table II SIPOC-diagram providing more detailed information about each process in the flowchart of the first business rule.

Supplier	Input	Process	Outputs	Customer
LVNL	Inbound data (AAA/ASAP)	P1.1 ELDT calculation	New ELDT	Airport partners Airport database / CISS
Airport database / CISS	ELDT	P1.2 EIBT calculation	New EIBT	Airport partners Airport database / CISS
LVNL Airport database / CISS	First moment auto-TOBT mechanism is active	P1.3 Eq. 2.4	New TOBT	Airport partners Airport database / CISS
LVNL Airport database / CISS	Aircraft landed	P1.4 Eq. 2.5	New TOBT	Airport partners Airport database / CISS
Airport database / CISS	No new TOBT	P1.5 No update of TOBT	Previous TOBT is reference	Airport partners Airport database / CISS
Airport database / CISS	TOBT later than SOBT	P1.6 Update TOBT	TOBT reference	Airport partners Airport database / CISS
Airport database / CISS	TOBT earlier than SOBT	P1.7 TOBT = SOBT	TOBT is set to SOBT	Airport partners Airport database / CISS
GH/AO Airport database / CISS	Aircraft in-blocks	P1.8 Eq. 2.6	New TOBT	Airport partners Airport database / CISS

Appendix IV – SIPOC-diagram processes flowchart second business rule

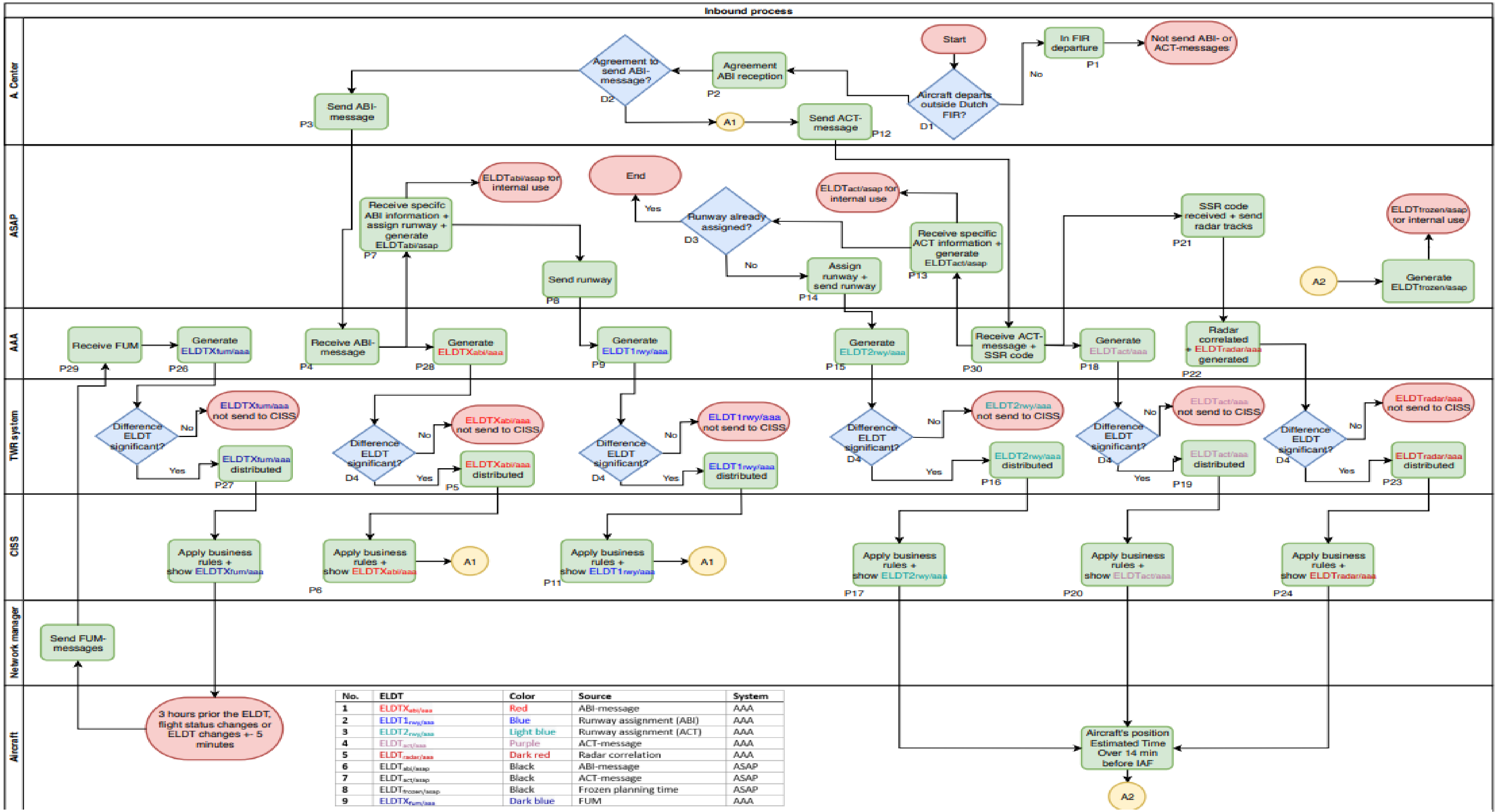
The processes (P2.X) shown in the flowchart of the second business rule at page 26 are explained in detail in the SIPOC-diagram below.

