Improving the outbound planning process at Amsterdam Airport Schiphol

An evaluation of Estimated Landing Time (ELDT) data sources

Thesis

KDC Main port Schiphol – Centre of Excellence
A collaboration with the Aviation Academy, Amsterdam University of Applied Sciences

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Preface

This report has been prepared as graduation thesis based on the questions posed by the CDM business expert group at mainport Amsterdam Airport Schiphol. This thesis entitled 'Validating air traffic systems of the LVNL in the arrival process of Schiphol' has been performed to understand the current performance of the available and feasible source of information for the calculation of the landing time of flights.

During the graduation period of 20 weeks, I worked with interest and pleasure on this graduation assignment. After three and a half years at the Aviation Academy, this graduation was a nice way to end my study. Throughout my period at the LVNL, I learned new skills, such as programming with Python, where I will benefit from for the rest of my career. Because of the many presentations I needed to give, my presentation skills have improved also. When I started here, the assignment was a bit vague. However, thanks to my supervisor, Catya Zuniga and the business experts' members, the assignment was eventually formed.

First of all, I want to thank my supervisor lecturer, Catya Zuniga, for her guidance throughout the whole length my thesis. Also, I want to thank my company supervisor Evert Westerveld for the opportunity to graduate at the KDC (LVNL, Schiphol and KLM). Additionally, I want to thank the members of the business experts' group for the help and feedback they gave me, Eric van Leeuwen, Hans Kelder, and David Zwaaf); in special, I want to thank Yiannis Alexopoulos of the business experts group, because he was the first person who gave me the opportunity to graduate in the CDM topic. I want to thank Ferdinand Dijkstra as well. I could always come to him with my questions. Finally, I want to thank Peter Oudendijk for providing me the data for my data analysis.

I hope you find my thesis report interesting and enjoy reading it!

Thijs Scheffers

Amsterdam, 11 March 2020

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List of Abbreviations

Abbreviation	Explanation
A/C	Aircraft
AAA	Amsterdam Advanced Air traffic control system
AAS	Amsterdam Airport Schiphol
ABI	Advanced Boundary Information
ACARS	Aircraft Communications and Reporting System
A-CDM	(Airport) Collaborative Decision Making
ACT	Activation
ADEP	Departure airport
ADES	Destination airport
AIBT	Actual In-Block time
ALDT	Actual Landing Time
AMAN	Arrival Manager
ANSP	Air Navigation Service Provider
APLN	Approach planner
ASAP	Advanced Schiphol Arrival Planner
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
ATS	Air Traffic Services
CFMU	Central Flight Management Unit
CISS	Central Information System Schiphol
EIBT	Estimated In-Block Time
ELDT	Estimated Landing Time
ETFMS	Enhanced Tactical Flow Management System
ETO	Estimate Time Over
FDPS	Flight Data processing System
FIR	Flight Information Region
FUM	Flight Update Messages
IAF	Initial Approach Fix
IATA	International Air Transport Association
IBP	Inbound Planning
IFR	Instrument Flight Rules
KDC	Knowledge and Development Centre
KLM	Royal Dutch Airlines
LoA	Letter of Agreement
LVNL	Luchtverkeersleiding Nederland
MUAC	Maastricht Upper Area Control Centre
NMOC	Network Manager Operations Centre
RDPS	Radar Data Processing System
RWY	Runway
SSR	Secondary Surveillance Radar
STAR	Standard Arrival Route
TWR	Tower

Summary

The focus of this thesis is to improve the outbound planning process of Schiphol Airport. The stability of the outbound planning process depends on the quality of the planning information that is available, i.e. the estimations of the ready-time of departing aircraft. These estimations are affected by many factors in the so-called turn-around process, but are also affected by the arrival time of the aircraft at the airport. Large delays in the arrival time cannot be compensated for by the turn-around process and therefore affect the ready-time of the aircraft.

To improve the outbound planning process of Schiphol Airport, the frequency, availability and accuracy of Estimated Landing Time (ELDT) data has been investigated. Special attention is placed on the information sharing and the calculation of the ELDT, that is calculated by Amsterdam Advanced Air traffic control system (AAA). In addition, the search for new and accurate data sources to estimate the landing time is a continuous effort. As of November, 2018, a new arrival management (AMAN) system is in use at LVNL, called Advanced Schiphol Arrival Planner (ASAP), which replaces the old arrival system, called Inbound Planning (IBP). The new AMAN has implemented different internal characteristics and processes, such as a new trajectory predictor and planning algorithm. Therefore, the new AMAN could potentially provide more accurate arrival time predictions, and is therefore of interest for this study. the following main research question has been formulated for this study:

“Which system calculates the most accurate landing time to improve the outbound planning process of mainport Schiphol, the Amsterdam Advanced Air traffic control system (AAA) or the arrival manager called ASAP?”

To answer the main question, the first step of this research included a desk research on the sources of information, which are used as input to calculate the different landing times in the time span of the reception of the ABI-message until the frozen planning time of ASAP. After the ELDTs were identified, further research on the sources of information and systems has been performed. This resulted in a cross-functional flow chart, which presents all generated landing times and the flows through the systems. The complete flow chart is shown in appendix VI.

Thus, to improve the outbound planning process, evaluation of the ELDT sources both in AAA and ASAP have been performed. Five available sources of ELDT information are analyzed with respect to frequency, availability and accuracy. These five sources are the FUM, ABI-, and ACT-message, radar data and the frozen ASAP planning time.

The second step of the main question is answered by means of a quantitative analysis. There have been 273,008 flights analyzed. The analysis has been divided into four main parts, the first one aims to provide a frequency analysis on four inbound sources of information: ABI, ACT, radar and FUM. The frequency of reception for the ABI-message is about 73%. Since the ACT-message is a mandatory message, the frequency of reception for the analyzed flights is 100%. Furthermore, radar correlation always occurs when the aircraft is in radar range, therefore, the frequency of reception for the analyzed flight is also 100%. Finally, the first FUM is received with almost 100%, for the second FUM, this has been decreased to 92%. Finally, for the third FUM, the frequency of reception is 73%.

The second part of the quantitative analysis provides an analysis on the time window of the arrival of the same four inbound sources of information. The coordination point, that is used to determine the time window, is the Initial Approach Fix (IAF). The FUM is the earliest available source of information to estimate the landing time. The next source of information is the ABI-message; following with the ACT-message. Finally, radar correlation occurs.

The next part of the analysis aims to provide an analysis on the quality of the generated landing times of the five inbound sources of information. For the AAA system, these sources are: ABI, ACT, radar and FUM; for the ASAP system, these are: ABI, ACT and the frozen ASAP planning time. It was found that the radar correlation is most interesting as ELDT source for the outbound planning process. The availability of this source is 100% and the accuracy of the arrival time estimate is 1 minute and 18 seconds. Finally, the last part of the analysis provides a comparative analysis between the ELDTs generated by the AAA system and the ELDTs generated by the ASAP system. It was found that the differences between ELDTs from AAA and ASAP have a maximum of 30 seconds, therefore, it can be concluded that the quality of the estimation of the landing from both systems is almost equal.

Resulting from this research, several recommendations are done. The first recommendation is to conduct further analysis on the outliers of the analyzes. These outliers are interesting, because the outliers determine whether there is a possibility for delay in the outbound planning process. Therefore, it is interesting to know what the characteristics are of these outliers, so these can be filtered out. This would improve the performance of the ELDT data source. There is another potential data source that has not been considered: ACARS. ACARS is a digital form of radio communication between aircraft and ground stations. ACARS could be interesting to analysis, because it is another source of information that could be used to determine the ELDT. Therefore, it might be interesting to analysis on ACARS data as well.

1 Introduction

The Knowledge and Development Centre (KDC) is a sector-wide cooperation between the founders Royal Dutch Airlines (KLM), Air Traffic Control Netherlands (LVNL) and Amsterdam Airport Schiphol (AAS). The purpose of the KDC is to identify valuable and innovative solutions for the sustainable development of the Mainport Schiphol. The focus is on the theme capacity management, because of its relevance to the aviation industry in the Netherlands. By investigating the capacity at Schiphol sector-wide, the possibilities of the current system of the airport and its surroundings can be utilized optimally (Knowledge & Development Centre, 2019).

The focus of this thesis is to improve the outbound planning process of Schiphol Airport. The stability of the outbound planning process depends on the quality of the planning information that is available, i.e. the estimations of the ready-time of departing aircraft. These estimations are affected by many factors in the so-called turn-around process, but are also affected by the arrival time of the aircraft at the airport. Large delays in the arrival time cannot be compensated for by the turn-around process and therefore affect the ready-time of the aircraft. This work aims to provide a comprehensive approach on the inbound phase of the flights arriving at Amsterdam Airport Schiphol, using the Airport - Collaborative Decision Making (A-CDM) approach. Special attention is placed on the information sharing and the calculation of the Estimated Landing Time (ELDT), that is predicted by the Amsterdam Advanced Air traffic control system (AAA) and the Arrival Manager (AMAN) at Schiphol, called Advanced Schiphol Arrival Planner (ASAP).

The A-CDM program at Schiphol is an initiative between the airport, LVNL, airlines and ground handlers. The main objective of the program is to facilitate a platform for sharing operational processes and data, to allow better informed decision making. Improvements in stand and gate management, resource management and slot adherence has shown in other major European airports, due to the implementation of the CDM program. This leading to reduced costs for all parties and improved accuracy of passenger information. The program is supported by Eurocontrol and the activities, where possible, will be carried out using a step-by-step process of the Eurocontrol Airport CDM concept elements, documented in the Eurocontrol Airport CDM Implementation Manual (Eurocontrol Airport CDM Team, 2017).

The aim of the A-CDM program is to optimize the turnaround process, in order to ensure the best possible coordination of resources. The A-CDM stakeholders require accurate and on-time information, so that the turnaround process of a flight is as efficient as possible and will be based on accurate decision making. The applicable systems will also alert the partners to potential delays and discrepancies and the partners will be prompted to take corrective action to ensure a correct flow of data and information (Schiphol Group, 2019).

One of the A-CDM concept elements stated by Eurocontrol is the Milestone Approach. The main objective of the Milestone Approach is to further improve the common situational awareness of all stakeholders when the flight is inbound, outbound and in the turnaround flight phases. In addition, the aim is to predict the forthcoming events for each flight with off-blocks and take off as the most critical events (Eurocontrol Airport CDM Team, 2017).

As can be seen from Figure 1, the milestone approach has been divided into three phases: inbound, turnaround and outbound. Due to the purpose of this project, the phase that will be focused on is the inbound phase of the flight, and especially on the milestones 3 to 6, which is shown in the red rectangle in Figure 1. Therefore, these milestones will be shortly explained. (Eurocontrol Airport CDM Team, 2017).

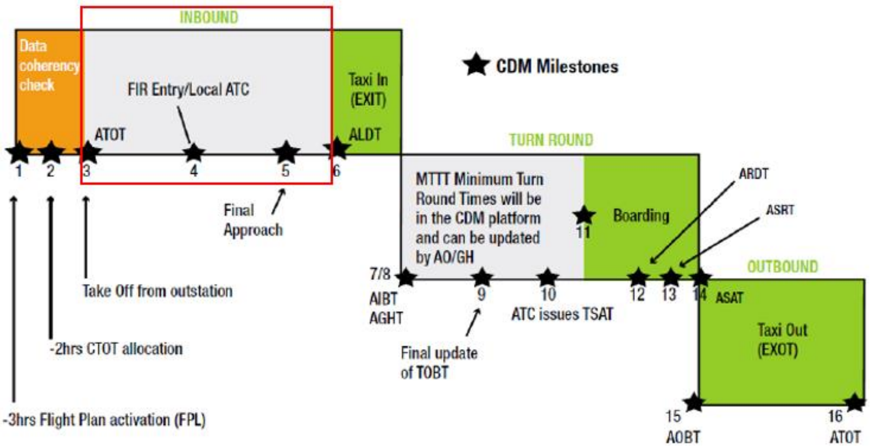

Figure 1 - A-CDM milestone approach by Eurocontrol

Milestone 3 is called Take Off from outstation. The outstation provides the Actual Take-Off Time (ATOT) to the Network Operator (NO) and the Aircraft Operator (AO), by means of a Flight Update Message (FUM). However, milestone 3 has not been implemented yet at Schiphol (Schiphol Group, 2019). Milestone 4 is called local radar update. At this milestone, the flight enters the Flight Information Region (FIR) or the local airspace of the destination airport (ADES). This information is normally available from the Area Control Centre (ACC) or the Approach Control Unit connected to an airport. The radar system can detect a flight based on the assigned SSR code when the flight exceeds a defined FIR/ATC boundary. At milestone 5, the flight enters the Final Approach phase at the ADES. Finally, milestone 6 is called Landed. The parameter for this milestone is the Actual Landing Time (ALDT). This is the time that an aircraft touches down on a runway (Eurocontrol Airport CDM Team, 2017).

There are several tools available to aid in the inbound phase for Air Traffic Control (ATC), such as printed flight-schedules, electronic aids and flight-progress strips on board. The best electronic tool is the one that not only helps in sequencing and optimizing the flow of arriving aircraft, but also provides information to Air Traffic Controllers (ATCOs) on what is needed to create and maintain the best order of arrival. One of the electronic aids is an AMAN system (SIATM, 2019a).

The objective of an AMAN system is stated as follows by Eurocontrol: *"an Arrival Manager is to provide electronic assistance in the management of the flow of arriving and departing traffic, respectively, in a specific airspace, to particular points, such as runway thresholds or metering points" (EUROCONTROL, 2010)*.

There are many airports with different types of AMAN systems. When talking about AMAN systems, people are usually talking about the type of software that is designed to assist in the sequencing of traffic arrivals, but also provides all the times and other information required to implement efficient arrival management (EUROCONTROL, 2010). An AMAN system ensures that air traffic is sequenced in order to respect the separation standards between aircraft and to allow as many flights as possible, while at the same time guaranteeing the safe and secure use of the airspace (InnovATM, 2019). In addition, the AMAN system provides a runway usage plan, that is set up by the tower controllers, and can be used as input for runway planning and take-off sequences, or as input for gate and stand planning by the airport (SIATM, 2019b).

The major benefits of an AMAN system are better matching of capacity and demand, improved efficiency and throughput, the reduction of controller workload, improvements to operational safety, efficiency and predictability and finally, the costs reduction (SIATM, 2019b).

The AMAN system interacts with several systems, including the host Flight Data processing System (FDPS) and Radar Data Processing System (RDPS). It uses a combination of flight-plan information, radar information, weather information, local airspace and route information, and an aircraft performance model in its trajectory prediction, resulting in a 'planned' time for any individual flight (EUROCONTROL, 2010).

To improve the outbound planning process of Schiphol Airport, the frequency, availability and accuracy of Estimated Landing Time (ELDT) data has been investigated. Special attention is placed on the information sharing and the calculation of the ELDT, that is calculated by Amsterdam Advanced Air traffic control system (AAA). In addition, the search for new and accurate data sources to estimate the landing time is a continuous effort. As of November, 2018, a new arrival management (AMAN) system is in use at LVNL, called Advanced Schiphol Arrival Planner (ASAP), which replaces the old arrival system, called Inbound Planning (IBP). The new AMAN has implemented different internal characteristics and processes, such as a new trajectory predictor and planning algorithm. Therefore, the new AMAN could potentially provide more accurate arrival time predictions. Both systems are compared to identify their performance. First, the sources of information are needed to be identified; this is done by means of desk research and process mapping. Then, the analysis on the input sources is performed on a data set of one year, divided into two seasons (winter and summer). The inbound sources of information are analyzed based on their frequency of reception, the time window of the arrival of the input information and the quality of the generated landing times. Also, a comparison on the quality between the AAA landing times and the ASAP landing times has been conducted. However, a more in-depth explanation is given in Chapter 2. As a result of the complete analysis, the source of information with the best quality landing time can be identified. In addition, the system that generates the most accurate landing time is determined.

1.1 Problem statement

To improve the outbound planning process of Schiphol Airport, the frequency, availability and accuracy of Estimated Landing Time (ELDT) data has been investigated. Special attention is placed on the information sharing and the calculation of the ELDT, that is calculated by Amsterdam Advanced Air traffic control system (AAA). In addition, the search for new and accurate data sources to estimate the landing time is a continuous effort. As of November, 2018, a new arrival management (AMAN) system is in use at LVNL, called Advanced Schiphol Arrival Planner (ASAP), which replaces the old arrival system, called Inbound Planning (IBP). The new AMAN has implemented different internal characteristics and processes, such as a new trajectory predictor and planning algorithm. Therefore, the new AMAN could potentially provide more accurate arrival time predictions. Both systems are compared to identify their performance.

1.2 Research Questions

Main-research question

The following main research question will be answered during this research:

"Which system calculates the most accurate landing time to improve the outbound planning process of mainport Schiphol, the Amsterdam Advanced Air traffic control system (AAA) or the arrival manager called ASAP?"

Sub-research questions

To be able to answer the main research question, sub-questions has been formulated. These sub-questions are derived from the main research question and problem definition. The following sub-questions were formulated:

1. How does the current CDM arrival process on Amsterdam Airport Schiphol work?
    a. Which are the different sources of information that triggers a new calculation of the landing time?
    b. What are the current flows of the calculated landing times through the systems?
    c. Who are the most important stakeholders in the CDM arrival process, and what are their objectives?

2. How frequent does the sources of information arrive and what is the time window of the arrival of these sources?

3. Which source of information provides the most accurate landing times on AAA?

4. Which source of information provides the most accurate landing times on ASAP?

1.3 Research scope

This research will focus on the time span between the sending of the ABI-message, by an adjacent center, and the frozen planning time of ASAP. So, the sub-questions about how the current CDM arrival process work on Schiphol and the data analysis will be between this period. In addition, aircraft that depart from inside the Dutch airspace are not being analyzed, due to the fact they do not receive an ABI- and ACT-message.

There are more systems in the time span of my project, such as the CDM platform of Schiphol, called the Central Information System Schiphol (CISS) and the tower (TWR) system. However, for the data analysis, the only systems which are analyzed, are the systems that are calculating landing times during the time span of this research.

The timeframe, in which the data analysis will be performed on, is from October 1st, 2018 to October 31st, 2019. ACARS data is not included in this research, because it is not a source used by the LVNL. In addition, only normal procedures are considered, i.e. no holding patters and bad weather conditions. Only the first three FUMs of each flight are analyzed as they trigger estimations of landing times, which are still used in the scope of this project.

1.4 Assumptions & limitations

The first assumption is the possibility to state a proper conclusion with the period of the acquired data. The received data is limited, due to the size of the data and because the ASAP system is still a new system. Another assumption is that the systems of the LVNL are operating correctly; so, no errors in the software of the systems.

A limitation is the fact that the analysis is only based on descriptive statistics. If the question was if the generated ELDTs has a significant difference to each other, hypotheses testing and a significance test would be interesting. However, to form a proper conclusion on what source and system calculates the most accurate landing time, descriptive statistics is enough.

1.5 Research relevance/significance

It is important that the conducted research is relevant and significant for its stakeholders. Because this research is initiated by the members of the KDC, three different wishes, objectives and the way of thinking of the companies have to be combined into one research. Therefore, the insights of this research for the stakeholders are:

- The different sources of information, which triggers new calculations of the landing times.
- The flows of the calculated landing times through the systems.
- How frequent the input sources arrive.
- The time window of the arrival of the sources of information.
- The most accurate landing time.
- The most accurate system of LVNL to calculate the landing time.