Table III SIPOC-diagram providing more detailed information about each process in the flowchart of the second business rule.

Supplier	Input	Process	Outputs	Customer
LVNL	Inbound data (AAA/ASAP)	P2.1 ELDT calculation	New ELDT	Airport partners Airport database / CISS
Airport database / CISS	ELDT	P2.2 EIBT calculation	New EIBT	Airport partners Airport database / CISS
Airport database / CISS	First EIBT update	P2.3 Eq. 2.7	New TOBT	Airport partners Airport database / CISS
Airport database / CISS	New EIBT	P2.4 Eq. 2.8	New TOBT	Airport partners Airport database / CISS
Airport database / CISS LVNL	No new TOBT	P2.5 No update of TOBT	Keep current TOBT	Airport partners Airport database / CISS
Airport database / CISS	TOBT later than SOBT	P2.6 Update TOBT	New reference TOBT	Airport partners Airport database / CISS
Airport database / CISS	TOBT earlier than SOBT	P2.7 TOBT set equal to SOBT	New TOBT is equal to SOBT	Airport partners Airport database / CISS
GH/AO Airport database / CISS	Aircraft in-blocks	P2.8 Eq. 2.9	New TOBT	Airport partners Airport database / CISS

Appendix V – Flowchart enhancement between different ATC-systems

In this appendix, a cross functional flowchart is shown (Scheffers, 2020). It gives an overview how different ATC-systems relate to each other and how, in this case, ELDT information is provided to CISS.



No.	ELDT	Color	Source	System
1	$ELDTX_{abi/aaa}$	Red	ABI-message	AAA
2	$ELDT1_{rwy/aaa}$	Blue	Runway assignment (ABI)	AAA
3	$ELDT2_{rwy/aaa}$	Light blue	Runway assignment (ACT)	AAA
4	$ELDT_{act/aaa}$	Purple	ACT-message	AAA
5	$ELDT_{radar/aaa}$	Dark red	Radar correlation	AAA
6	$ELDT_{abi/asap}$	Black	ABI-message	ASAP
7	$ELDT_{act/asap}$	Black	ACT-message	ASAP
8	$ELDT_{frozen/asap}$	Black	Frozen planning time	ASAP
9	$ELDTX_{fum/aaa}$	Dark blue	FUM	AAA

.Figure II Cross functional flowchart explaining how different ATC systems enhance with each other and how ELDT information is shared with CISS (Scheffers, 2020).

Appendix VI – Pivot tables of the data analysis of the current business rule

This appendix consists of pivot tables of the current business rule which are the source of the bar charts which are shown in sub-paragraph 3.1.2 up to and including paragraph 3.3.

Inter arrival time (minutes) between auto-TOBT updates	Frequency
-11	2
-10	2
-9	4
-8	4
-7	11
-6	24
-5	28
-4	34
-3	102
-2	429
-1	971
1	1032
2	624
3	323
4	190
5	103
6	88
7	57
8	40
9	20
10	34
11	30
12	29
13	22
14	23
15	23
16	21
17	13
18	19
19	16
20	14
21	8
22	8
23	11
24	3
25	10
26	8
27	9
28	7
29	6
30	5
31	6
32	7
33	7
34	1
35	6
36	3
37	3
38	2

Inter arrival time (minutes) between auto-TOBT updates	Frequency
39	1
40	1
41	4
42	6
43	4
44	4
45	4
46	2
48	1
49	2
50	2
51	2
52	2
53	2
54	1
55	4
56	1
57	4
58	1
59	3
60	1
61	1
62	2
63	1
64	2
65	2
66	2
67	3
68	1
71	2
72	1
73	1
77	2
80	1
81	1
82	4
83	2
84	1
87	1
88	3
89	1
90	1
94	1
96	1
99	2
101	1
102	1
103	1
104	1
106	1
107	1
109	1
111	1
114	1
118	1
120	1
121	1

Inter arrival time (minutes) between auto-TOBT updates	Frequency
121	1
122	2
125	1
138	1
139	1
140	1
145	1
150	2
159	1
176	1
180	1
182	1
184	2
192	1
290	1
344	1
601	1
1203	1
Total updates	**4565**

Figure III Raw data of the inter arrival time between TOBT updates for the current business rule.

Difference in minutes	Count of Diff TOBT_at AIBT vs TOBT_at AIBT-10
0	261
1	379
2	204
3	74
4	26
5	6
6	4
7	5
8	6
9	1
10	4
11	2
12	3
13	1
15	1
18	1
114	1
Total	**979**

Difference in minutes	Count of Diff TOBT_at AIBT vs TOBT_at AIBT-20
0	238
1	308
2	197
3	102
4	58
5	25
6	14
7	9
8	10
9	1
10	6
11	2
12	4
13	2
15	1
18	1
114	1
Total	**979**

Difference in minutes	Count of Diff TOBT_at AIBT vs TOBT_at AIBT-40
0	169
1	206
2	179
3	111
4	78
5	47
6	47
7	32
8	17
9	15
10	11
11	8
12	10
13	4
14	2
15	3
16	3
17	3
18	2
20	1
22	1
23	3
24	1
27	2
28	1
29	1
30	1
31	1
32	2
35	2
36	1
37	1
38	1
39	1
43	1
44	1
48	1
49	1
51	1
52	1
54	1
61	1
114	1
122	1
181	1
185	1
Total	**979**

Figure IV Raw data of the difference between TOBT update and TOBT@AIBT for the current business rule at AIBT-40, AIBT-20, and AIBT-10.

Clock time prior AIBT (in minutes)	Frequency
-29	1
-28	1
-20	2
-18	1
-16	1
-15	4
-14	1
-13	3
-12	1
-11	1
-10	2
-9	1
-8	1
-7	3
-6	1
-5	1
-3	2
-1	13
0	654
1	1
2	11
3	24
4	28
5	36
6	38
7	50
8	52
9	39
10	66
11	88
12	57
13	48
14	45
15	64
16	58
17	64
18	61
19	44
20	49
21	45
22	24
23	33
24	34
25	32
26	38
27	52
28	52
29	64
30	76
31	62
32	69
33	77
34	97
35	94
36	90
37	96
38	116
39	111
40	110
41	99
42	151
43	130
44	138
45	127
46	132
47	121
48	121
49	104
50	85
51	87
52	54
53	43
54	59
55	29
56	14
57	17
58	21
59	5
60	9
61	11
62	5
63	3
64	1
65	4
66	3
70	2
72	1
Total updates	**4565**

Figure V Raw data of the time a TOBT update occurred prior AIBT for the current business rule.