1.6 Thesis structure

This section describes the structure of the report. The report starts with the chapter about the methodology (chapter 2). The approach on how to solve the sub-questions and, therefore, the main-research question is elaborated. In the following chapter, the background of the problem is described (chapter 3). To understand the problem, it is essential to know which systems are used to calculate the different ELDTs. In addition, the input of these calculation needs to be clear in order to conduct a proper data analysis. This chapter also explains how the CDM arrival process work at Schiphol. Finally, to know which stakeholders are using the different ELDTs, a stakeholder analysis has been performed. The succeeding chapter consist of the data analysis (chapter 4). The results of the executed analysis will be thoroughly explained step-by-step. The next chapter contains the research findings (chapter 5). The results of the data analysis will be explained here. The second last chapter consist of the discussion and conclusions (chapter 6). The discussion describes how the researcher could have approached the problem in a better way afterwards. The conclusion explains the answer to the research questions. This is based on the results of the research, described in chapter 5. Finally, the recommendations are presented in the last chapter (chapter 7). Suggestions for possible follow-up researchers are presented.

2 Methodology

The methodology will provide guidance in answering the main and sub questions. If the methodology is carefully explained, someone can perform the same research, using the same methodology and will roughly achieve the same results. In this way you can guarantee the validity and reliability of the research (University of Southern California, 2020). It also explains which methods are used and why they are used. The methodology has been subdivided in 4 phases. A schematic format is shown in Figure 2.

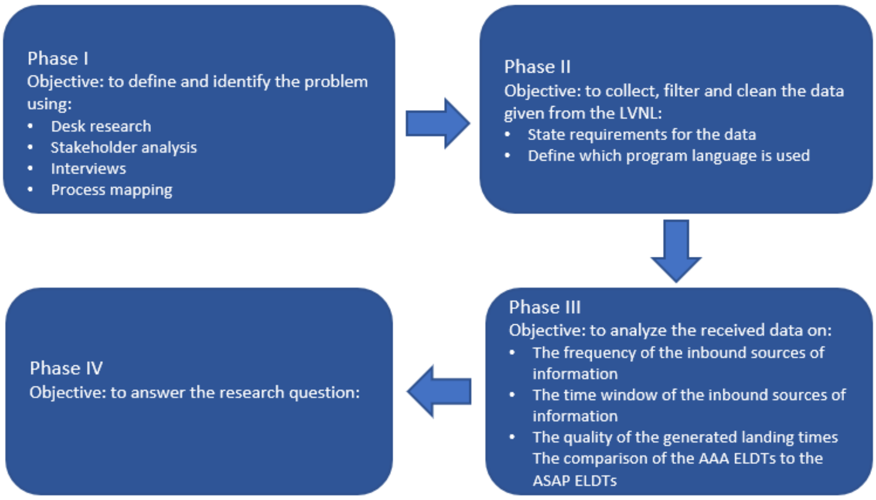

Figure 2 - Methodology project

2.1 Phase I

The first phase is to understand the CDM arrival process and determine the different input sources for the calculation of the landing time. A schematic overview about the steps taken in phase I are shown in Figure 3. Phase I starts with a thorough desk research. The first step of the desk research is a literature review about the CDM process; general information about this process and how to implement it can be found in manuals online. Since Eurocontrol is one of the founders of the European CDM, they provide an online implementation manual for airports (Eurocontrol Airport CDM Team, 2017). IATA, also one of the founders of the European CDM, provides a document for their recommendation regarding CDM as well (IATA, 2018). Although the CDM concept includes a wide variety of different standards and constraints, the implementation of CDM is always a local process. Therefore, Schiphol provides their own CDM Operations manual (Schiphol Group, 2019).

The second step is the stakeholder analysis. The stakeholder analysis is being performed to determine the most important stakeholders. First the overall companies, who are the stakeholders of the CDM arrival process, are identified. These stakeholders are identified by means of desk research, for example on the CDM manuals (Schiphol Group, 2019)(Eurocontrol Airport CDM Team, 2017)(AACG, 2018). They are prioritized by their power and interest in the CDM arrival process. The individual stakeholders are based on several aspects, such as which department they are, what their main duties are related to the CDM arrival process and what the timing is of those activities.

Not all parts of the CDM arrival process is written in the manuals, therefore a lot of valuable information can be retrieved from conducting interviews. To find out which organizations and persons should be interviewed, the stakeholder analysis is done. This has been explained in the previous step. After the main stakeholders are identified, interviews can be conducted with these stakeholders.

Another tool that is used to understand the CDM arrival process, is process mapping. A process map is a planning and management tool that visually describes the flow of work (White & Cicmil, 2016). To keep track of which person, department or system is responsible for each step, the process map that is used for this project is the cross-functional flowchart. It shows the relationship between the processes and the functional units responsible for that process (International Six Sigma Institute, 2020). The cross-functional flow chart is the outcome of the first phase; all the info is gathered and combined in this chart. The documentation of the processes is limited, therefore, the information inside the flowchart is mainly obtained by conducting small meetings with the stakeholders. This flow chart displays the flow of the input sources and shows which ELDTs are generated by which source and system. The complete cross-functional flowchart is shown in Appendix VI. In addition, the objectives per process are explained also in Appendix VI.

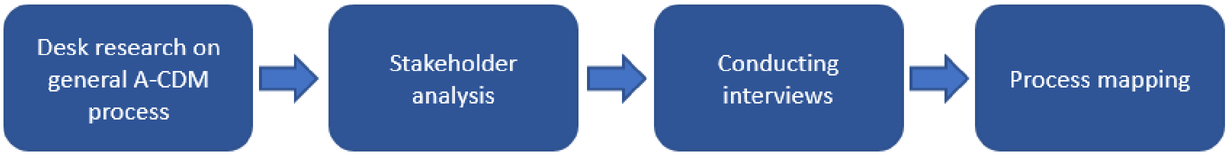

Figure 3 - Methodology phase I

2.2 Phase II

The source of the data for the quantitative analysis is the LVNL and it will be provided by the S&I department. Furthermore, before analyzing the data a programming language will be chosen. This decision depends on if the whole data is used, or just a sample of the data. There are a set of suitable programming languages possible to use for the data analysis, such as Excel, Java, Python, C++ or R. However, due its strong features for data analysis and a specific module, called Python Data Analysis Library (Pandas), the programming language that will be used is Python. Pandas creates a Python object with rows and columns, called data frames, which is very similar to a table in a statistical program (e.g. Excel or SPSS)(Bronshtein, 2017). In addition, there are a few advantages why Python is ideal for data analysis. To begin with, Python is a flexible programming language; it is a useful language if the data analysist wants to try something new and creative. Also, it is easier for beginners to learn, in comparison to, for example, Java (Putano, 2018). This is due Python's focus on simplicity and readability. Python offers programmers the advantage of using fewer lines of code to perform tasks than is necessary when using older languages. Just like Java, Python is an open source programming language; it is free, and it uses a community-based model for development. Lastly, this programming language is well supported. Python has a large support base and is widely used in academic and industrial circles, which means that there are many useful analytical libraries available, such as Pandas (Terra, 2019).

2.3 Phase III

The quantitative analysis of phase III has been divided into several parts. A schematic representation of the complete analysis is shown in Figure 4. The first part of the analysis is on the frequency of the reception of the arriving input information of the flights, such as OLDI-messages, FUMs and radar information. It could be interesting to include an analysis on the influence of flight characteristics, like arriving sector, airline (aircraft identification), A/C type, wake turbulence coefficient (WTC), IAF point or STAR. The second part of the analysis is about the time window of the arrival of the input information. This means the time interval at which the different sources of information arrive. The IAF is the coordination point that is used for this analysis. In addition, an analysis without the outliers of the data sets is conducted; an explanation on how these outliers are identified, is given in the next paragraph. The third part of the analysis is on the quality of the generated landing times, by subtracting the ELDT from the ALDT. This also includes an analysis without the outliers. The final part of the analysis is about the comparison between the AAA ELDTs and the ASAP ELDTs.

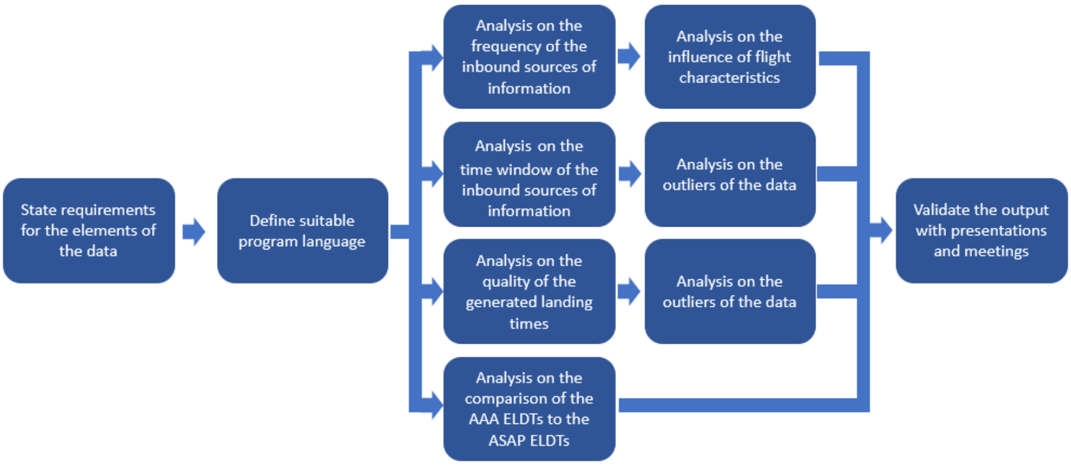

Figure 4 - Methodology phase III

To give an understanding of the features of the data sets, descriptive statistics is used to help describe the output. It gives simple summaries of the samples and measures the data. Descriptive statistics is used to repurpose quantitative insights across large data sets (Kenton, 2019). There are two general types of statistics that are used to describe data:

- Measures of central tendency: these are ways to describe the central position of a frequency distribution for a group of data. The central position is described by several statistics, like mode, median and mean.
- Measures of spread: these are ways to summarize a group of data by describing how scattered the scores are. To describe this spread, a number of statistics is used, including the range, quartiles, absolute deviation, variance, and standard deviation (Leard statistics, 2018).

The standard deviation, also represented as sigma (σ), is the measurement of the average distance between each quantity and the mean. In other words, how spread the data is from the mean. A low standard deviation indicates that the data points are close to the average of the dataset, while a high standard deviation indicates that the data points are spread over a wider range of values (Narkhede, 2018). As can be seen from Figure 5, values that are within one standard deviation of the mean, represent 68.2% of the data. Two standard deviation represent 95.4% of the data. Finally, three standard deviation represent 99.6% of the data. Values that lie outside three standard deviation are considered outliers (Narkhede, 2018).

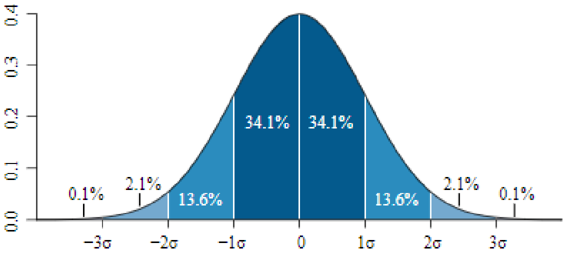

Figure 5 - Basic overview standard deviation

The median is the middle value in a sorted list of numbers. To determine the median value in a set of numbers, the numbers must first be sorted, or ranked, in value order from lowest to highest or highest to lowest. The median can be used to determine an estimated mean or average, but should not be confused with the actual mean (Akhilesh, 2019).

The Interquartile range (IQR) is a measure of variability, based on dividing a data set into quartiles. Quartiles divide a rank-ordered data set into four equal parts. The values that divide each part are called the first, second and third quartile. They are indicated by Q1, Q2 and Q3 respectively. The interquartile range is equal to Q3 minus Q1 and shows how the data is distributed across the median (Stat Trek, 2020). A schematic view of the interquartile range is shown in Figure 6.

The interquartile range rule is useful for detecting the presence of outliers. Outliers are individual values that are outside the general pattern of the rest of the data. The interquartile range rule is a helpful rule to consider whether a data point is really an outlier or not. In order to detect the outliers in a data set, the following steps have to be taken (Taylor, 2018):

1. Calculate the IQR for the data set
2. Multiply the IQR by the number 1.5.
3. Add 1.5 x (IQR) to the third quartile. Any number greater than this is considered an outlier.
4. Subtract 1.5 x IQR from the first quartile. Any number less than this is considered an outlier.

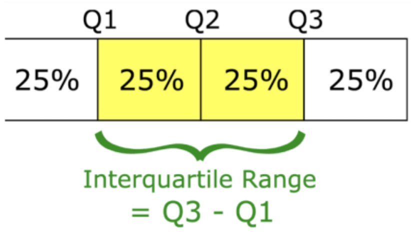

Figure 6 - Interquartile Range

When the complete analysis is done, it is necessary to ensure the quality of the outcome. The quality of the data is determined by the validity and the reliability. Therefore, several presentations and interviews will be held to check the validity and the reliability of the outcome of the analysis. Validity is the extent to which you measure what your intent to measure. This term could also be interpreted as trustworthiness or credibility. Reliability is the extent to which a measurement is dependent of chance. A reliable measurement does not mean that it is automatically valid. If a measurement is unreliable, it can never be valid. Reliability is therefore a requirement, but not a guarantee of validity (Key Differences, 2017). In addition, the results will be presented and validated in the CDM business meetings.

3 Background

This chapter will provide a more in-depth explanation of the systems used by the LVNL to determine the ELDTs and distribute them to the CDM platform. In addition, the CDM arrival process is elaborated and a step-by-step description of the cross-functional flow chart is given. Finally, the stakeholder analysis is explained.

3.1 Description of the systems

3.1.1 AAA

Air traffic control across The Netherlands takes place using the AAA system. The main objective of the AAA system is to enable LVNL air traffic controllers to handle air traffic as efficiently and safely as possible. With the aid of this system, air traffic control at LVNL is carried out in most parts of the Netherlands and air traffic from and to main port Schiphol are completely separated and regulated (LVNL, 2018). The AAA system consist of equipment that performs various air traffic control functions in the specific geographical area within the Netherlands assigned to LVNL. This must consider the regulations and guidelines of national, European and coordinating international aviation organizations, such as restricted and military areas and longitude and latitudinal separation rules. The AAA system (software and hardware) was specifically developed in the 1990s and was eventually put into service in 1998. According to the specifications and user requirements of LVNL, AAA has since been further developed internally at LVNL (LVNL, 2018).

AAA provides the air traffic controllers with information about expected and actual flights within the Dutch airspace and it monitors flight progress. For this purpose, AAA has a database in which all flight plans for the next five hours, originating from the Central Flight Management Unit (CFMU) in Brussels, are stored (LVNL, 2018).

In addition, the AAA system cooperates intensively with other air traffic control systems, such as the Tower system (often being referred to as the TWR or TWR system) and the ASAP system. For the exchange of data between the two systems and AAA, there is a special data link, the TWR-AAA LINK for TWR and T-ASAP and F-ASAP LINK for ASAP. These links keep the databases of both systems consistent: every relevant change in the databases is reported to the other system (LVNL, 2018).

3.1.2 ASAP

ASAP is the planning system for all Instrument Flight Rules (IFR) inbound flights to Schiphol. The goal of this system is to (Grutter, 2018):

- Create stable inbound traffic flows in the Schiphol TMA.
- Use the available runway capacity most optimally
- Generate realistic and stable ELDTs

Before ASAP was introduced, the inbound planning function was a part of the AAA system. However, ASAP has been developed as a separate module, which can be combined with both the current AAA system and the future system that will replace AAA, called iCAS. It is designed as a separate module, because ASAP's implementation was necessary on a short term. For example, ASAP should support the precise delivery of traffic on the TMA, which in turn is required as a 4-stack airspace design facilitator. (KDC mainport, 2013) (Grutter, 2018).

One of the benefits for the air traffic controllers is that they can plan further in advance and can work more efficiently. ASAP makes it possible to select the correct airspeed earlier in the flight, so that aircraft can be added to the chain of landing aircraft without having to make a detour or be put in holding. The smaller the adjustment to the airspeed or route, the greater the savings on fuel consumption (KDC mainport, 2015).

According to the meeting with the CDM experts on the 24th of September (CDM experts. (2019, September 24). Expert interview), ASAP has a new trajectory predictor, using different input information than its predecessor AMAN system, IBP. Also, ASAP has a new planning algorithm. This is a new and improved algorithm that calculates the time the aircraft is expected to be on the runway. The algorithm considers the different aircraft types, the wind and the typical flight behavior during the final approach. In addition, according to the CDM experts, ASAP can determine the best landing sequence based on a reliable estimate of the landing times. This CDM expert meeting is elaborated and shown in Appendix I.

All aircraft coming to Schiphol are allocated a time calculated by ASAP for one of the three holding areas above the Netherlands. It is important that the ACC controllers' hand over the aircraft to the approach controllers as accurately as possible at the given time, regardless of whether they must circle in the holding area or whether they can continue flying without delay. This prevents too many aircraft from being reported at the same time at the Approach and it becomes too busy in the TMA of Schiphol (KDC mainport, 2015).

3.1.3 Tower (TWR)

The purpose of TWR system is that it provides track data, weather data and plan data to the TWR controllers and assistants.

The track data comes from various radar sources. Tower controllers can monitor ground traffic at Schiphol and flying traffic up to a maximum of 60Nm around Schiphol and approximately 85 NM around Rotterdam. Schiphol ground traffic consists of taxiing and towed aircraft and vehicles and comes from the following radar sources: ASTRA, MLT, SMR1 and SMR3. For flying traffic one of the following radar sources is used: ARTAS-APP, TAR1, TARW. The weather data comes from the KNMI (Grove & van Heurn, 2019).

The plan data is formed by the flight plans, the towing plans and the vehicle plans. The flight plans come from AAA and the tow plans and vehicle plans are supplied by AAS. Towing and vehicle plans are only in the TWR system and not in AAA. These plans are continuously updated by the TWR system and presented on screens and EFSS. On TWR-E and TWR-ICE the flight plans are still printed on paper strips, because no EFSS is available there. Furthermore, the system sends plan data to internal and external customers. These are KLM, AAS, FANOMOS and VEMMIS (Grove & van Heurn, 2019).

The airborne part of the inbound flights is supported by AAA. In the last part, when the flight is at the final approach in front of the runway, the TWR system also calculates its own landing time (Grove & van Heurn, 2019).

Within the CDM framework, calculation of the TWR system are also performed. The airborne part of the inbound flight is supported by AAA; however, when the flight is at final approach, the TWR takes care of the calculation of the landing time (ELDT). This is done based on track data linked to the flight plan. After the aircraft has landed, the ALDT is determined and shortly after the red line at the gate has passed, the flight is removed from the TWR and AAA system (Grove & van Heurn, 2019).

3.1.4 CISS

Since 2004, the CISS has been operative by Schiphol. CISS provides relevant information for each flight, such as arrival or departure time, ADEP or ADES, the check-in desk, the gate and the assigned baggage belt. It also ensures the link between the flight plans of LVNL and the flights at Schiphol (Luchtvaartniews.nl, 2004).

According to the airport, the planning of numerous operational processes at the airport depends on the information from CISS, such as gate planning, taxi-time, financial handling of the flights and planning of the resources. In addition, CISS sends the current arrival and departure times directly to, among others, NOS and RTL Teletekst, the 2500 public monitors in the terminal and www.schiphol.nl. Most of the data processing is fully automated (Luchtvaartniews.nl, 2004).

Airlines, air traffic control, customs, handling agents, cleaning companies and other stakeholders all have their own interface with the CISS. Many of Schiphol's internal systems also have direct interfaces, such as for the allocation of baggage belts and aircraft parking spaces and the administration of airport charges (Luchtvaartniews.nl, 2004).