Difference in minutes between TOBT@AIBT and TOBT@AOBT	Frequency
-43	5
-27	4
-21	1
-20	2
-19	4
-17	8
-15	20
-14	8
-12	9
-11	19
-10	49
-9	16
-8	42
-7	26
-6	80
-5	85
-4	32
-3	76
-2	119
-1	92
0	1149
1	257
2	146
3	159
4	150
5	414
6	144
7	112
8	166
9	134
10	118
11	97
12	67
13	75
14	86
15	73
16	33
17	39
18	48
19	35
20	31
21	24
22	19
23	27
24	26
25	7
26	5
27	15
28	12
29	13
30	16
31	3
32	7
33	6
34	8
35	12
37	7
40	5
44	6
45	3
48	7
52	4
55	7
61	19
62	10
64	14
65	14
82	4
83	2
87	4
88	6
94	4
103	4
113	4
223	6
300	5
Total updates	**4565**

Figure VI Raw data of the difference in minutes between TOBT@AIBT and TOBT@AOBT for current business rule.

Appendix VII – Pivot tables of the data analysis of the first business rule

This appendix consists of pivot tables of the first business rule which are the source of the bar charts which are shown in sub-paragraph 3.1.2 up to and including paragraph 3.3.

Inter arrival time (minutes) between auto-TOBT updates	Frequency
-9	2
-7	3
-6	4
-5	13
-4	15
-3	38
-2	72
-1	145
1	151
2	124
3	82
4	45
5	88
6	74
7	54
8	45
9	34
10	55
11	42
12	41
13	33
14	27
15	28
16	25
17	18
18	23
19	17
20	14
21	8
22	8
23	12
24	4
25	10
26	8
27	9
28	7
29	6
30	5
31	6

Inter arrival time (minutes) between auto-TOBT updates	Frequency
32	7
33	7
34	1
35	6
36	3
37	3
38	2
39	1
40	1
41	4
42	6
43	4
44	4
45	4
46	2
48	1
49	2
50	2
51	2
52	2
53	2
54	1
55	4
56	1
57	4
58	1
59	3
60	1
61	1
62	2
63	1
64	2
65	2
66	2
67	3
68	1
71	2
72	1
73	1
77	2

Inter arrival time (minutes) between auto-TOBT updates	Frequency
80	1
81	1
82	4
83	2
84	1
87	1
88	3
89	1
90	1
94	1
96	1
99	2
101	1
102	1
103	1
104	1
106	1
107	1
109	1
111	1
114	1
118	1
120	1
121	1
122	2
125	1
138	1
139	1
140	1
145	1
150	2
159	1
176	1
180	1
182	1
184	2
192	1
290	1
344	1
601	1
1203	1
Total updates	**1547**

Figure VII Raw data of the inter arrival time between TOBT updates for the first business rule.

Difference in minutes	Count of Diff TOBT_at AIBT vs TOBT_at AIBT-10
0	100
1	220
2	162
3	123
4	72
5	54
6	44
7	27
8	19
9	14
10	12
11	7
12	8
13	7
14	4
15	2
16	1
17	1
18	2
114	1
Total	**880**

Difference in minutes	Count of Diff TOBT_at AIBT vs TOBT_at AIBT-20
0	54
1	138
2	120
3	113
4	73
5	71
6	61
7	54
8	38
9	38
10	25
11	17
12	19
13	14
14	5
15	14
16	6
17	5
18	5
19	1
20	3
21	1
22	1
23	2
30	1
114	1
Total	**880**

Difference in minutes	Count of Diff TOBT_at AIBT vs TOBT_at AIBT-40
0	43
1	125
2	112
3	100
4	65
5	69
6	60
7	53
8	41
9	39
10	28
11	20
12	23
13	16
14	6
15	17
16	9
17	7
18	6
19	1
20	4
21	1
22	2
23	5
24	1
27	2
28	1
29	1
30	2
31	1
32	2
35	2
36	1
37	1
38	1
39	1
43	1
44	1
48	1
49	1
51	1
52	1
54	1
61	1
114	1
122	1
181	1
185	1
Total	**880**

Figure VIII Raw data of the difference between TOBT update and TOBT@AIBT for the first business rule at AIBT-40, AIBT-20, and AIBT-10.

Clock time prior AIBT (in minutes)	Frequency
-29	1
-28	1
-25	1
-21	1
-20	2
-18	1
-16	1
-15	4
-14	1
-13	3
-12	1
-11	2
-10	2
-9	1
-8	1
-7	4
-6	3
-5	3
-4	1
-3	2
-2	1
-1	12
0	702
1	17
2	31
3	25
4	19
5	29
6	14
7	8
8	18
9	34
10	31
11	42
12	29
13	23
14	16
15	9
16	7
17	5
20	2
28	2
30	3
31	2
32	3

Clock time prior AIBT (in minutes)	Frequency
33	5
34	6
35	9
36	5
37	8
38	4
39	14
40	13
41	9
42	25
43	24
44	24
45	31
46	32
47	41
48	28
49	19
50	24
51	22
52	14
53	12
54	17
55	8
56	5
57	5
58	3
59	4
60	3
61	6
62	2
63	2
66	2
72	1
Total updates	**1547**

Figure IX Raw data of the time a TOBT update occurred prior AIBT for the first business rule.

Appendix VIII – Pivot tables of the data analysis of the second business rule

This appendix consists of pivot tables of the second business rule which are the source of the bar charts which are shown in sub-paragraph 3.1.2 up to and including paragraph 3.3.

Inter arrival time (minutes) between auto-TOBT updates	Frequency
-11	2
-10	2
-9	4
-8	9
-7	11
-6	20
-5	57
-4	18
-3	49
-2	81
-1	103
1	156
2	127
3	83
4	49
5	232
6	143
7	91
8	54
9	29
10	36
11	32
12	32
13	24
14	23
15	23
16	20
17	15
18	19
19	16
20	14
21	8
22	8
23	11
24	3
25	10
26	8
27	9
28	7
29	6
30	5
31	6
32	7
33	7
34	1
35	6
36	3
37	3
38	2
39	1
40	1
41	4
42	6
43	4
44	4
45	4
46	2
48	1
49	2
50	2
51	2
52	2
53	2
54	1
55	4
56	1
57	4
58	1
59	3
60	1
61	1
62	2
63	1
64	2
65	2
66	2
67	3
68	1
71	2
72	1
73	1
77	2
80	1
81	1
82	4
83	2
84	1
87	1
88	3
89	1
90	1
94	1
96	1
99	2
101	1
102	1
103	1
104	1
106	1
107	1
109	1
111	1
114	1
118	1
120	1
121	1
122	2
125	1
138	1
139	1
140	1
145	1
150	2
159	1
176	1
180	1
182	1
184	2
192	1
290	1
344	1
601	1
1203	1
Total updates	**1807**

Figure X Raw data of the inter arrival time between TOBT updates for the second business rule.