3.2 Description of the sources of information

As mentioned in the first chapter, one of the sources of information are the ABI-messages and the ACT-message. However, these messages fall into another type of messages, called On-Line Data Interchange (OLDI) messages. Therefore, first the general concept of the OLDI-messages is explained, and then the other input sources are explained as well, including the ABI-message and ACT-message, FUM, radar and the frozen planning time of ASAP.

3.2.1 OLDI-messages

OLDI is a protocol for coordination and transfer of actual flight data between adjacent air traffic control units. The development of these OLDI-messages started in the 1990s in Europe. The main objective of OLDI-messages for ATC purposes are (Eurocontrol, 2017):

- to automate the co-ordination and exchange of flight data between ATC units.
- to ensure the timely delivery of standard messages.

In order to facilitate implementation, the agencies concerned have developed and adopted common rules and message formats. OLDI is one of the main factors enabling the Single European Sky (SES). As required by Regulation 1032/2006, it must be operational from 2009 for all ATC units providing services to general air traffic, and the reliability of each OLDI connection must be at least 99,86% (Eurocontrol, 2017).

There are several benefits concerning OLDI-messages. First, automation of routine actions (information exchange) allowing the controllers to focus on more complex tasks (e.g. conflict detection and resolution). Furthermore, there is a reduced workload for the controller due the reduced need for oral coordination. Next, there is a better situational awareness. Finally, OLDI-messages have indirect improvement of air traffic services (ATS) system safety features (Eurocontrol, 2017).

OLDI-messages can be categorized into three categories. Category 1 is transfer of communication, category 2 is coordination and category 3 is notification. Transaction time limits are defined for each category of messages. The transaction times comprise the transmission, initial processing in the receiving unit, creation of the confirmation message and its transmission and receipt in the transferring unit (Eurocontrol, 2017).

The OLDI-messages referred to in this project are notification messages, so category 3. These most important messages for this project are ABI-messages and ACT-messages. These will be thoroughly described in the next paragraph. However, the objectives of the other messages will be explained shortly beneath (Eurocontrol, 2017):

- ABI - notifies the next ATC unit of the flight and facilitates early correlation of radar tracks.
- ACT - replaces the oral estimate.
- REV (revision message) - replaces the verbal revision if the accepting unit does not change as a result of the amendment.
- PAC (preliminary activate message) - informs the next ATC unit of a flight not yet departed in situations where the flight time from departure to the limit is less than the requirement for an ACT message.
- MAC (message for retraction of coordination) - indicates that a previous coordination or notification is being retracted.
- LAM (logical acknowledgement message) - informs the FDPS of the sending ATC unit of the receipt of an OLDI message.

ABI is an acronym for Advanced Boundary Information. The purpose of an ABI-message is that it satisfies the following operational requirements; to begin with, it provides acquisition of missing flight plan data. It provides advanced boundary information and revisions for the next ATC unit. Also, it updates the basic flight plan data and it enables early correlation of radar tracks. Furthermore, the ABI-message facilitate accurate short-term sector load assessment. Finally, it requests the assignment of a SSR code from the unit to which the above notification is sent (Eurocontrol, 2017).

The ABI message contains the following data (Eurocontrol, 2017):

- Message Type.
- Message Number.
- Aircraft Identification.
- SSR Mode and Code (if available).
- Departure Aerodrome.
- Estimated Time Over at the COP
- Destination Aerodrome.
- Number and Type of Aircraft.
- Type of Flight.
- Equipment Capability and Status.

If bilaterally agreed, the ABI message shall contain one of the following data elements (Eurocontrol, 2017):

- Route.
- Other Flight Plan Data

There are several rules of application regarding the ABI-message. First, the use of the code request shall be agreed bilaterally. When bilaterally agreed, the ABI-message shall precede the ACT-message. Furthermore, the generation of the ABI message shall be prevented if a PAC (Preliminary Activation) message is to be sent. Also, ABI transmission shall be blocked if the ACT-message is to be sent immediately or within a bilaterally agreed time interval. The next rule is that a revised ABI message shall be sent if the next ACT-message has not been generated and any of the following changes or is being modified (Eurocontrol, 2017):

- COP.
- expected SSR code at the transfer of control point.
- aerodrome of destination.
- type of aircraft.
- equipment capability and status

Also, if there is a change of COP, a revised ABI-message may contain the estimate data and the route field. Finally, a revised ABI message shall be sent if the next ACT message has not been generated and one of the following items is subject to change (Eurocontrol, 2017):

- the estimated boundary crossing point.
- the estimated time over (ETO) at the COP differs from that in the previous ABI-message by more than the time specified in the Letter of Agreement (LoA).
- any other data as bilaterally agreed.

The purpose of the ACT-message that it satisfies the following operational requirements; it replaces the verbal boundary estimate by the automatic transmission of data of a flight from one ATC unit to the next ATC unit prior to the transfer of control of the aircraft. The ACT-messages updates the basic flight plan data in the receiving ATS unit with the most recent information as well. Furthermore, it facilitates the distribution and display of flight plan data within the receiving ATC unit to the affected workstations. Also, the ACT-message enables display of correlation in the receiving ATS unit and, finally, it provides transfer conditions to the receiving ATS unit (Eurocontrol, 2017).

The ACT message contains the following data (Eurocontrol, 2017):

- Message Type.
- Message Number.
- Aircraft Identification.
- SSR Mode and Code
- Departure Aerodrome.
- Estimated Time Over at the COP
- Destination Aerodrome.
- Number and Type of Aircraft.
- Type of Flight.
- Equipment Capability and Status.

If bilaterally agreed, the ACT message shall contain any of the following items of data (Eurocontrol, 2017):

- Route.
- Other flight plan data.
- Actual Take-Off Time.

The same as for the ABI-message, there are several rules of application regarding the ACT-message. Firstly, one ACT message shall be sent for eligible flights crossing the FIR boundary. Next, the ACT message shall be generated and transmitted automatically at the calculated time as specified in the LoA, unless it is manually started at an earlier time. Furthermore, ATC personnel shall be provided with a means to initiate the transmission of ACT messages before the calculated time of transmission. Following, the operational content of the ACT message to be transmitted shall be made available prior to the actual transmission at the working position responsible for the co-ordination of the flight. In relation to the previous rule, the time at which it is calculated that the ACT-message is to be sent automatically shall be displayed together with its contents. The next rule is the ACT message shall contain the latest information on the flight, reflecting the expected exit conditions. Subsequent, the relevant workstation shall be informed of the transmission of the ACT message. Finally, acceptance by the receiving unit of the transfer conditions implied in the ACT message shall be assumed, unless the receiving unit initiates co-ordination to modify them (Eurocontrol, 2017).

3.2.2 FUM

The general objective of the FUM is to connect the destination airport to the ATM network, in order to better coordinate Air Traffic Flow and Capacity Management (ATFCM) with CDM airport operations. In addition, the FUM is to ensure that flight data at the destination airport is updated in a timely manner. The network manager receives the flight plan, including an estimation of the landing time, from the airlines. If there is, for example, over-capacity in the airspace, the network manager can issue a Calculated Take-Off Time (CTOT), i.e. a delay on the ground to avoid take-off. Therefore, in the case of a landing time which is different from the flight plan, LVNL will be informed about this by means of a FUM. This FUM could include a new landing time with a CTOT. In addition, the systems of the LVNL also calculates their own landing time based on the information from the FUM. The landing time that is used for the data analysis, is the landing time that has been determined by the systems of LVNL. FUM data is usually provided to the Airport Platform (CISS), from where they can be shared with all stakeholders at the destination airport to improve their planning (Eurocontrol, 2019).

The purpose of the FUM is to make Network Manager Operations Centre (NMOC) partners aware of the situation of a flight, regarding the ELDT, by means of a message which can be processed automatically. The FUM contains the following main items (Eurocontrol, 2019):

- ELDTs of a flight to a destination airport.
- estimated Time Over (ETO) of the last point en-route or the Initial Approach Fix (IAF) (STAR entry point).
- status of the flight in ETFMS.
- APTYPE field. It indicates that the airport of departure is a CDM airport, an advanced TWR airport or a standard airport.

There are numerous benefits regarding the FUM (Eurocontrol, 2019).

- The FUM provides a way to integrate the airports and the ATFCM process and thus supports the management of the network. They contribute to a common view of the network situation, thus facilitating the understanding and further decision making of the network.
- The FUM enables the airport to better know the traffic to its destination and to take it into account in its own processes.
- The FUM allows an optimal adjustment between the airport and the ATC capacity.
- Although intended for the exchange of messages between systems, the FUM is a short message that can be used directly by people and can also be easily integrated into systems.
- The FUM shall improve the short-term forecast of the traffic situation for the airport.
- The FUM allows airlines to better understand their respective fleet situation before the flight arrives.
- The FUM will support the management of the critical situation at airports and the impact on other stakeholders.

The FUM is an event driven message. The first FUM could be provided as soon as the flight is reported as airborne. This is particularly useful for long-haul flights (e.g. departing from Singapore) as it would allow the destination airports to be informed of the ELDT more quickly. In any case, a FUM shall be sent 3 hours before the ELDT of the flight. The FUM updates are also provided when the ELDT changes for more than 5 minutes or when the status of the flight changes. However, the first FUM may be provided later than 3 hours before the ELDT, if the flight plan is filed later (Eurocontrol, 2019).

3.2.3 Radar

Radar is an acronym for RAdio Detection And Ranging; it is an electronic system that measures the range and position of an object by emitting an electromagnetic pulse at the object and listening to its echo. Radar may be used for identification, traffic coordination and separation. There are many types of radar used in the aviation industry (Chris, 2019).

- Surveillance radars, area radars and approach radars allow air traffic controllers to track aircraft within their area of responsibility.
- Precision Approach Radars (PAR) enable air traffic controllers to provide precision guidance when landing aircraft under instrument condition, for example ILS.
- Surface Movement Radar enables air traffic controllers to track movements of aircraft and vehicles on the surface of an airport.
- Weather Radar provides pilots with situational awareness of dangerous weather conditions, particularly thunderstorms.
- Radio Altimeters accurately measure the height of an aircraft above the surface.
- Secondary Surveillance Radar (SSR) enables aircraft to return additional information, such as identification and flight level, to the interrogation radar.

AAA receives current radar data (primary and secondary tracks) and displays it on the various radar screens. The secondary SSR tracks show a label with SSR code and altitude information. AAA searches for the corresponding flight plan for each received SSR radar track. AAA can do this by comparing the SSR code, which is sent with the radar track, with the SSR codes listed in the flight plans. If a match is found, the relevant radar tracks is linked to that flight plan (correlation) and AAA tries to maintain this correlation during the rest of the flight. This enables the AAA system to monitor the flight and carry out time-related actions independently of each other, such as determining the Actual Time Over (ATO) and ELDT.

3.2.4 Frozen planning time of ASAP (slot time)

ASAP shall not commence its planning until an ABI, or an ACT-message is received. If the position of the flight is then Estimated Time Over (ETO) the IAF, 14 minutes, the planning shall be fixed and a frozen ELDT and slot time will be generated. When the planning is fixed, only the Approach Planner (APLN) can adjust this planning. These changes are communicated to the Area Control Center (ACC) via their radar display. So, the frozen planning of ASAP is the moment when ASAP freezes its planning. The time window between the frozen planning time and the IAF, is also being referred to as the freeze horizon.

3.3 A-CDM data sharing

One of the pillars and element of the A-CDM program is data sharing. Eurocontrol states that: *'The Information Sharing element defines the sharing of accurate and timely information between the Airport CDM Partners in order to achieve common situational awareness and to improve traffic event predictability (Eurocontrol Airport CDM Team, 2017).'*

The existing system of Schiphol, CISS, is the chosen platform for the realization of the Airport CDM system. The airport's CDM system collect all the available information for the flights during the inbound, turnaround and outbound flight phases. This only includes flights with Schiphol as destination airport (ADES) or departure airport (ADEP). The system uses a set of business rules describing the source priority to identify the 'best' time element available and to share this with all the interested stakeholders. If a new ELDT arrives into the system, CISS determines whether this new ELDT has a higher or equal priority as the previously known ELDT. If this is the case, CISS displays this new ELDT in the CDM platform, if not, this new ELDT is not shown in the CDM platform. The ELDT is the main element for this project, and therefore, the business rules for the ELDT are shown in appendix III (Eurocontrol Airport CDM Team, 2017).

CISS performs the following function regarding data sharing:

- Collect all relevant data from sector parties.
- Calculation of estimations of new events or determining that an event has occurred.
- Ensure that this new data is available to all stakeholders, so there is a common view.
- Correlate flight plan with flight in the Airport Operational Data Base (AODB).

Although all CDM flight information is facilitated in CISS, the sources of information may be the LVNL, ground handling systems or airline systems. In addition, a screenshot of the CDM platform, where all the data is shared, is shown in Figure 7.

Alert	Flight	Callsign	Fltst	SIBT	LDT	RWY	IBT	Stand	AcReg	Type	Handler	Alert	Flight	Callsign	Fltst	SOBT	EOBT	TOBT	AEGT	PBRY	ARDT	TSAT	ASRT	AOBT	CTOT	TOT	Stand	RWY
	EZY8873	EZY47AV	IBK	18-11:15	11:28A	27	11:32A	H01	GEZAF	319	Menzi		EZY8874	EZY72QB	SCH	18-11:50	11:50	12:01				12:01				12:16T	H01	36L
	EJU4563	EJU35ER	IBK	18-12:00	11:33A	27	11:37A	H02	OELQY	319	Menzi		EJU4564	EJU4564	SCH	18-12:30	12:30	12:30				12:34				12:47T	H02	24
	KL1188	KLM1188	IBK	18-11:45	11:30A	27	11:37A	A44	PHEXV	E90	KLM		KL1051	KLM1051	SCH	18-12:55	12:55	12:55				12:55				13:04T	A44	24
	KL0958	KLM20J	IBK	18-11:45	11:35A	27	11:40A	D12	PHBGP	73W	KLM		KL1509	KLM49M	SCH	18-13:25	13:25	13:25				13:31				13:39T	D12	24
	KL1754	KLM52G	IBK	18-12:00	11:37A	27	11:41A	A55	PHEZR	E90	KLM		KL1425	KLM1425	SCH	18-13:00	13:00	13:00				13:01				13:10T	A55	24
	KL1740	KLM22E	TAX	18-12:00	11:42A	27	11:48E	A72	PHEXR	E75	KLM																	
	EZY1831	EZY85EF	TAX	18-12:15	11:45A	27	11:50E	H05	GEZAI	319	Menzi		EZY1832	EZY71VZ	SCH	18-12:45	12:45	12:45				12:52				13:07T	H05	36L
	QY6724	BCS72E	TAX	18-11:05	11:39A	27	11:50E	S90	DAEAG	ABY	DHL		QY1239		SCH	19-12:00		12:00									S92	
	KL0988	KLM988	FNL	18-12:10	11:46E	27	11:52E	A54	PHEZW	E90	KLM		KL1365	KLM93N	SCH	18-14:15	14:15	14:15				14:16				14:30T	A54	24
	KL0792	KLM792	TMA	18-11:40	11:49E	27	11:53E	E09	PHBVN	77W	KLM																	
	PC1253	PGT62K	FNL	18-12:20	11:51E	27	11:56E	G02	TCDCB	320	Dnata		PC1254	PGT79A	SCH	18-13:25	13:25	13:25				13:25				13:38T	G02	24
	PY994	SLM994	TMA	18-12:20	11:59E	27	12:03E	G08	ECMUA	772	Aviap		PY993		SCH	18-15:15		15:15									G08	
	DL0410	DAL410	TMA	18-12:15	11:57E	27	12:04E	D03	N172DZ	76W	KLM		DL0051		SCH	18-14:30		14:30									D03	
	PS101	AUI101	FIR	18-12:05	11:59E	27	12:04E	D23	URPSQ	73H	Swiss		PS102	AUI5HE	SCH	18-13:10	13:10	13:10				13:15				13:23T	D23	24
	KL0706	KLM706	TMA	18-12:15	12:01E	27	12:05E	F04	PHBQM	772	KLM		KL0861	KLM861	SCH	18-14:35	14:35	14:35				14:42				14:56T	F04	36L
	TK1961	THY3AS	AIR	18-12:35	12:11E	27	12:16E	E04	TCJPN	320	Swiss		TK1962	THY9QJ	SCH	18-13:35	13:35	13:35				13:35				13:49T	E04	24
	UA909	UAL909	AIR	18-09:20	12:15E	27	12:20E	J86	N646UA	76W	Swiss		UA947	UAL947	SCH	18-12:00	13:50	13:50				13:50				14:04T	J86	24
	DL0162	DAL162	AIR	18-11:00	12:15E	27	12:21E	E02	N803NW	333	KLM		DL0139		SCH	18-15:20		15:20									E02	
	KL0622	KLM168	AIR	18-12:25	12:18E	27	12:23E	E20	PHBQB	772	KLM		KL0621		SCH	18-16:50		16:50									E20	
	HV5132	TRA132K	AIR	18-12:30	12:18E	27	12:24E	C12	PHHZE	73H	KLM		HV5665	TRA52T	SCH	18-14:10	14:10	14:10				14:11				14:25T	C12	36L
	KL1534	KLM66H	AIR	18-12:35	12:20E	27	12:26E	A53	PHEXU	E75	KLM		KL1725	KLM91L	SCH	18-13:30	13:30	13:30				13:33				13:42T	A53	24
	VK8319	FOO8319	AIR	18-12:30	12:21E	27	12:28E	B31	OELCN	321	Aviap																	
	KL1486	KLM1486	AIR	18-12:40	12:24E	27	12:30E	A43	PHEXK	E75	KLM																	
	KL1056	KLM1056	AIR	18-12:40	12:23E		12:31E	A35	PHEXO	E75	KLM																	
	KL1546	KLM1546	AIR	18-12:15	12:24E		12:32E	A46	PHEZE	E90	KLM																	
	DL0050	DAL50	AIR	18-12:40	12:25E		12:33E	E06	N178DZ	76W	KLM		DL0411		SCH	18-14:50		14:50									E06	
	OS379	AUA379	AIR	18-12:40	12:27E		12:35E	B15	OELWM	E95	Aviap		OS380	AUA3DL	SCH	18-14:00	14:00	14:00				14:02				14:16T	B15	24
	KL1060	KLM14N	AIR	18-12:35	12:28E		12:36E	B93	PHEXW	E75	KLM		KL1909	KLM1909	SCH	18-13:25	13:25	13:25				13:31				13:41T	B93	24
	KL1856	KLM1856	AIR	18-12:30	12:29E		12:37E	B16	PHEXB	E90	KLM		KL1781	KLM63J	SCH	18-13:05	13:05	13:05				13:09				13:17T	B16	24
	KL0656	KLM656	AIR	18-12:15	12:30E		12:38E	F08	PHBHD	789	KLM		KL0867		SCH	18-14:50		14:50									F08	
	KL1810	KLM1810	AIR	18-12:50	12:30E		12:38E	A34	PHEXM	E75	KLM																	
	HV6412	TRA412B	AIR	18-13:05	12:30E		12:38E	D56	PHXRX	73W	KLM		HV6883		SCH	18-14:55		14:55									D56	
	QR273	QTR3AU	AIR	18-13:15	12:32E		12:40E	F06	A7BEL	77W	Swiss		QR274		SCH	18-15:15		15:15									F06	
	EI604	EIN60T	AIR	18-12:45	12:34E		12:42E	D29	EIDEG	320	Swiss		EI605	EIN605P	SCH	18-13:25	13:25	13:25				13:26				13:34T	D29	24
	KL1986	KLM82K	AIR	18-12:45	12:37E		12:45E	A56	PHEZT	E90	KLM		KL1027	KLM73L	SCH	18-14:00	14:00	14:00				14:05				14:19T	A56	36L

Figure 7 - A-CDM platform (CDM portal, 2019)

3.4 Stakeholder analysis

The stakeholder analysis is used to identify primary and secondary stakeholders, who have interest or/and power in the CDM inbound process at Schiphol. Some stakeholders of the CDM arrival process are not written in the manuals, therefore a lot of valuable information can be retrieved from conducting interviews and meeting with the stakeholders. To find out which organizations or persons are interesting to meet, and which stakeholders uses the generated landing times using the sources of information, it is important to understand which organizations and persons are involved in the CDM process. Stakeholders can be both organizations and people within those organizations. Therefore, it is important to identify correct individual stakeholders within a stakeholder organization (Oxford University Press, 2000).

First the overall companies, who are the stakeholders of the CDM arrival process, are identified. These stakeholders are identified by means of desk research, for example on the CDM manuals (Schiphol Group, 2019)(Eurocontrol Airport CDM Team, 2017)(AACG, 2018). They are prioritized by their power and interest in the CDM arrival process. The individual stakeholders are based on several aspects, such as which department they are, what their main duties are related to the CDM arrival process and what the timing is of those activities.

The following stakeholders are identified:

	Company	Abbreviation
1.	LVNL	[LVNL]
2.	Amsterdam Airport Schiphol	[AAS]
3.	KLM	[KLM]
4.	Ground handlers	[GH]
5.	EUROCONTROL	[EC]
6.	Other airlines	[OA]
7.	IATA	[IATA]
8.	ICAO	[ICAO]
9.	Government	[GOV]

The description of the power and interest of each stakeholder regarding the CDM arrival process is stated below. In addition, each stakeholder is prioritized in a Power/Interest grid, which is shown in Figure 8. The abbreviations of the stakeholders have been used as names in the grid, to keep it organized.

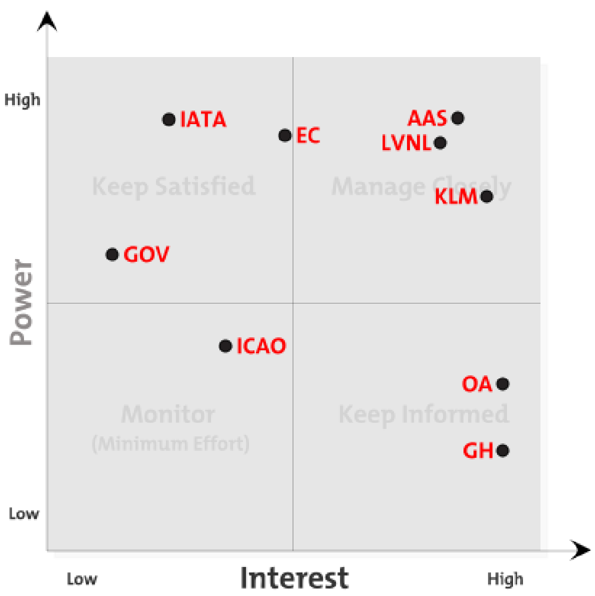

Figure 8 - Power/interest grid

As shown in the Figure 8, the most important stakeholders are KLM, AAS and LVNL. Therefore, the explanations for these stakeholders are given. For the remaining stakeholders, the explanation per stakeholder is given in appendix II. Firstly, LVNL is one of the initiators of the CDM program at Schiphol. They have a great influence on the CDM arrival process, because their systems are used in this process. Their systems generate specific times, e.g. ELDT, EIBT and TOBT, needed for the arrival process. In addition, LVNL has a significant interest in the arrival process, because they want this process to be as efficient as possible to avoid disruptions and delays. Furthermore, AAS is also one of the initiators of the CDM program. Their facilities and systems on the airport are used by the airlines and ground handlers. Therefore, they have a great influence and interest in the CDM arrival process. Finally, KLM is the home carrier of Schiphol. KLM is one of the initiators of the CDM program as well. Their interest and power in the CDM arrival process is high, because they have many aircraft arriving at Schiphol. Therefore, KLM wants the arrival process to be as efficient as possible, to keep the costs as low as possible. Within these companies, there are individual stakeholders, who might be interesting to interview.

The following individual stakeholders from KLM, AAS and LVNL are chosen:

Company	**Person**	**Expertise**
KLM	Hans Kelder	CDM expert
	F. Sonsma	CDM expert/aviation consultant
Schiphol	Eric van Leeuwen	CDM-expert
	Yiannis Alexopoulos	CDM expert
	B.D. Onnes	Manager Traffic Analysis and Forecasts
	F. Duivenvoorde	CDM-expert
LVNL	David Zwaaf	CDM-expert
	Ferdinand Dijkstra	LVNL systems expert
	Fred Olislagers	Tower system expert
	Ronald van Eijk	AAA system expert
	Stefan de Jong	OPS\ MP\ TWR/APP
	A. Jongen	Program manager
	Radjesh Nathie	AAA system
	Gert Hans Grutter	ASAP system

3.5 The arrival process at Amsterdam Airport Schiphol

Since there has been a change of AMAN system, the arrival planning of ASAP starts at the moment when the ABI-message is received, instead of when the ACT-message is received, which was the case at the old AMAN system. Therefore, as mentioned in the methodology, a cross-functional flow chart is used to understand the new CDM arrival process at Schiphol and to get an insight in the different ELDTs that are generated by the systems of the LVNL.

In the arrival process, different ELDTs are calculated at various times. In order to keep an overview of which ELDT is generated by which system and from what source, a pre-defined format has been used. In case of the same source and system, a number (X) is added to the ELDT; it represents an update of that message. The format for the ELDT is: $ELDT(X)_{source/system}$. So, for example, the $ELDT1_{abi/aaa}$, is the first ABI-message, generated by the AAA system, with the ABI-message as input. All the generated ELDTs in the cross-functional flowchart are shown in Table 1.

Table 1 - Generated landing times

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	$ELDT_{act/aaa}$	Pink	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	ETO 14 minutes to IAF	ASAP
9	$ELDTX_{fum/aaa}$	Dark blue	FUM	AAA

The ABI-message and ACT-message are both received from an upstream center (adjacent center), for The Netherlands, this is the Maastricht Upper Area Control Centre (MUAC). The ACT-message will be sent after the ABI message. According to the CDM expert meeting (CDM experts. (2019, September 24). Expert interview), agreements with the LVNL and the adjacent centers determines whether the ABI-message is sent or not. Therefore, the ABI-messages are optional, but is it is possible that the adjacent center sends more than one ABI-message; this is due, for example, a change of the Coordination Point (COP), destination airport or equipment capability. The ACT-message, however, is mandatory. A schematic overview of the CDM arrival process, with the ELDTs, is shown in Figure 9.

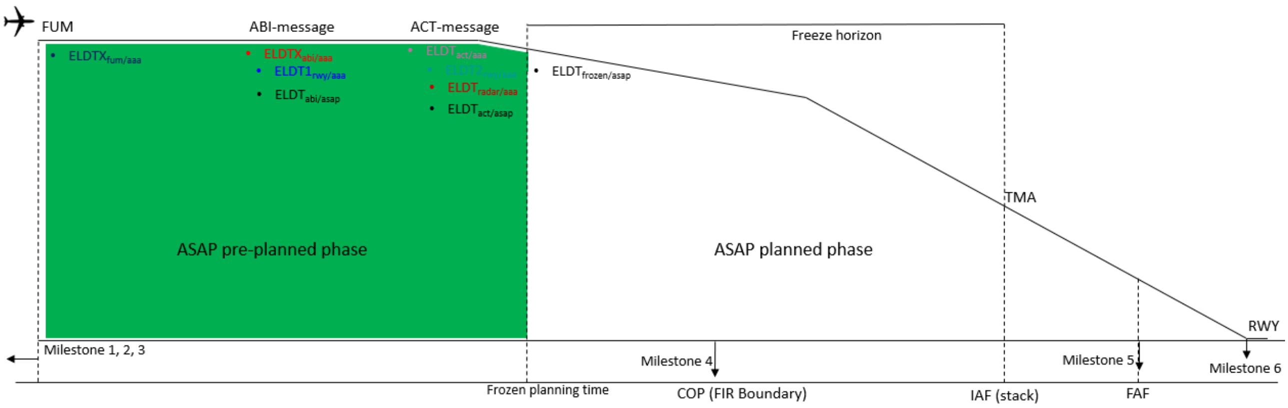

Figure 9 - A-CDM arrival process

The objective of the cross-functional flow chart is to understand the exchange of input information between the different system in the CDM process. This section will present in more detail the flows and relations of the input sources to each other. The complete flow chart is shown in Appendix VI.

The first part (Figure 10) of the flow chart is the part where the FUM is sent and received. The FUMs are triggered by multiple triggers, which has been explained in section 3.2.2. If a FUM is triggered, the FUM is sent to the AAA system by the network manager. Then, the AAA receives this message and estimates a landing time, which is called the $ELDTX_{fum/aaa}$. After this, AAA sends the $ELDTX_{fum/aaa}$ to the TWR system. If the $ELDTX_{fum/aaa}$ has a difference of +- 1 minute with a previously known ELDT, $ELDTX_{fum/aaa}$ is send to the CISS. As mentioned in section 3.3, CISS also got his own business rules regarding the ELDT implied into the system (appendix III). These business rules determine if the ELDT is send to the CDM portal or not.

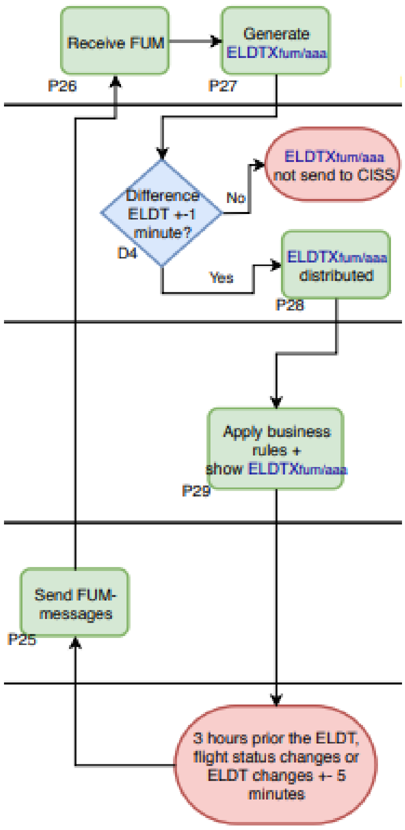

Figure 10 - First part

The following part (Figure 11) of the arrival process and the calculation of the landing times is the decision if the aircraft departs from inside or outside the Dutch airspace. If the aircraft departs from inside the Dutch airspace, the adjacent centers does not send any ABI-message or ACT-message. However, as mentioned in Chapter 1, the flights that departs inside the Dutch airspace are outside the scope of the project. So, no further analyzing is done on this process.

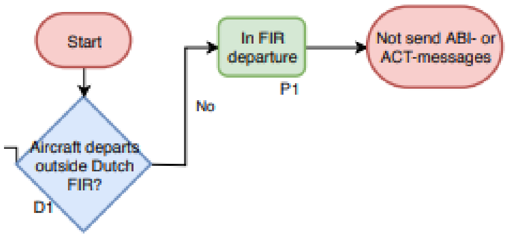

Figure 11 - Second part

The next part (Figure 12) of the flow chart is the flow of the ABI-message. It starts with the question whether the LVNL has agreements with the adjacent centers or not. If they have agreement to send the ABI-message, it is sent to the AAA system and AAA generates a new landing time, called ELDTX$_{abi/aaa}$. Subsequently, the AAA system sends the generated ELDTX$_{abi/aaa}$ to the tower system. Same as with the FUM, if the ELDTX$_{abi/aaa}$, has a difference of +- 1 minute with a previously known ELDT, ELDTX$_{abi/aaa}$ is send to the CISS.

Also, after the AAA received the ABI-message from the adjacent center, a part of this information is sent to the ASAP system. ASAP then assigns a runway to the flight and generates a new ELDT$_{abi/asap}$. However, in the current situation, this ELDT$_{abi/asap}$ is only used internally by the LVNL and, therefore, not send to CISS, because the accuracy of the ASAP ELDTs is still unknown.

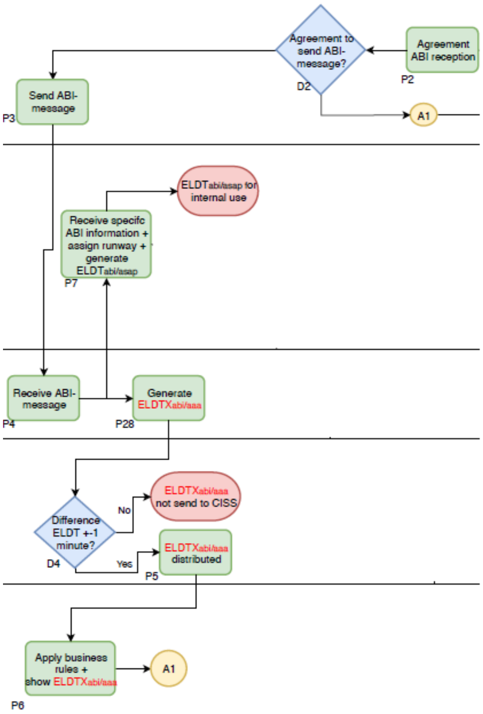

Figure 12 - Third part

In addition, the fourth part (Figure 13) of the flow chart is the part where ASAP assigns the runway. ASAP sends the runway information is back to AAA and AAA generates a new landing time based on the assigned runway, called ELDT1$_{rwy/aaa}$. However, ELDTX$_{abi/aaa}$ and ELDT1$_{rwy/aaa}$ differs approximately 1 à 2 seconds, because the process of assigning a runway happens almost instantly. After the new landing times are generated by the AAA system, the processes that follow are applied for each new update of the ELDT. These processes are already explained in the previous paragraph.

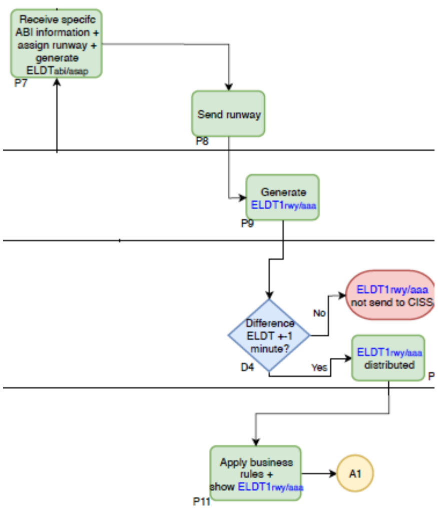

Figure 13 - Fourth part

The following part of the flow chart (Figure 14) is the sending of the ACT-message by the adjacent center. AAA receives the ACT-message with an SSR code included in the message, and the system generates a new landing time, called $ELDT_{act/aaa}$. Afterwards, $ELDT_{act/aaa}$ is send to the CISS via the tower and same procedures repeats itself.

In addition, after the AAA system receives the ACT-message from the adjacent center, a part of this information is sent to ASAP and ASAP will generate a new landing time, which is called $ELDT_{act/asap}$. However, $ELDT_{act/asap}$ is only used internally by the LVNL, and therefore, not sent to CISS.

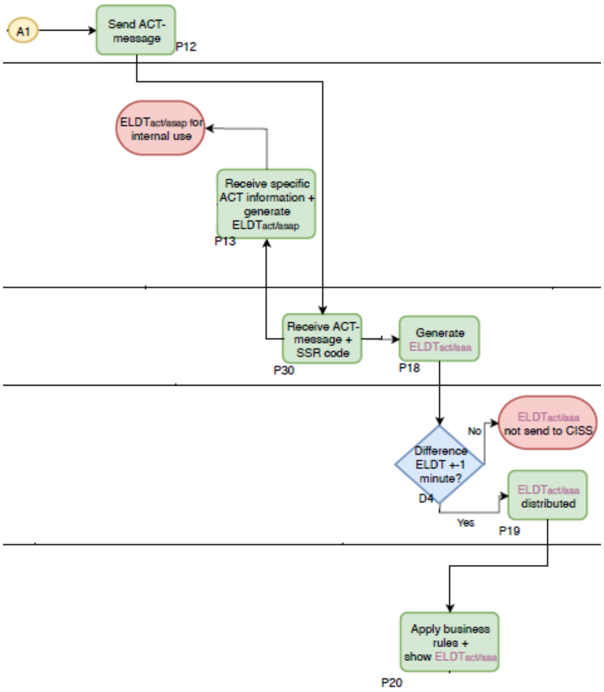

Figure 14 - Fifth part

The sixth part of the flow chart (Figure 15) is the part where the runway has not been assigned yet. For certain flights, the ABI-message is not sent. If this is the case, the assignment of the runway will be at the moment when the ACT-message is received. ASAP assigns a runway to the flight and send it to the AAA system, which will generate a landing time, called $ELDT2_{rwy/aaa}$. $ELDT2_{rwy/aaa}$ is then sent to CISS via the tower and the same procedure repeats itself.

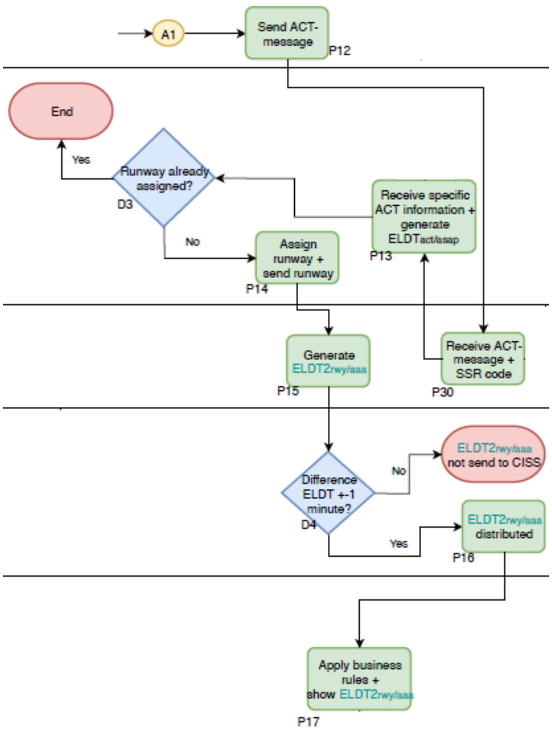

Figure 15 - Sixth part

Furthermore, the seventh part of the flow chart (Figure 16) is the flow of the radar information. AAA receives the ACT-message, which includes a specific SSR code for each flight. Then, AAA sends this SSR code to ASAP, and ASAP sends radar tracks back to the AAA system. Then, the radar is correlated, and AAA generates a new landing time, called $ELDT_{radar/aaa}$. $ELDT_{radar/aaa}$ is also sent to CISS via the tower and the same procedure repeats itself.