Difference in minutes	Count of Diff TOBT_at AIBT vs TOBT_at AIBT-10
0	139
1	252
2	202
3	136
4	69
5	37
6	23
7	7
8	9
9	2
10	5
11	3
12	3
13	2
15	1
16	1
18	1
114	1
Total	**893**

Difference in minutes	Count of Diff TOBT_at AIBT vs TOBT_at AIBT-20
0	110
1	205
2	178
3	143
4	88
5	56
6	48
7	22
8	14
9	6
10	7
11	5
12	4
13	2
15	2
16	1
18	1
114	1
Total	**893**

Difference in minutes	Count of Diff TOBT_at AIBT vs TOBT_at AIBT-40
0	76
1	158
2	150
3	127
4	82
5	66
6	63
7	37
8	23
9	20
10	18
11	11
12	10
13	4
14	1
15	6
16	4
17	3
18	2
20	1
22	1
23	3
24	1
27	2
28	1
29	1
30	1
31	1
32	2
35	2
36	1
37	1
38	1
39	1
43	1
44	1
48	1
49	1
51	1
52	1
54	1
61	1
114	1
122	1
181	1
185	1
Total	**893**

Figure XI Raw data of the difference between TOBT update and TOBT@AIBT for the second business rule at AIBT-40, AIBT-20, and AIBT-10.

Clock time prior AIBT (in minutes)	Frequency
-29	1
-28	1
-25	1
-21	1
-20	2
-18	1
-16	1
-15	4
-14	2
-13	2
-12	1
-11	3
-9	1
-8	1
-7	4
-6	3
-5	3
-4	1
-3	1
-2	1
-1	12
0	704
1	1
4	1
5	3
6	1
7	3
8	4
9	6
10	11
11	13
12	8
13	9
14	4
15	13
16	7
17	18
18	22
19	11
20	9
21	7
22	4
23	5
24	4

Clock time prior AIBT (in minutes)	Frequency
25	6
26	4
27	4
28	10
29	7
30	10
31	8
32	10
33	11
34	25
35	23
36	16
37	25
38	16
39	35
40	23
41	23
42	46
43	44
44	54
45	56
46	57
47	60
48	48
49	46
50	34
51	42
52	30
53	21
54	25
55	19
56	8
57	8
58	9
59	5
60	4
61	8
62	4
63	2
65	2
66	2
70	1
72	1
Total updates	**1807**

Figure XII Raw data of the time a TOBT update occurred prior AIBT for the second business rule.

Appendix IX – Boxplot inter arrival time of TOBT updates

In this appendix, the data distribution of the inter arrival time for each business rule is shown. These boxplots are based on the data provided in Figure III, Figure VII, and Figure X.