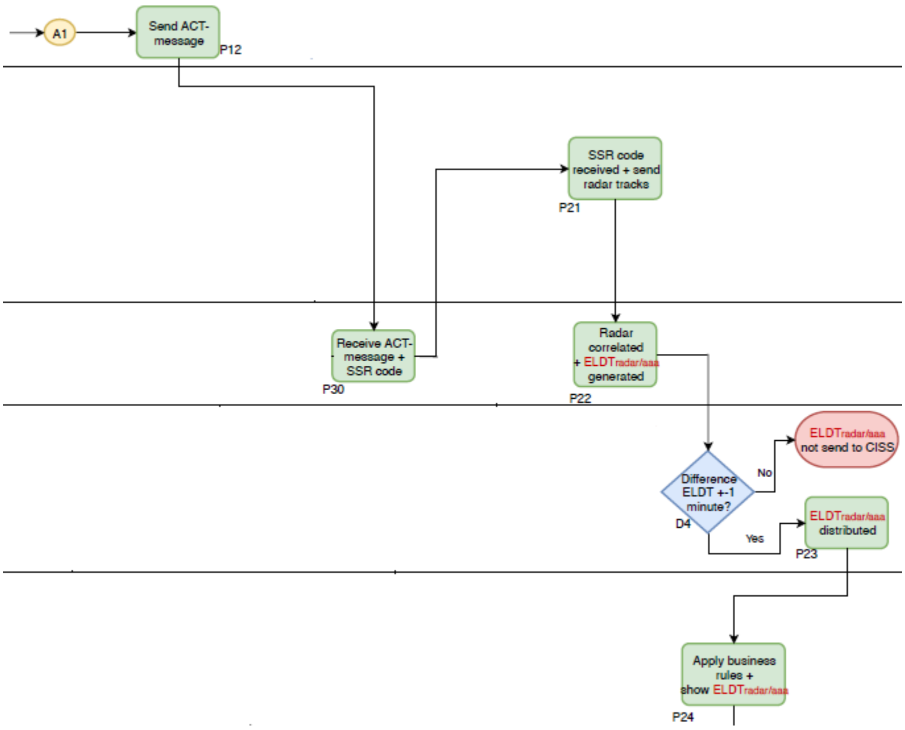

Figure 16 - Seventh part

The final part of the flow chart (Figure 17) is the part of the frozen planning time of ASAP. When the aircraft's position is ETO 14 minutes before the IAF, ASAP freezes its planning and only the approach planner (APLN) can edit elements of ASAP's planning. ASAP then generated a new landing time, called $ELDT_{frozen/asap}$. However, $ELDT_{frozen/asap}$ is, same as with the other ELDTs of ASAP, only used internally by the LVNL.

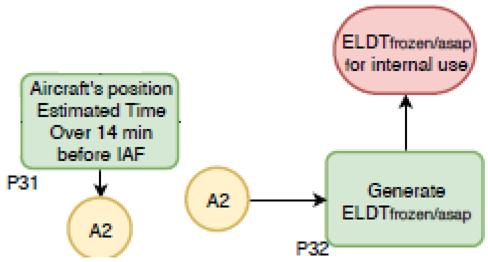

Figure 17 - Eight part

CTA

There are five possible sectors where aircraft could enter the Dutch FIR. These sectors are called control areas (CTA) and are shown in Figure 18. The control areas are intended to protect overflights along the 'highways' in the air, the so-called ATS routes. Because of the relatively small size of the Schiphol TMA, compared to other major airports, Dutch civilian CTAs also see a lot of climbing and descending traffic. Within the CTAs are defined sectors, in which (depending on traffic density, whether combined or not) an air traffic controller is responsible for all approaching and departing traffic (Ministry of Infrastructure and the Environment, 2011).

In addition, special traffic areas may be defined if (temporary) prohibitions or restrictions are necessary to accommodate operations that cannot be combined with civil aviation. A distinction is made between the so-called restricted areas (HER), danger areas (EHD) and prohibited areas (EHP). These (temporarily) prohibited or restricted areas are generally activated in the case of military aviation activities, which cannot be combined with civil traffic. These military exercise areas are located above the Waddenzee, Twente and the South-East of the Netherlands (see Figure 19) (Ministry of Infrastructure and the Environment, 2011).

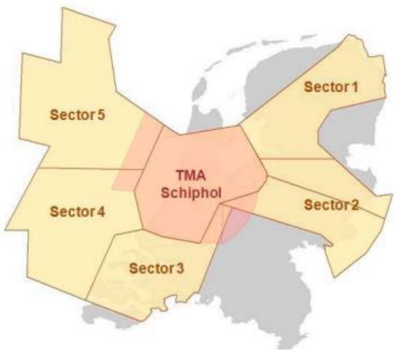

Figure 18 - Schiphol TMA and CTA sectors

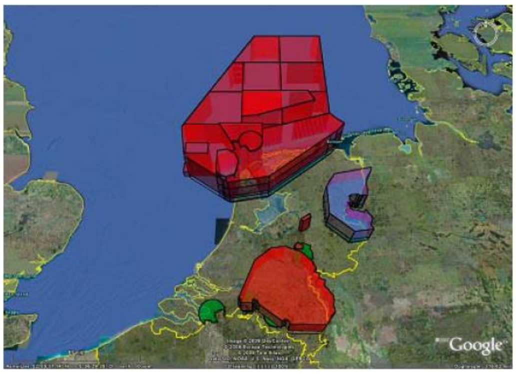

Figure 19 - Location of military exercise areas

In order to simplify the work of air traffic controllers, a route structure is established so that the relevant routes and procedures can be used within the available airspace. There are different types of routes, with the routes for IFR traffic being the most important for the organization of the airspace. These routes are ATS routes, departure routes (SID), arrival routes (STAR) and approach procedures. The most relevant route for this project is the arrival route. Therefore, this route will be further elaborated (Ministry of Infrastructure and the Environment, 2011).

Arrival routes

The arrival routes are usually Standard Instrument Arrivals (STARs), which are used to connect the ATS route and the start of the actual approach procedure. This point is also called the Initial Approach Fix (IAF). The IAF always has a holding area; these holding areas are only used in situations where unexpectedly more traffic is flying to the airport that can be handled within the available capacity, or where there is disruption due to extreme weather condition. In such cases, approaching traffic may be held before starting the approach. In all other cases, the traffic will continue to fly without flying into the holding area. All approaches to Schiphol are in the CTAs, and end at the edge of the Schiphol TMA, i.e. at the points ARTIP (near Lelystad), RIVER (near Rotterdam) and SUGOL (above the North Sea). These points, or IAFs, are shown in Figure 20. 'Wachtgebied' is a translation of the word holding area (Ministry of Infrastructure and the Environment, 2011).

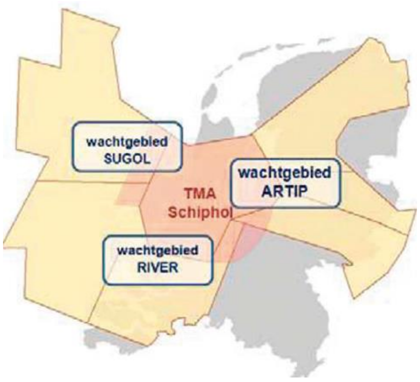

Figure 20 - Location of current Schiphol holding areas

4 Analysis on the landing times

This chapter presents three main analysis performed, the first one, introduced in Section 4.1, aims to provide a frequency analysis on four inbound sources of information: ABI, ACT, radar and FUM; Section 4.2 provides an analysis on the time window of the arrival of the same four inbound sources of information; Section 4.3 aims to provide an analysis on the quality of the generated landing times of five inbound sources of information: ABI, ACT, radar, FUM and frozen planning time of ASAP, and finally, Section 4.4, provides an comparison of the landing times generated by the AAA system and the ASAP system.

There have been 273,008 flights analyzed and these have been carried out in the period between October 1st, 2018 and October 31st, 2019. The data have been divided into a winter period and a summer period. The winter period commences at October 1st, 2018 and ends at March 31st, 2019 with 117,224 flights, and the summer period starts at April 1st, 2019 and ends at October 31st, 2019 with 155,784 flights. Within this Chapter, figures and tables distinguish the winter period by the abbreviation 'w' and the summer, with 's'. Because the difference between the summer and winter is almost equal, all calculations performed for the summer period are shown in Appendix V. Appendix IV presents a preview of the first five flights (rows) of the complete data set.

4.1 Frequency of the reception inbound sources of information

This Section presents the analysis on the frequency of the reception on four inbound sources of information: ABI, ACT, radar and FUM as schematized in Figure 21.

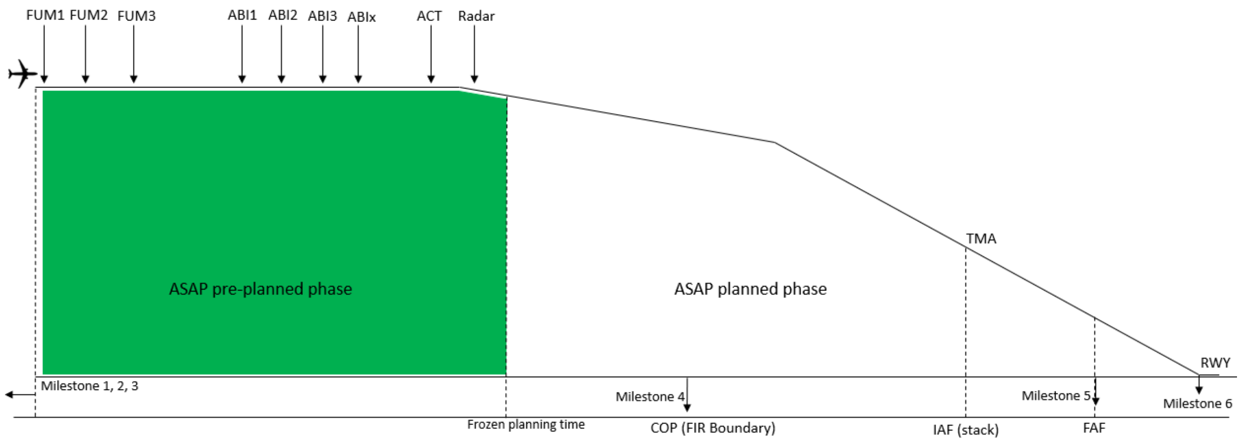

Figure 21 - ABI-message timeline

ABI-message

As mentioned in Chapter 3, the ABI-message is optional. Its reception depends on the letter of agreements between the adjacent centers and Air Navigation Service Providers (ANPS), in this case, LVNL. Therefore, an analysis on its frequency is performed. Due to the characteristics of ABI-messages, two types of analysis are performed: one on the number of updates received and the second one on the updates receives per sector.

Figure 22 describes the frequency of the reception for ABI-messages of the analyzed inbound flights. The first ABI-message is received 72.92% and 71.95% for the winter and summer, respectively. However, a second ABI-message is only received 2.32% and 1.75% for the winter and summer, respectively; this is a drop of almost 70%. For the total amount of flights in the period analyzed, there is a maximum of 6 ABI-messages received. However, as it can be seen from the figure, they are not representative, and therefore, excluded on for further analysis.

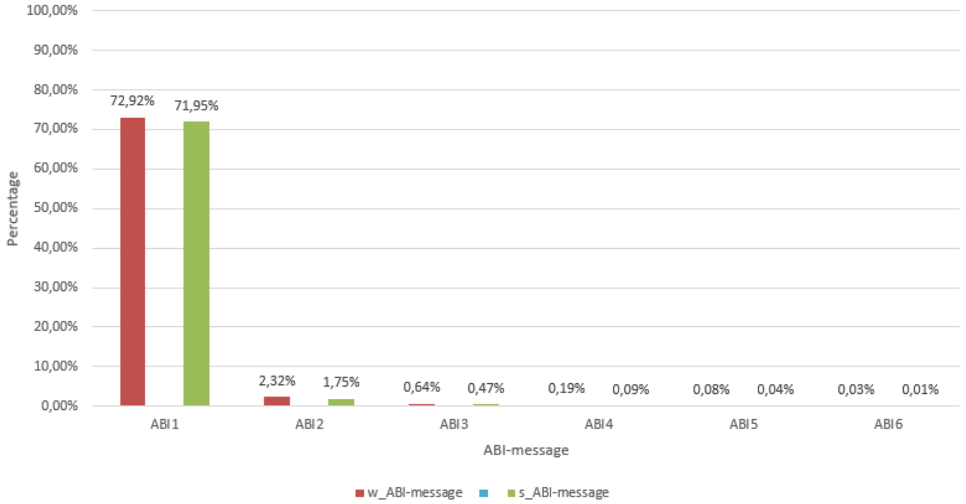

Figure 22 - Percentage ABI-message frequency

As presented in Chapter 3, the reception of the ABI-message depends on whether LVNL has agreements with the adjacent centers in the sector that the flight is crossing to enter the Dutch airspace. Figure 23 describes all the flights that enter the Dutch airspace in the winter and summer. From all the flights, sector 3 is the one which receives the lowest number of ABI-messages (for winter and summer 4,27% and 3,69%, respectively), while the other sectors receive on average about 99-84%. Therefore, it can be concluded that LVNL has less agreements with adjacent centers in sector 3, and further analysis on why LVNL they do not have agreements is interesting; this will be further elaborated in Chapter 6, recommendation.

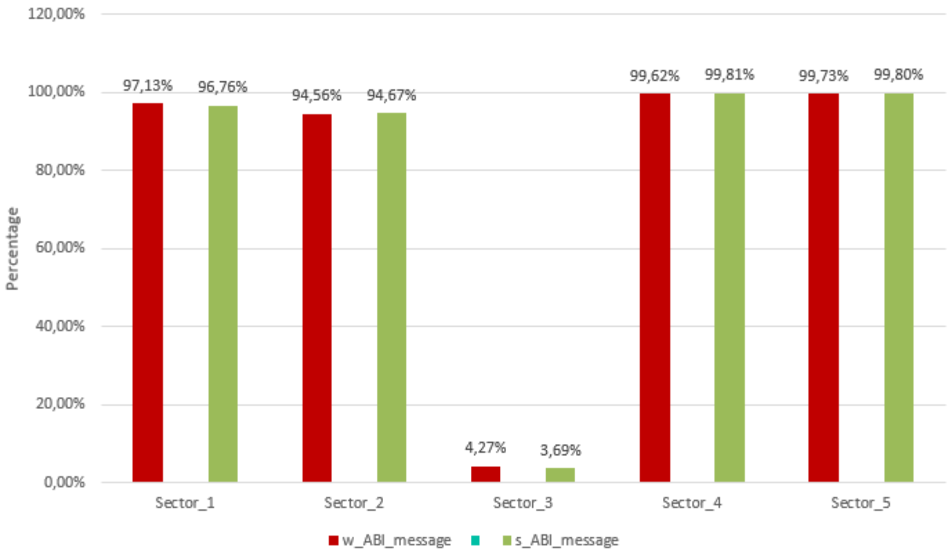

Figure 23 - First ABI-message frequency per sector

FUM

Figure 24 describes the frequency of the reception for the first three FUMs of the analyzed inbound flights. Only the first three FUMs of each flight are analyzed as they trigger estimations of landing times, which are still used in the scope of this project. It can be seen that the first FUM is received, for the winter and summer, 99,69% and 99,60%, respectively. For the second FUM, this has been decreased for the winter and summer to 91,65% and 91,31%, respectively; which is a drop of around 8%. Finally, for the third FUM, the reception for the winter and summer is respectively, 72,54% and 75,61%; which is a drop of approximately 20%. So, the drop from the second to the third FUM is 12% higher, than from the first to the second FUM. The decrease in percentage can be explained by the fact that, as stated in Section 3.2.2, a FUM is an event driven message by Eurocontrol, and therefore further investigation is needed on the events that trigger these updates of information.

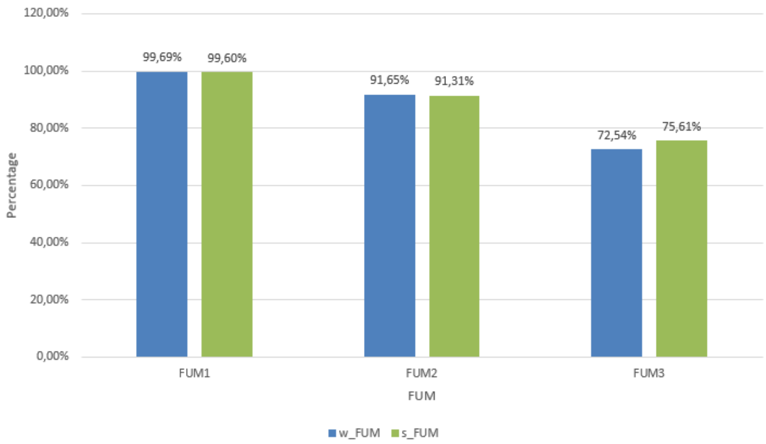

Figure 24 - Percentage FUM frequency

Figure 25 describes all the flights than enter the Dutch airspace in the winter and summer period per sector. It shows that all sectors are almost 100%, therefore, it can be concluded that the sending of the FUM will not depend on the sector where the aircraft enters the Dutch airspace.

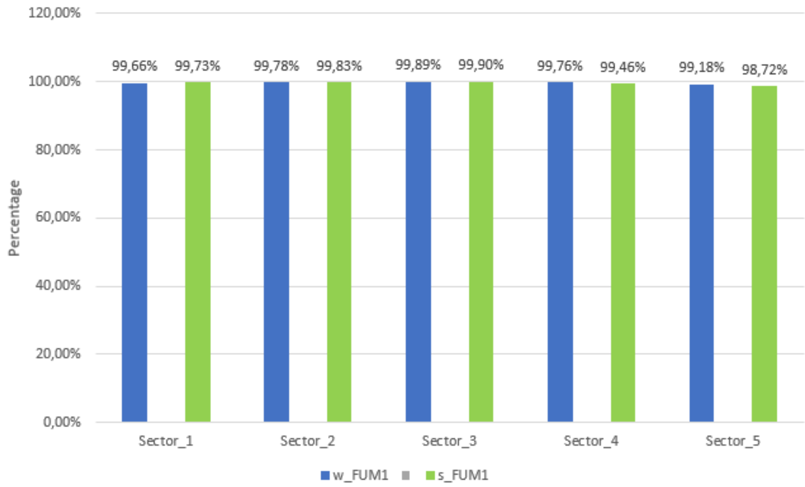

Figure 25 - First FUM frequency per sector

ACT-message

Contrary to the ABI-message, the ACT-message is a mandatory message. The flight will certainly arrive at Schiphol if the ACT-message has been received. Due to the fact this message is mandatory, the frequency of reception for the analyzed flights is 100%. Therefore, no further analysis on the reception of the ACT-message has been performed.

Radar correlation

Due radar correlation always occurs when the aircraft is in radar range, the frequency of reception of radar correlation for the analyzed flights is 100%. Therefore, no further analysis on the frequency of the radar correlation has been done.

4.2 Time window of the reception of inbound sources of information

The second part of the quantitative analysis provides an analysis on the time window of the arrival of four inbound sources of information: ABI, ACT, radar and FUM. Figure 26 displays a schematic view of the time intervals of the arriving sources of information; i.e. spread of reception between the inbound information. The initial approach fix (IAF) is used as coordination point to determine this time window. The brackets represent the interval of the reception of the sources of information called *"time window"*; the middle arrow of the boxes represents the average time the sources arrive. The measures of central tendency and spread are determined for four sources of information. For the FUM, further analysis is performed on its updates.

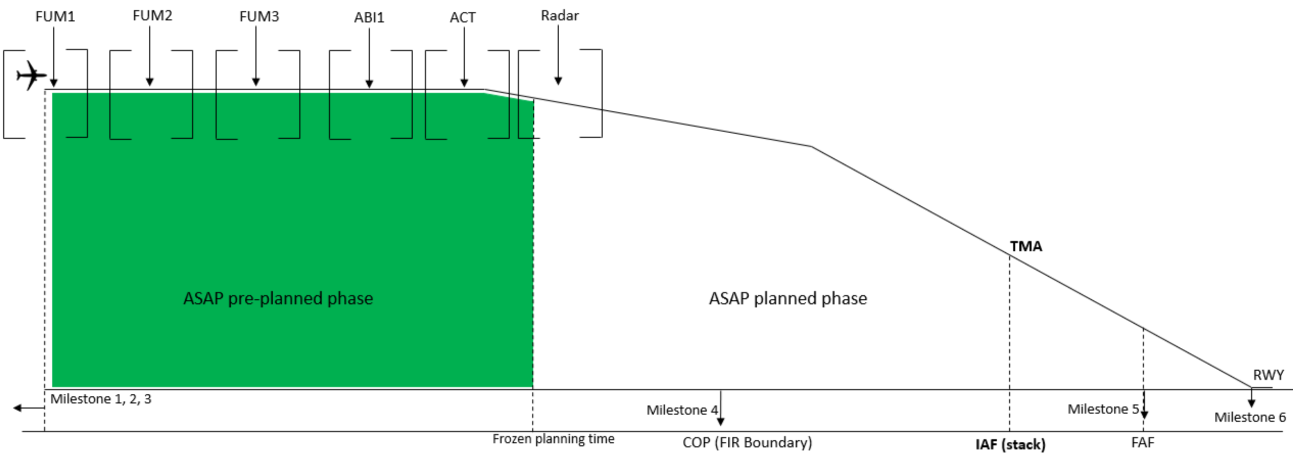

Figure 26 - Schematic overview time window analysis

ABI-message

Table 2a presents the measures of central tendency and spread of the reception of the first ABI-message of the complete set of data, while Table 2b presents the analysis of the data without "outliers". It can be seen that the reception time is on average around 38 minutes before the IAF, however, it is also possible that the first ABI-message is received 2 hours and 58 minutes in advance, but in the other hand, it can also be received until 15 minutes prior to the IAF, which means that the time window for the arriving ABI-message will last about 2 hours and 43 minutes. The standard deviation (represented by the sigma 'σ') of the reception of the first ABI-message is 5 minutes and 54 seconds. This means that for 68.2% of the flights, the first ABI-message are received between 45 minutes and 33 minutes before the IAF, 95.4% will arrive within 51 minutes to 27 minutes prior to the IAF, and 99.6% of the flights will arrive between 57 minutes and 21 minutes before the IAF. The 50% percentile, also known as the median or the 'middle' value of the data set, is 39 minutes and 27 for the first ABI-message. Because the mean and median only differ 29 seconds, it can be concluded that the outliers do not influence the time window of the first ABI-message (Department of Education, 2015).

Table 2 - Time window ABI-message winter a) with outliers b) without outliers

a) with outliers

	w_Time_window_ABI1	Time_window_std_time
mean	2339	00:38:58
std	354	00:05:54
min	933	00:15:33
50%	2367	00:39:27
max	10735	02:58:55

b) without outliers

	Time_window_ABI1	Time_window_std_time
mean	2361	00:39:20
std	248	00:04:08
min	1739	00:28:59
50%	2375	00:39:35
max	2979	00:49:39

Figure 27 displays the difference between the time window of the first ABI-message with and without the outliers on a more graphical manner, where the '0' is the coordination point (IAF). The data without the outliers decreases its interval from 2 hours and 58 minutes to 49 minutes and increases its interval from 15 minutes to 28 minutes. However, these outliers only represent 0.4% of the complete data set (342 out of 85,481). It can also be noticed that the most spread of the outliers is in the 2 hours before the IAF; which means that the first ABI-message could be received earlier in time, for planning purposes, further research will be interesting. The difference between the average time window with and without the outliers is 22 seconds. Therefore, as stated before, the outliers do not influence the overall analyses further presented on the time window.

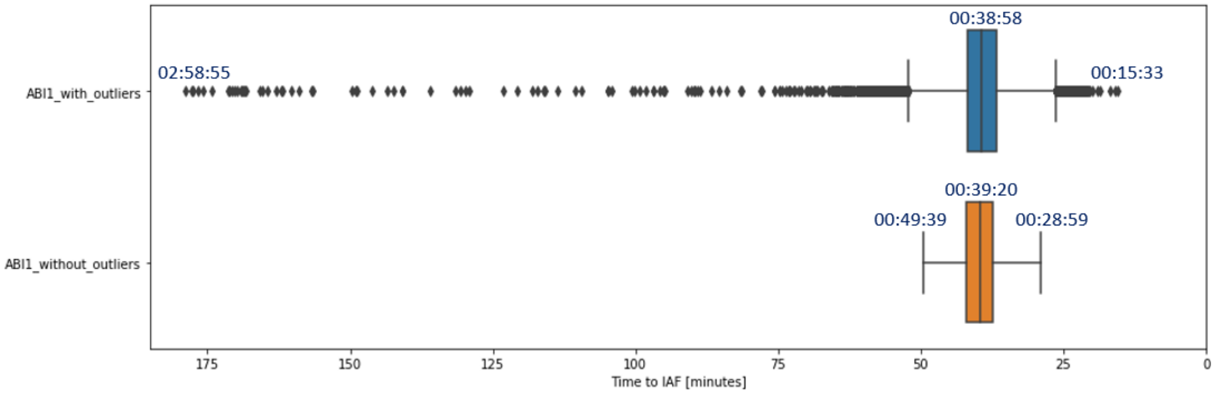

Figure 27 - Graphical comparison time window first ABI-message with & without outliers AAA

ACT-message

Table 3a presents the measures of central tendency and spread of the reception time window of the ACT-message for the complete data set, and Table 3b presents the one excluding the outliers. It shows that the reception time of the ACT-message is on average 25 minutes prior to the IAF, however, it could also happen that the ACT-message is received 2 hour and 45 minutes in advance, but it can also be received until 1 minute before the IAF, which means that the time window for the arrival of the ACT-message will last around 2 hours and 44 minutes. The standard deviation (σ) of the reception of the ACT-message is 4 minutes and 17 seconds. This implies that 68.2% of the flights corresponds to a time window when the ACT-message is received between 29 minutes and 21 minutes before the IAF, 95.4% corresponds of a time window between 34 minutes and 17 minutes prior to the IAF, and 99.6% of the flights will arrive between 38 minutes and 12 minutes before the IAF. The median for the reception time window of the ACT-message is 25 minutes and 25 seconds. Due to the fact that the mean and median only differ 5 seconds, it can be concluded that the outliers do not influence the general time window (Department of Education, 2015).

Table 3 - Time window ACT-message winter a) with outliers b) without outliers

a) with outliers

	w_Time_window_ACT	Time_window_std_time
mean	1520	00:25:20
std	257	00:04:17
min	107	00:01:47
50%	1525	00:25:25
max	9933	02:45:33

b) without outliers

	Time_window_ACT	Time_window_std_time
mean	1517	00:25:17
std	193	00:03:12
min	950	00:15:50
50%	1525	00:25:25
max	2073	00:34:33

Figure 28 shows the difference between the time window of the ACT-message with and without the outliers on a graphical manner, where the '0' is the coordination point (IAF). It can be seen that the data without the outliers decreases its interval from 2 hours and 45 minutes to 34 minutes and increases its interval from 1 minute to 15 minutes before the IAF. However, these outliers only represent 0.4% of the complete data set (469 out of 117,224). It can also be noticed that the most spread of the outliers is in the 2 hours before the IAF; which means that the ACT-message could be received earlier in time, for planning purposes, further research will be interesting. The difference between the average time window of the ACT-message with and without outliers is 3 seconds. Therefore, it can be concluded that the outliers do not influence the common analyses further presented on the time window.

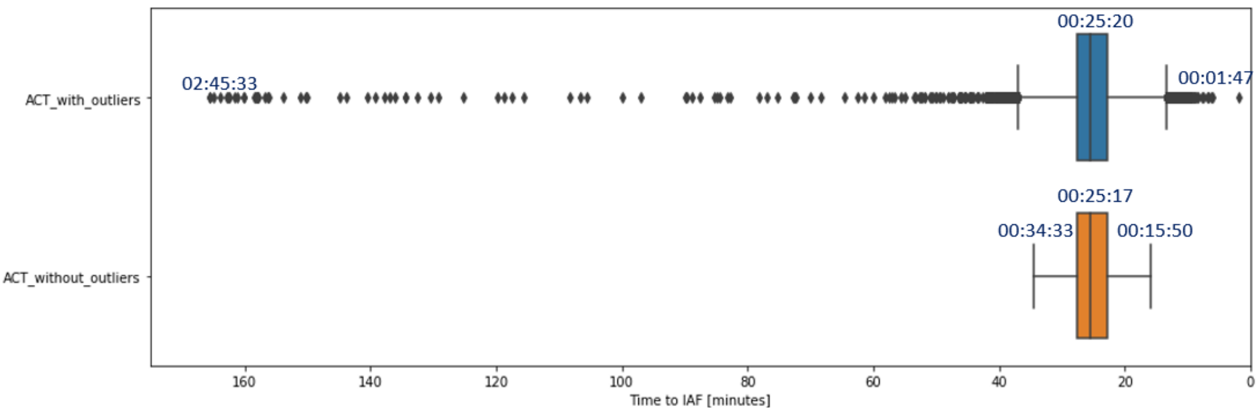

Figure 28 - Graphical comparison time window ACT-message with & without outliers AAA

Radar correlation

Table 4a presents the measures of central tendency and spread of the time radar correlation occurs for the complete data set, while Table 4b presents the analysis of the data without outliers. It can be seen that the time radar correlation occurs is on average around 23 minutes before the IAF, however, it is also possible that radar correlation occurs 3 hours and 52 minutes in advance, and even until 13 seconds before the IAF, which means that the time window when radar correlation occurs will last approximately 2 hours and 52 minutes. The standard deviation (σ) of the time radar correlation occurs is 4 minutes and 55 seconds. This means that for 68.2% of the analyzed flights, radar correlation occurs between 28 minutes to 18 minutes before the IAF, for 95.4% of the analyzed flights, this time window is equal to 33 minutes to 13 minutes prior to the IAF, and for 99.6% of the flights, radar correlation occurs between 38 minutes and 8 minutes before the IAF. The median for the time when radar correlation occurs is 22 minutes and 43 seconds. The difference between the median and mean is only 18 seconds, therefore, it can be concluded that the outliers do not influence the overall time window when the radar correlation occurs (Department of Education, 2015).

Table 4 - Time window radar correlation winter a) with outliers b) without outliers

a) with outliers

	w_Time_window_radar	Time_window_std_time
mean	1381	00:23:01
std	296	00:04:55
min	13	00:00:13
50%	1363	00:22:43
max	13947	03:52:27

b) without outliers

	Time_window_radar	Time_window_std_time
mean	1372	00:22:52
std	192	00:03:12
min	829	00:13:49
50%	1361	00:22:41
max	1917	00:31:57

Figure 29 displays the difference between the time window when radar correlations occurs with and without the outliers in a more graphical way, where the '0' represents the coordination point (IAF). The data without the outliers decreases its interval from 3 hours and 52 minutes to 31 minutes and increases its interval from 13 seconds to 13 minutes. However, these outliers only represent 0.4% of the complete data set (480 out of 117,224). It can also be noticed that there are only a few data points between 130 minutes and 70 minutes before the IAF; which would imply that radar correlation is hard between that period. Further research on why there are only a few data points available is interesting. The difference between the average data time window with and without the outliers is 9 seconds, and therefore, it can be concluded that the outliers do not influence the general analyses further presented on the time window.

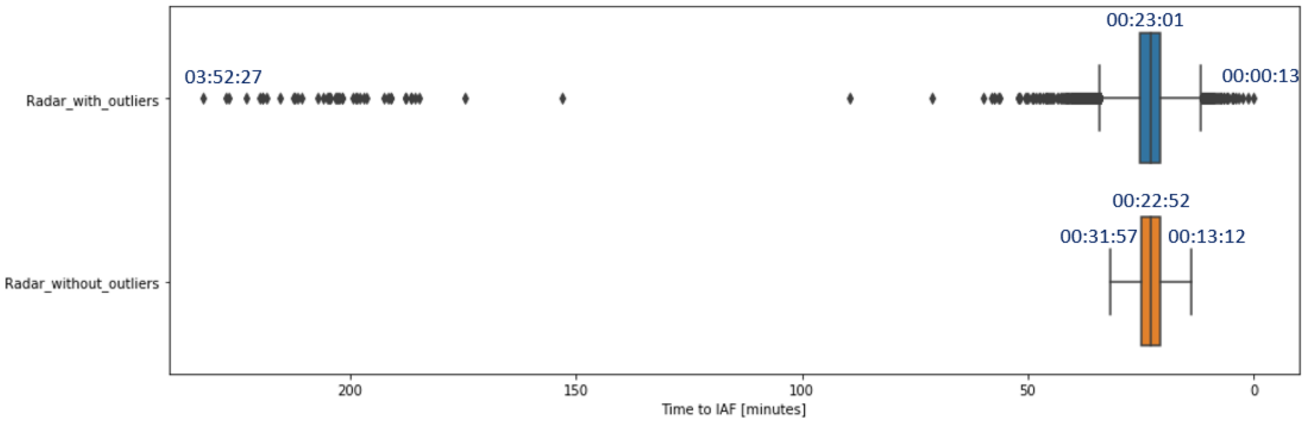

Figure 29 - Graphical comparison time window radar correlation with & without outliers AAA

First FUM

Table 5a presents the measures of central tendency and spread of the reception of the first FUM of the complete set of data, while Table 5b illustrates the analysis of the one excluding the outliers. It can be seen that the reception time is on average around 2 hours and 56 minutes prior to the IAF, however, it is also possible that the first FUM is received 3 hours and 52 minutes before the IAF, but in the other hand, it can also be received until 10 minutes after the IAF, which means that the time window for the arriving first FUM will last about 4 hours and 2 minutes. The standard deviation (σ) of the reception of the first FUM is 18 minutes and 50 seconds. This means that for 68.2% of the flights, the first FUM is received between 3 hours and 15 minutes and 2 hours and 37 minutes before the IAF, 95.4% will arrive within 3 hours and 33 minutes and 2 hours and 18 minutes before the IAF, and 99.6% of the flights will arrive between 3 hours and 50 minutes and 2 hours before the IAF. The median is 2 hours and 53 minutes for the first FUM. Because the mean and median differ 2 minutes and 31 seconds, it can be concluded that the outliers do not influence the general time window of the first FUM (Department of Education, 2015).

Table 5 - Time window FUM1 winter a) with outliers b) without outliers

a) with outliers

	w_Time_window_FUM1	Time_window_std_time
mean	10566	02:56:05
std	1131	00:18:50
min	-637	23:49:23
50%	10414	02:53:34
max	13933	03:52:13

b) without outliers

	Time_window_FUM1	Time_window_std_time
mean	10496	02:54:55
std	796	00:13:15
min	8304	02:18:24
50%	10382	02:53:02
max	12707	03:31:47

Figure 30 presents the difference between the time window of the first FUM with and without the outliers on a more graphical manner, where the '0' is the coordination point (IAF). It can be seen that the data without the outliers decreases its interval from 3 hours and 52 minutes to 3 hours and 31 minutes and increases its interval from 10 minutes after the IAF to 2 hours and 18 minutes before the IAF. However, these outliers only represent 0.4% of the complete data set (490 out of 116,858). It can also be noticed that the outliers are close to each other and mainly after 160 minutes before the IAF. Further research on why the first FUM could be send so late is interesting. Furthermore, the difference between the average time window with and without outliers is 1 minutes and 10 seconds. Therefore, as stated before, the outliers do not influence the overall analyses further presented on the time window.

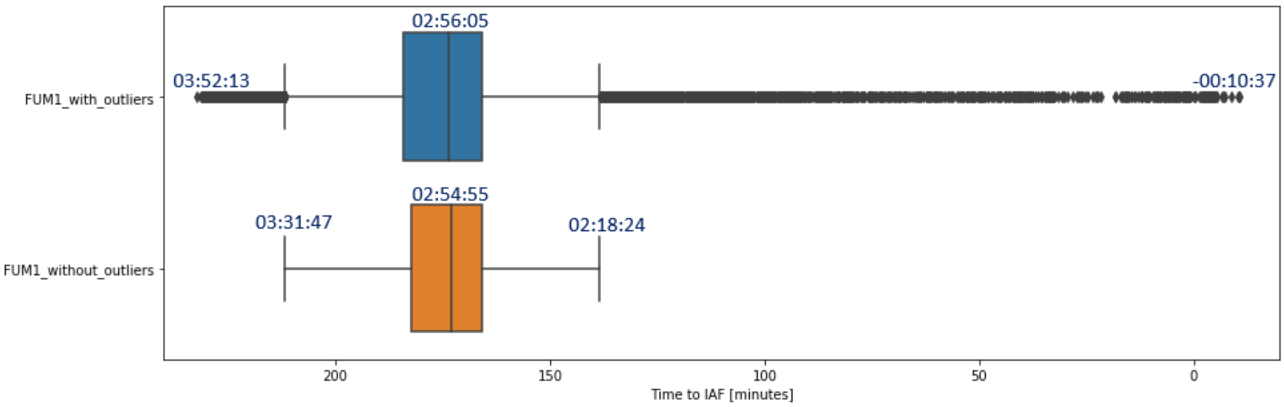

Figure 30 - Graphical comparison time window first FUM with & without outliers AAA

Second FUM

Table 6a presents the measures of central tendency and spread of the reception time window of the arrival of the second FUM for the complete data set, and Table 6b presents the analysis of data without outliers. It shows that the reception time of the second FUM is on average 1 hour and 52 minutes prior to the IAF; it could also happen that the second FUM is received with a maximum of 3 hour and 26 minutes before the IAF, but it can also be received 16 minutes after the IAF, which means that the time window for the arrival of the second FUM will last around 3 hours and 41 minutes. The standard deviation (σ) of the reception of the second FUM is 51 minutes and 22 seconds. This implies that 68.2% of the flights corresponds to a time window when the second FUM is received between 2 hours and 44 minutes and 1 hour and 1 minute before the IAF, 95.4% corresponds of a time window between 3 hours and 35 minutes and 10 minutes prior to the IAF, and 99.6% of the flights will arrive between 4 hours and 27 minutes before the IAF and 41 minutes after the IAF. The median for the reception time window of the second FUM is 1 hour and 56 minutes. Because the difference between the median and the mean is 3 minutes and 17 seconds, it can be concluded that the outliers do not influence the overall time window of the seconds FUM (Department of Education, 2015). In addition, the tables with and without outliers are the same; this is due to fact there are no flights considered as outlier.

Table 6 - Time window FUM2 winter a) with outliers b) without outliers

a) with outliers

	w_Time_window_FUM2	Time_window_std_time
mean	6769	01:52:48
std	3082	00:51:22
min	-998	23:43:22
50%	6965	01:56:05
max	12385	03:26:25

b) without outliers

	Time_window_FUM2	Time_window_std_time
mean	6769	01:52:48
std	3082	00:51:22
min	-998	23:43:22
50%	6965	01:56:05
max	12385	03:26:25

Third FUM

Table 7a presents measures of central tendency and spread of the reception time window of the third FUM of the complete set of data, while Table 7b presents the one excluding outliers. It can be seen that the reception time is on average about 1 hour and 29 minutes prior to the IAF, however, it is also possible that the third FUM is received 3 hours and 20 minutes in advance, but it can also be received 22 minutes after the IAF, which means that the time window for the arriving third FUM will last around 3 hours and 42 minutes. The standard deviation (σ) of the reception of the third FUM is 48 minutes and 54 seconds. This means that for 68.2% of the flights, the third FUM is received between 2 hours and 18 minutes and 40 minutes before the IAF, 95.4% will arrive within 3 hours and 7 minutes before the IAF and 8 minutes after the IAF, and 99.6% of the third FUM will arrive between 3 hours and 56 minutes before the IAF and 57 minutes after the IAF. The median is 1 hour and 23 minutes for the third FUM. The mean and median differ 6 minutes and 18 seconds, therefore, it can be concluded that the outliers could influence the general time window of the third FUM (Department of Education, 2015). Because there are no flights considered as outlier, the tables with and without outliers are the same.