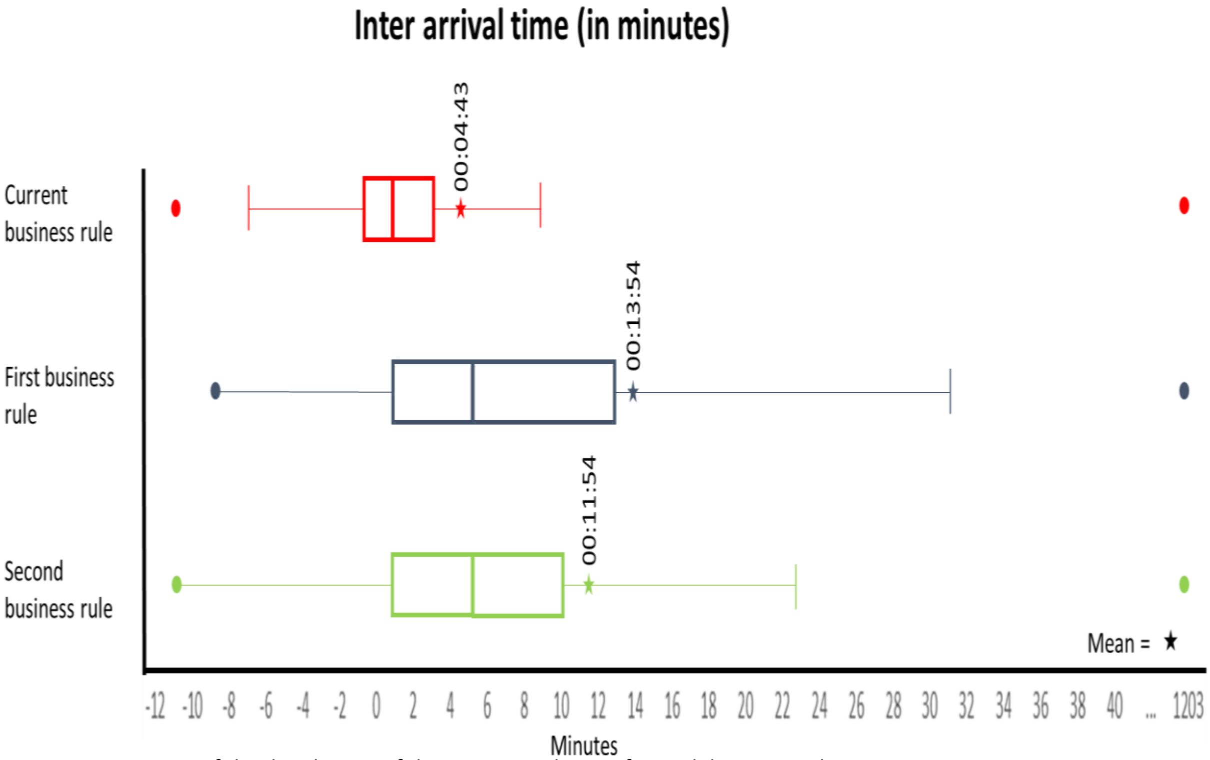


Figure XIII Overview of the distribution of the inter arrival times for each business rule.

Appendix X – Boxplot time before AIBT

In this appendix, the data distribution of the minutes before AIBT is shown. These boxplots are based on the data provided in Figure V, Figure IX, and Figure XII.