Table 7 - Time window FUM3 winter a) with outliers b) without outliers

a) with outliers

	Time_window_FUM3	Time_window_std_time
mean	5364	01:29:23
std	2934	00:48:54
min	-1324	23:37:56
50%	4986	01:23:06
max	12036	03:20:36

b) without outliers

	Time_window_FUM3	Time_window_std_time
mean	5364	01:29:23
std	2934	00:48:54
min	-1324	23:37:56
50%	4986	01:23:06
max	12036	03:20:36

Conclusion time window FUMs

Figure 31 presents a graphical comparative representation of the reception time window of the three FUMs in the AAA system. As it can be seen, the first boxplot represents the time window of the first FUM arrived in the AAA; the second boxplot represents the second one and so on. The first FUM arrives with an average of 2 hours and 54 minutes before the IAF while the second updated message arrives with an average of 1 hour and 52 minutes before the IAF. Finally, a third FUM can arrive with an average of 1 hour and 29 minutes before the IAF. It can also be noticed that the dispersion of the reception time window of the second and third FUM is more than the reception time window of the first FUM; it can be seen that 50% of the data of the first FUM arrives between 3 hours and 2 minutes and 2 hours and 45 minutes before the IAF, which is a time interval of 17 minutes, while the 50% of the data of the second FUM arrives between 2 hours and 39 minutes and 1 hour and 9 minutes before the IAF, which is a time interval of 1 hour and 30 minutes. Finally, the 50% of the data of the third FUM arrives between 2 hours and 9 minutes and 50 minutes prior to the IAF, which is a time interval of 1 hour and 19 minutes. Therefore, further research on the triggers of the FUM is interesting

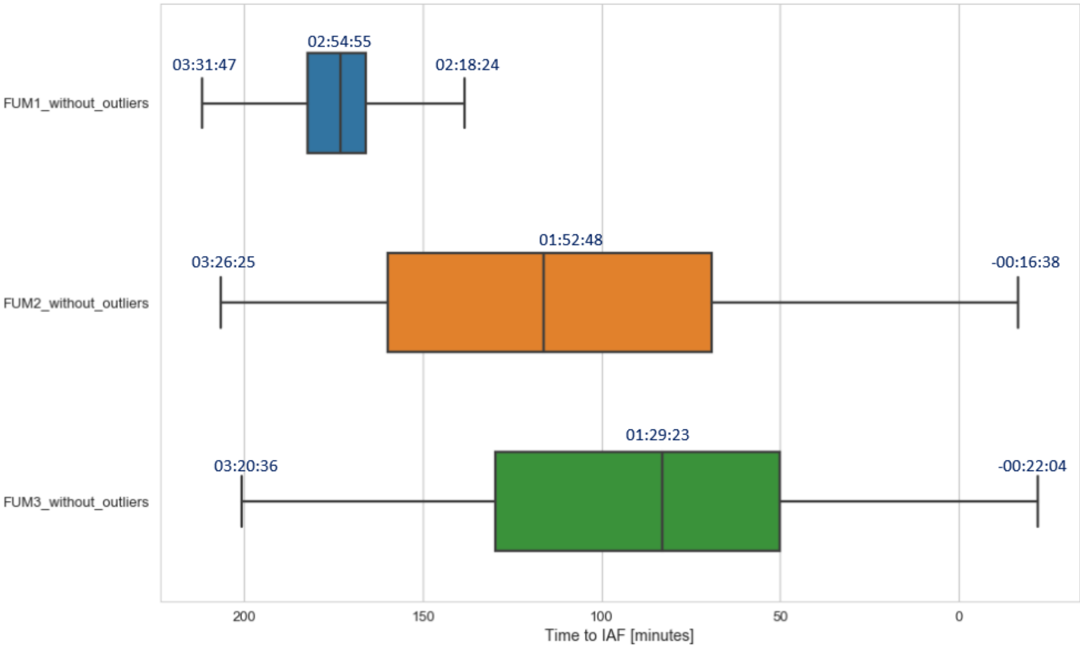

Figure 31 - Graphical comparison Time window FUMs without outliers AAA

Conclusion time window first FUM, ABI-message, ACT-message and Radar correlation

Figure 32 presents a chronological comparative analysis of the reception time window for the first time the four sources of information are used in the AAA system, to estimate the landing time of flights known as ELDT. As it can be seen, the first boxplot represents the time window of the first FUM received by AAA; the second one represents the reception time window of the ABI-message, while the third and the fourth one representing the ACT-message and radar time windows, respectively.

As it can be seen, the FUM is the earliest available source of information to estimate the landing time, with an average of 2 hours and 54 minutes before the IAF. The next source arrives with an average of 39 minutes before the IAF, which is the ABI-message; following is the ACT-message, which arrives with an average of 25 minutes before the IAF, and finally, radar correlation occurs on average 22 minutes prior to the IAF. Therefore, if looking isolated to Figure 32, it can be thought that there is a gap of no reception of information to estimate with more accuracy the landing times, however, if an overlapping of Figure 32 and Figure 31, it can be concluded that within this period, updates of FUMs can be used to estimate landing times.

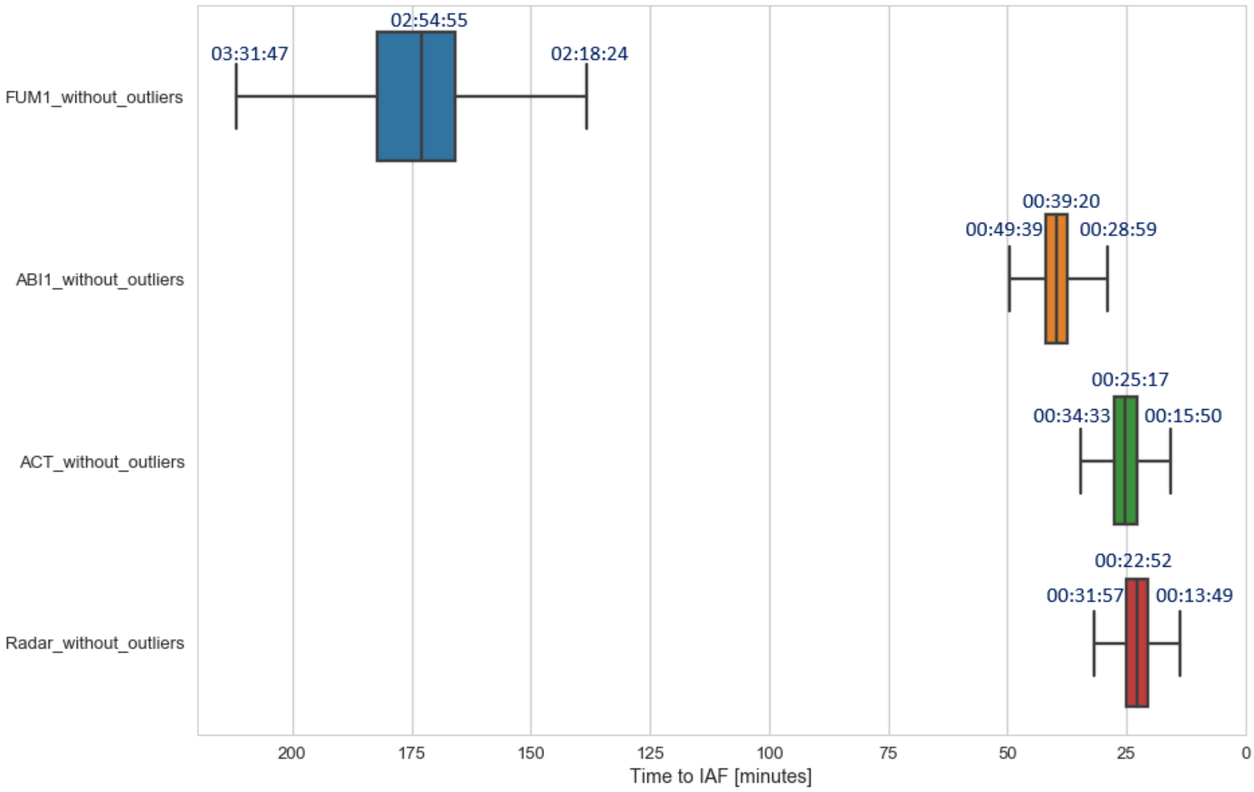

Figure 32 - Graphical comparison time windows first FUM, ABI, ACT and radar without outliers AAA

4.3 Quality of the generated landing times

The next part of the analysis aims to provide an analysis on the quality of the generated landing times; the quality is measured by subtracting the ELDT from the ALDT. It is possible that the results of this analysis are less than zero; these outcomes mean that the actual time the aircraft has landed on the runway, is earlier than the landing time that has been calculated. Table 8 presents an example of the quality to clarify this statement. This analysis will explain accuracy and quality of the calculated landing times for each source and system. The measures of central tendency and spread are determined for five different sources of information. For the AAA system, these sources are: ABI, ACT, radar and FUM; for the ASAP system, these are: ABI, ACT and the frozen planning time.

Table 8 - Calculation quality ELDT

ALDT	ELDT	ALDT - ELDT
12:00	12:05	-5 minutes
12:00	11:55	+5 minutes

AAA first ABI-message

Table 9a presents the measures of central tendency and spread of the quality of the calculated landing time, using the first ABI-message from AAA as source for the complete set of data, while Table 9b presents the analysis of the data without "outliers". It can be seen that the quality of the ELDT is on average around 2 minutes, however, it is also possible that the estimation using the first ABI-message is 59 minutes earlier than the ALDT, but in the other hand, the estimation can be -58 minutes later than the ALDT, which means that the quality of the estimation of the landing time has an interval of 1 hour and 57 minutes. The standard deviation (represented by the sigma 'σ') of the quality of the calculated landing time using the first ABI-message from AAA is 4 minutes and 51 seconds. This means that for 68.2% of the flights, the quality of the first ABI-message ELDT is between 7 minutes and -2 minutes, for 95.4% of the flights, the quality of the ELDT is between 12 minutes and -7 minutes, and for 99.6% of the flights, the quality of the ELDT is between 17 minutes and -11 minutes. The 50% percentile, also known as the median or the 'middle' value of the data set, is 2 minutes and 10 seconds. Because the mean and median only differ 19 seconds, it can be concluded that the outliers do not influence the quality of the first ABI-message ELDT of the AAA system (Department of Education, 2015).

Table 9 - Quality first ABI-message ELDT winter AAA a) with outliers b) without outliers

a) with outliers

	w_ABI1_ALDT	w_std_time_ABI1_ALDT
mean	160	00:02:39
std	292	00:04:51
min	-3509	23:01:31
50%	130	00:02:10
max	3549	00:59:09

b) without outliers

	w_ABI1_without_outliers	w_ABI1_std_time
mean	145	00:02:25
std	251	00:04:11
min	-715	23:48:05
50%	127	00:02:07
max	1035	00:17:15

Figure 33 displays the difference between the quality of the calculated landing time for the first ABI-message with and without the outliers on a more graphical manner, where the '0' is the point where the difference between the ALDT and ELDT is equal to 0. It can be seen that the data without the outliers decreases its interval from 59 minutes to 17 minutes and increases its interval from -58 minutes to -11 minutes. However, these outliers only represent 0.4% of the complete data set (350 out of 85,481). It can also be noticed that most of the outliers are positive values; this indicates that the estimation of the landing time is often earlier than the actual landing time. Further research on why the estimation is often earlier is interesting. The difference between the average estimation of the landing time with and without the outliers is 14 seconds. Therefore, as stated before, the outliers do not influence the overall analyses further presented on the quality.

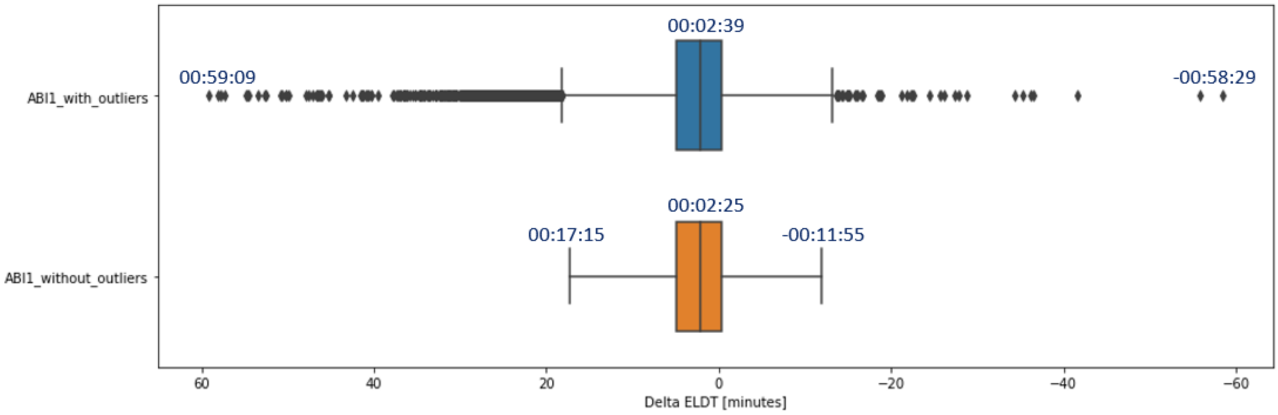

Figure 33 - Graphical comparison quality ELDT first ABI-message with & without outliers AAA

AAA ACT-message

Table 10a presents the measures of central tendency and spread of the quality of the calculated landing time, using the ACT-message from AAA as source for the complete data set, and Table 10b presents the one excluding the outliers. It shows that the quality of the ELDT is on average about 2 minutes, however, it could also happen that the estimation using the ACT-message is 59 minutes earlier than the ALDT, but the estimation can be -51 minutes later than the ALDT, which means that the quality of the estimation of the landing time has an interval of 1 hour and 50 minutes. The standard deviation (σ) of the quality of the calculated landing time using the ACT-message from AAA is 4 minutes and 26 seconds. This implies that for 68.2% of the flights, the quality of the ACT-message ELDT is between 6 minutes and -2 minutes, for 95.4% of the flights, the quality of the ELDT is between 11 minutes and -6 minutes, and for 99.6% of the flights, the quality of the ELDT is between 15 minutes and -11 minutes. The median of the quality of the ACT-message ELDT is 1 minute and 34 seconds. Due to the fact that the mean and median only differ 38 seconds, it can be concluded that the outliers do not influence the quality of the ACT-message ELDT of the AAA system (Department of Education, 2015).

Table 10 - Quality ACT-message ELDT winter AAA a) with outliers b) without outliers

a) with outliers

	w_ACT_ALDT	w_std_time_ACT_ALDT
mean	132	00:02:12
std	267	00:04:26
min	-3067	23:08:53
50%	94	00:01:34
max	3598	00:59:58

b) without outliers

	w_ACT_without_outliers	w_ACT_std_time
mean	116	00:01:55
std	221	00:03:40
min	-668	23:48:52
50%	91	00:01:31
max	932	00:15:32

Figure 34 shows the difference between the quality of the calculated landing time for the ACT-message with and without the outliers on a graphical manner, where the '0' is the point where the difference between the ALDT and ELDT is equal to 0. The data without the outliers decreases its interval from 59 minutes to 15 minutes and increases its interval from -51 minutes to -11 minutes. However, these outliers only represent 0.4% of the complete data set (480 out of 117,224). It can also be noticed that most of the outliers are positive values; this indicates that the estimation of the landing time is often earlier than the actual landing time. Further research on why the estimation is often earlier is interesting. The difference between the average estimation of the landing time with and without outliers is 17 seconds. Therefore, as stated before, the outliers do not influence the overall analyses further presented on the quality.

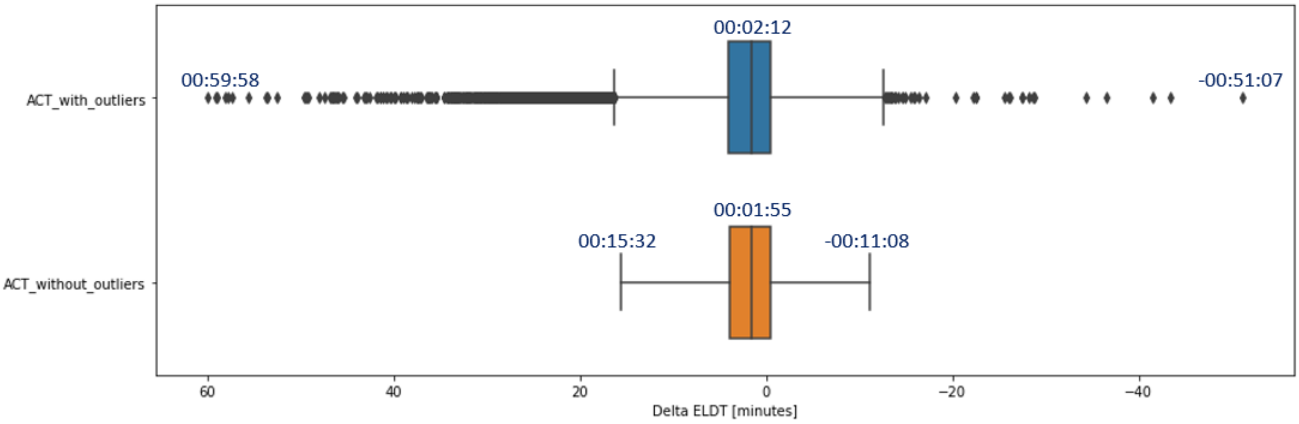

Figure 34 - Graphical comparison quality ELDT ACT-message with & without outliers AAA

AAA radar correlation

Table 11a presents the measures of central tendency and spread of the quality of the calculated landing time, using the radar correlation from AAA as source for the complete data set, while Table 11b presents the analysis of the data without outliers. It can be seen that the quality of the ELDT is on average 1 minutes, however, it is also possible that the estimation using the radar correlation is 59 minutes earlier than the ELDT, and even -33 minutes later than the ALDT, which means that the estimation of the landing time has an interval of 1 hour and 32 minutes The standard deviation (σ) of the quality of the calculated landing time using the radar correlation from AAA is 4 minutes and 19 seconds. This means that for 68.2% of the flights, the quality of the radar correlation ELDT is between 5 minutes and -2 minutes, for 95.4% of the flights, the quality of the ELDT is between 10 minutes and -7 minutes, and for 99.6% of the flights, the quality of the ELDT is between 14 minutes and -11 minutes. The median of the quality of the radar correlation ELDT is 59 seconds. The difference between the median and the mean is 35 seconds, therefore, it can be concluded that the outliers do not influence the quality of the radar correlation ELDT of the AAA system (Department of Education, 2015).

Table 11 - Quality radar correlation ELDT winter AAA a) with outliers b) without outliers

a) with outliers

	w_radar_ALDT	w_std_time_radar_ALDT
mean	95	00:01:34
std	259	00:04:19
min	-1987	23:26:53
50%	59	00:00:59
max	3571	00:59:31

b) without outliers

	w_radar_without_outliers	w_radar_std_time
mean	79	00:01:18
std	213	00:03:33
min	-680	23:48:40
50%	56	00:00:56
max	871	00:14:31

Figure 35 displays the difference between the quality of the calculated landing time for the radar correlation with and without the outliers in a more graphical way, where the '0' is the point where the difference between the ALDT and ELDT is equal to 0. It can be seen that the data without the outliers decreases its interval from 59 minutes to 14 minutes and increases its interval from -33 minutes to -11 minutes. However, these outliers only represent 0.4% of the complete data set (470 out of 117,224). It can also be noticed that most of the outliers are positive values; this means that the estimation of the landing time is often earlier than the actual landing time. Further research on why the estimation is often earlier is interesting. The difference between the average estimation of the landing time with and without outliers is 16 seconds, and therefore, the outliers do not influence the general analyses further presented on the quality.