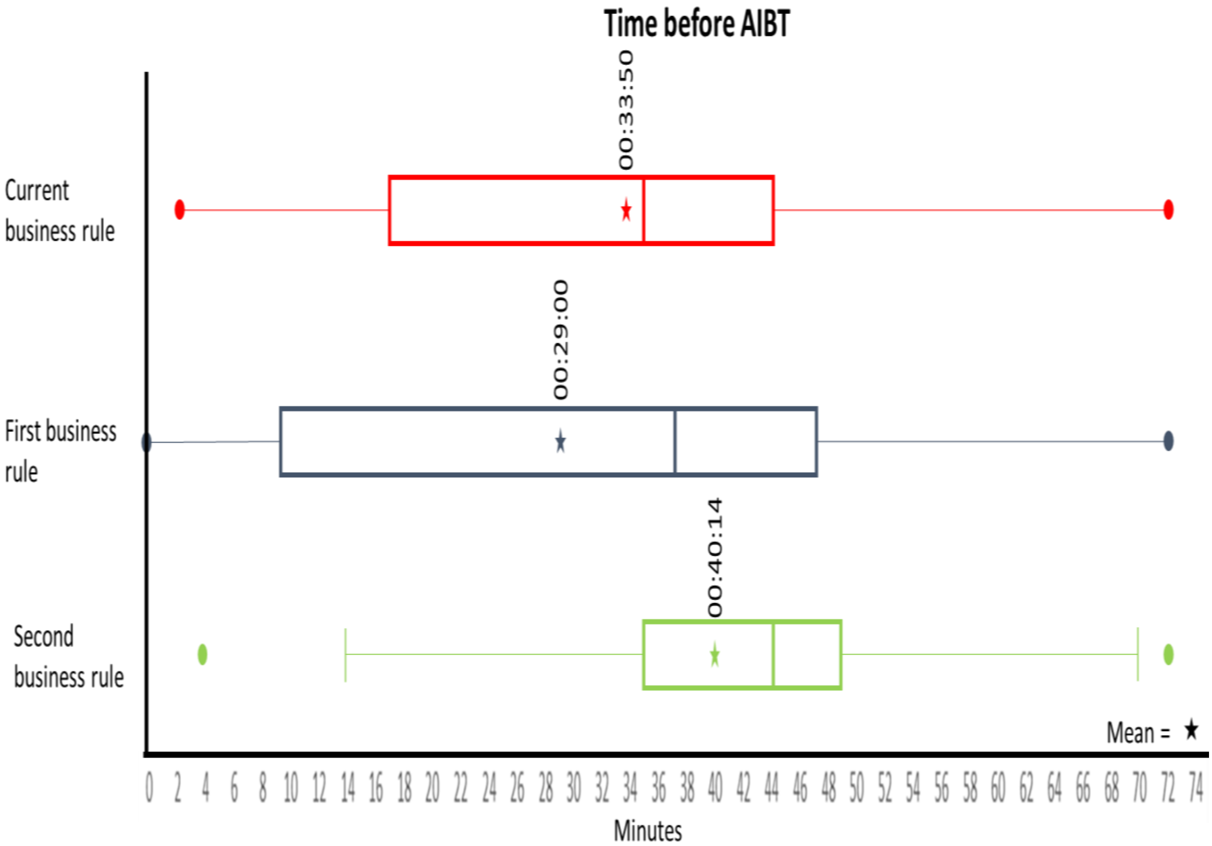


Figure XIV Overview of the data distribution of the updates occurred in minutes before AIBT.

Appendix XI – Boxplot difference in minutes between TOBT@AIBT and TOBT@AOBT

In this appendix, the data distribution of the difference between the TOBT@AIBT and TOBT@AOBT is shown. This boxplot is based on the data provided in Figure VI, as the results for each business rule is the same.

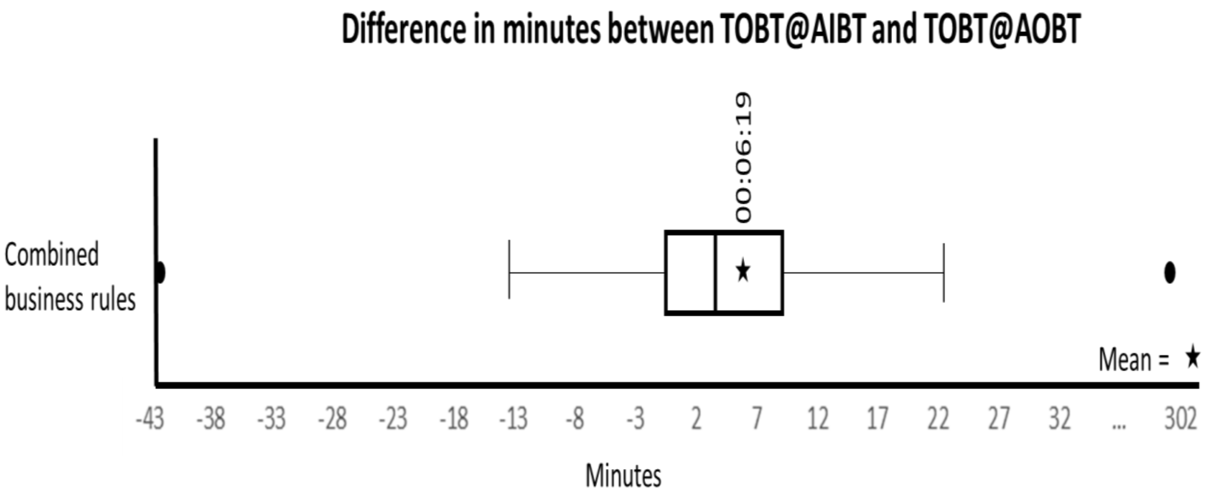


Figure XV Visualization of the distribution of data of the difference between TOBT@AIBT and TOBT@AOBT, which is the same for each business rule.