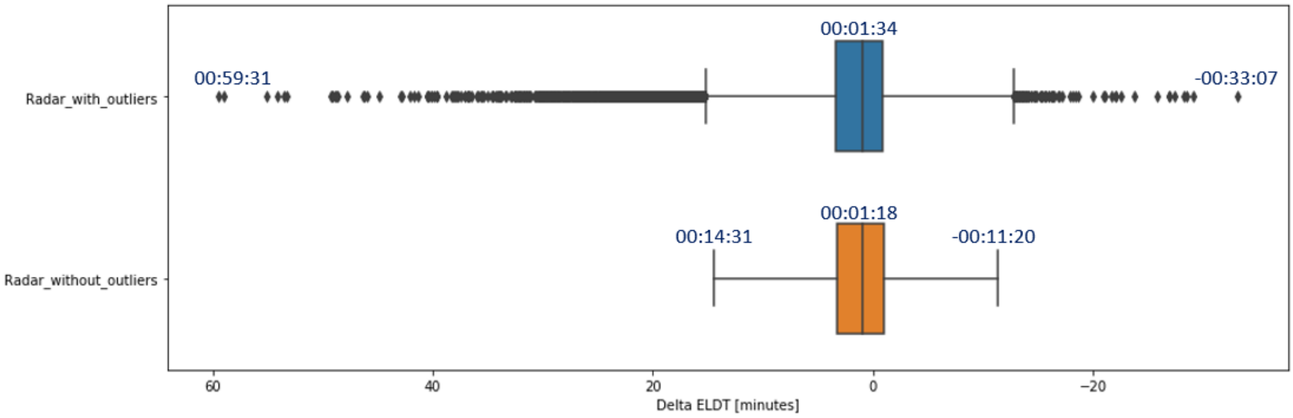

Figure 35 - Graphical comparison quality ELDT radar correlation with & without outliers AAA

AAA first FUM

Table 12a presents the measures of central tendency and spread of the quality of the calculated landing time, using the first FUM from AAA as source for the set of data, while Table 12b illustrates the analysis of the one excluding the outliers. It can be seen that the quality of the ELDT is on average 4 minutes, however, it is also possible that the estimation using the first FUM is 1 hour and 59 minutes earlier than the ELDT, but in the other hand, the estimation can be 1 hour and 59 minutes later than the ALDT, which means that the quality of the estimation of the landing time has an interval of 3 hours and 58 minutes. The standard deviation (σ) of the quality of the calculated landing time using the first FUM from AAA is 16 minutes and 26 seconds. This means that for 68.2% of the flights, the quality of the first FUM ELDT is between 21 minutes and -11 minutes, for 95.4% of the flights, the quality of the ELDT is between 37 minutes and -28 minutes, and for 99.6% of the flights, the quality of the ELDT is between 54 minutes and -44 minutes. The median of the quality of the first FUM ELDT is 3 minutes and 54 seconds. Because the mean and median differ 54 seconds, it can be concluded that the outliers do not influence the quality of the first FUM ELDT of the AAA system (Department of Education, 2015).

Table 12 - Quality first FUM ELDT winter AAA a) with outliers b) without outliers

a) with outliers

	w_FUM1_ALDT	w_std_time_FUM1_ALDT
mean	289	00:04:48
std	987	00:16:26
min	-7192	22:00:08
50%	234	00:03:54
max	7159	01:59:19

b) without outliers

	w_FUM1_without_outliers	w_FUM1_std_time
mean	278	00:04:37
std	768	00:12:47
min	-2671	23:15:29
50%	231	00:03:51
max	3248	00:54:08

Figure 36 presents the difference between the quality of the calculated landing time for the first FUM with and without the outliers on a more graphical manner, where the '0' is the point where the difference between the ALDT and ELDT is equal to 0. The data without the outliers decreases its interval from 1 hour and 59 minutes to 54 minutes and increases its interval from -1 hour and -59 minutes to -44 minutes. However, these outliers only represent 0.4% of the complete data set (470 out of 116,858). Furthermore, the difference between the average estimation of the landing time with and without outliers is 11 seconds. Therefore, as stated before, the outliers do not influence the overall analyses further presented on the quality.

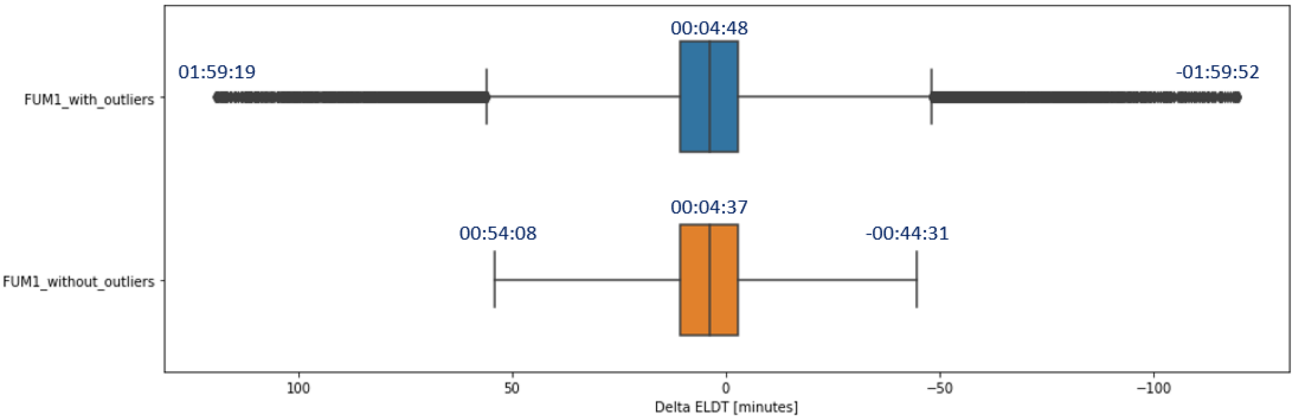

Figure 36 - Graphical comparison quality ELDT first FUM with & without outliers AAA

AAA Second FUM

Table 13a presents the measures of central tendency and spread of the quality of the calculated landing time, using the second FUM from AAA as source for the complete data set, and Table 13b presents the analysis of the data without outliers. It shows that the quality of the ELDT is on average 4 minutes; it could also happen that the estimation using the second FUM is 1 hour and 59 minutes earlier than the ELDT, but the estimation can also be 1 hour and 59 minutes later than the ALDT, which means that the quality of the estimation of the landing time has an interval of 3 hours and 58 minutes. The standard deviation (σ) of the quality of the calculated landing time using the second FUM from AAA is 14 minutes and 37 seconds. This implies that for 68.2% of the flights, the quality of the second FUM ELDT is between 19 minutes and -9 minutes, for 95.4% of the flights, the quality of the ELDT is between 34 minutes and -24 minutes, and for 99.6% of the flights, the quality of the ELDT is between 48 minutes and -39 minutes. The median of the quality of the second FUM ELDT is 4 minute and 8 seconds. Because the mean and median differ 39 seconds, it can be concluded that the outliers do not influence the quality of the second FUM ELDT of the AAA system (Department of Education, 2015).

Table 13 - Quality second FUM ELDT winter AAA a) with outliers b) without outliers

a) with outliers

	w_FUM2_ALDT	w_std_time_FUM2_ALDT
mean	287	00:04:47
std	877	00:14:37
min	-7168	22:00:32
50%	248	00:04:08
max	7182	01:59:42

b) without outliers

	w_FUM2_without_outliers	w_FUM2_std_time
mean	287	00:04:47
std	641	00:10:40
min	-2339	23:21:01
50%	247	00:04:07
max	2916	00:48:36

Figure 37 displays the difference between the quality of the calculated landing time for the second FUM with and without the outliers in a more graphical way, where the '0' is the point where the difference between the ALDT and ELDT is equal to 0. The data without the outliers decreases its interval from 1 hour and 59 minutes to 48 minutes and increases its interval from -1 hour and -59 minutes to -38 minutes. However, these outliers only represent 0.4% of the complete data set (430 out of 107,433). The difference between the average estimation of the landing time with and without outliers is 0 seconds; therefore, the outliers do not influence the overall analyses further presented on the quality

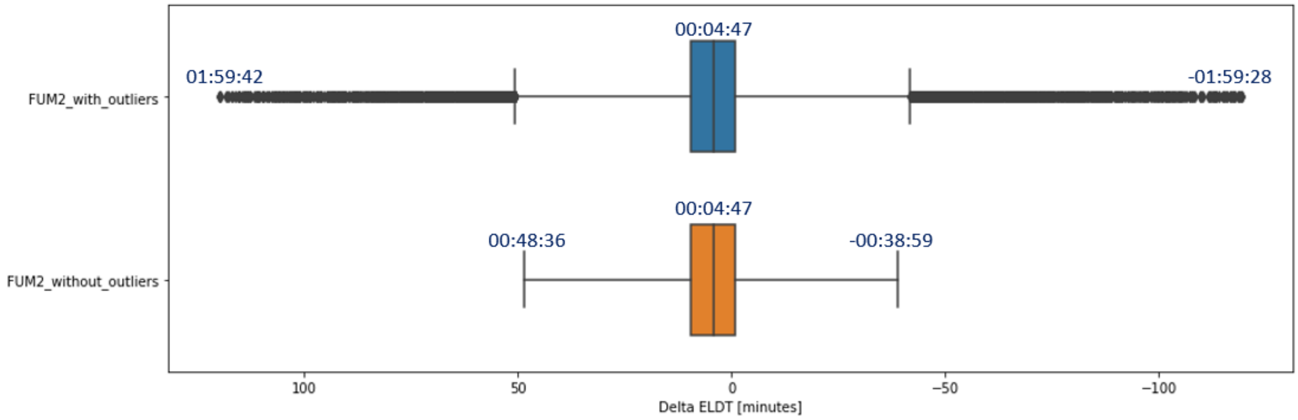

Figure 37 - Graphical comparison quality ELDT second FUM with & without outliers AAA

AAA Third FUM

Table 14a presents measures of central tendency and spread of the quality of the calculated landing time, using the third FUM from AAA as source for the complete data set, while Table 14b presents the one excluding the outliers. It can be seen that the quality of the ELDT is on average 3 minutes, however, it is also possible that the estimation using the third FUM 1 hour and 59 minutes earlier than the ELDT, and 1 hour and 59 minutes later than the ALDT, which means that the quality of the estimation of the landing time has an interval of 3 hours and 58 minutes. The standard deviation (σ) of the quality of the calculated landing time using the third FUM from AAA is 13 minutes and 41 seconds. This means that for 68.2% of the flights, the quality of the third FUM ELDT is between 17 minutes and -9 minutes, for 95.4% of the flights, the quality of the ELDT is between 31 minutes and -23 minutes, and for 99.6% of the flights, the quality of the ELDT is between 45 minutes and -37 minutes. The median of the quality of the third FUM ELDT is 3 minute and 42 seconds. Due to the fact that the mean and median only differ 17 seconds, it can be concluded that the outliers do not influence the quality of the third FUM ELDT of the AAA system (Department of Education, 2015).

Table 14 - Quality third FUM ELDT winter AAA a) with outliers b) without outliers

a) with outliers

	w_FUM3_ALDT	w_std_time_FUM3_ALDT
mean	240	00:03:59
std	822	00:13:41
min	-7188	22:00:12
50%	222	00:03:42
max	7185	01:59:45

b) without outliers

	w_FUM3_without_outliers	w_FUM3_std_time
mean	248	00:04:07
std	568	00:09:27
min	-2225	23:22:55
50%	223	00:03:43
max	2705	00:45:05

Figure 38 shows the difference between the quality of the calculated landing time for the third FUM with and without the outliers on a graphical manner, where the '0' is the point where the difference between the ALDT and ELDT is equal to 0. It can be seen that the data without the outliers decreases its interval from 1 hour and 59 minutes to 45 minutes and increases its interval from -1 hour and -59 minutes to -37 minutes. However, these outliers only represent 0.4% of the complete data set (340 out of 85,032). The difference between the average estimation of the landing time with and without outliers is 8 seconds. Therefore, as stated before, the outliers do not influence the overall analyses further presented on the quality.

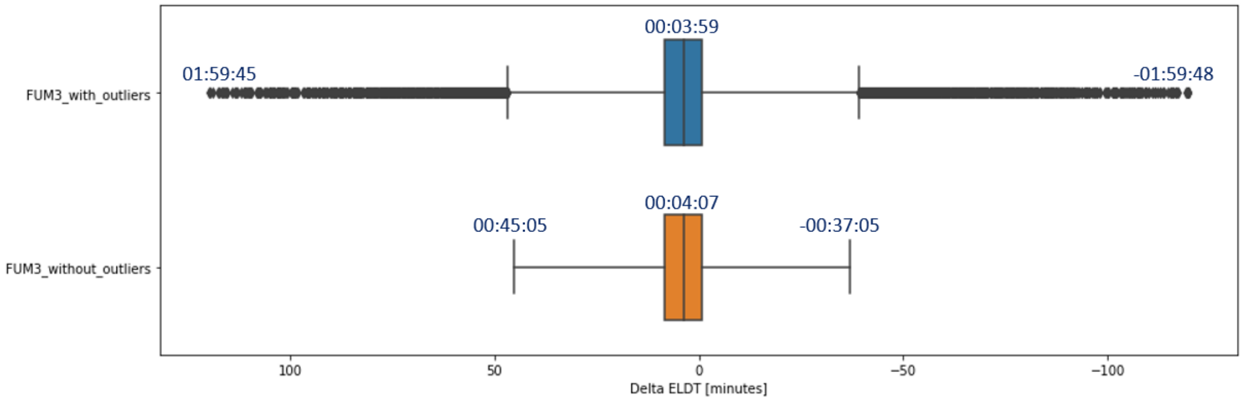

Figure 38 - Graphical comparison quality ELDT third FUM with & without outliers AAA

Conclusions quality FUMs

Figure 39 presents a graphical comparative representation of the quality of the ELDT of first three FUMs, generated by the AAA system, where the '0' is the point where the difference between the ALDT and ELDT is equal to 0. As it can be seen, the first boxplot represents the quality of the estimated landing time using the first FUM as source of information; the second boxplot represents the second FUM and the third boxplot represents the third FUM. The quality of the first FUM ELDT is on average 4 minutes and 37 seconds, while the quality of the ELDT from the second updated message is on average 4 minutes and 47 seconds. Finally, the quality of the third FUM is on average 4 minutes and 7 seconds. The FUMs are updates for the same flight, and therefore, the three FUMs behave in a similar way. The difference between the maximum and minimum averages is 40 seconds. In addition, the spread of the updates of the FUM is decreasing, but this is since the estimation of the landing time will be more accurate when the source is received later in time. For the first FUM, this was on average 2 hours and 54 minutes before the IAF, while the second and third FUM arrived on average 1 hour and 52 minutes and 1 hour and 29 minutes, respectively. Therefore, as can be concluded from this figure, the FUMs have almost the same quality (Department of Education, 2015).

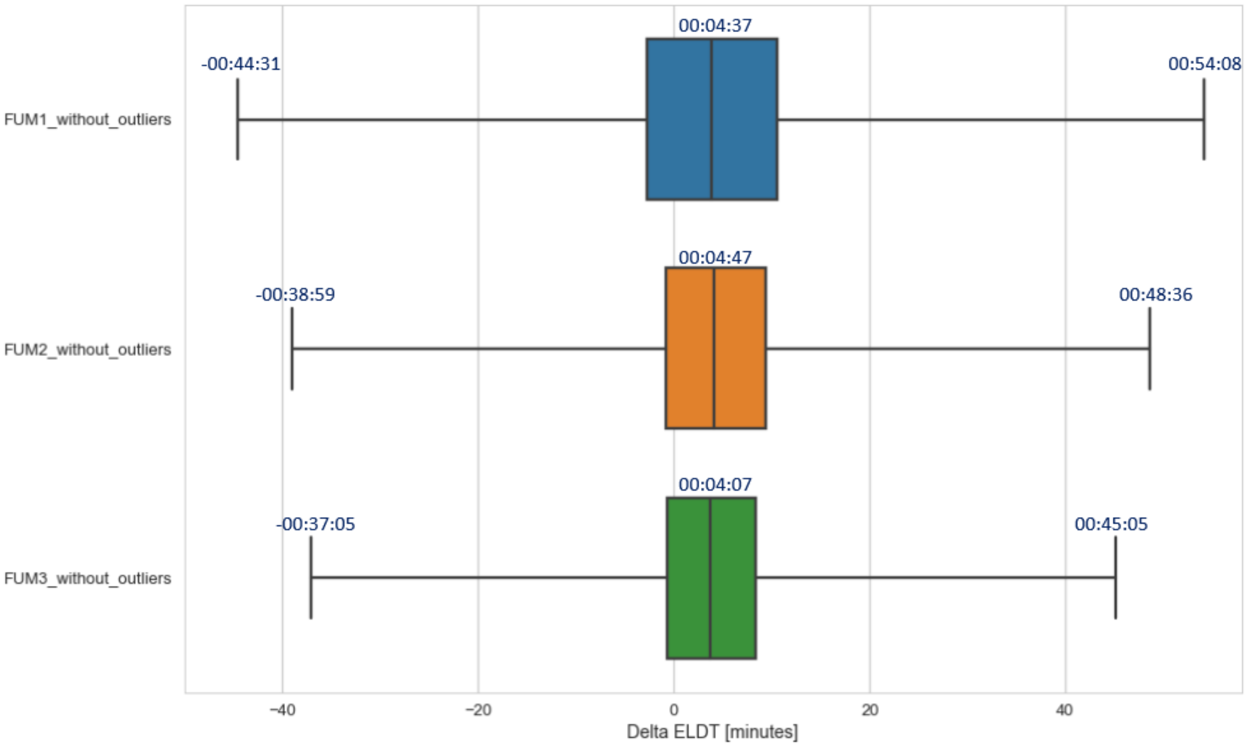

Figure 39 - Graphical comparison quality ELDT FUMs without outliers AAA

Conclusions quality ELDT of the first FUM, ABI, ACT, radar AAA
Figure 40 presents a graphical comparative illustration of four sources of information, used in the AAA system, to estimate the landing time, where the '0' is the point where the difference between the ALDT and ELDT is equal to 0. As it can be seen, the first boxplot represents the quality of the estimated landing time produced by AAA using the first FUM; the second one represents the quality of the estimated landing time using the first ABI-message as source of information, while the third and the fourth one representing the ACT-message and radar, respectively.

If the spread of the ELDT is too high, then the accuracy of ELDT decreases. As it can be seen, the maximum and minimum of the ABI-message, ACT-message and radar ELDT differ around 3 minutes. Therefore, it can be concluded that these sources behave in the same manner. However, the difference between the maximum and minimum of the first FUM and the remaining sources is almost 30 minutes. Thus, the accuracy of the FUM is spread with more than 30 minutes, and therefore, the first FUM is less accurate than the other sources. In addition, as a result of the previous analysis about the time window, the first FUM arrives on average 2 hours and 54 minutes before the IAF. The next source, which is the first ABI-message, arrives on average 39 minutes before the IAF. Because the first FUM arrives around 2 hours and 15 minutes earlier than the ABI-message, it is a reason why the first FUM is less accurate.

If the average ELDT of the input sources decreases, the quality of the ELDT increases. The difference between the average of the first FUM and the other input sources is around 3 minutes. Therefore, as can be seen from the figure, based on just the average in the figure, the radar ELDT is the most accurate, and the first FUM ELDT is the least accurate.

As explained in Section 4.2, 68.2% of the data for the first FUM lies be between 21 minutes and -11 minutes. Therefore, it can be concluded that approximately 100% of the other remaining sources, has an equal quality as 68.2% of the data from the first FUM.

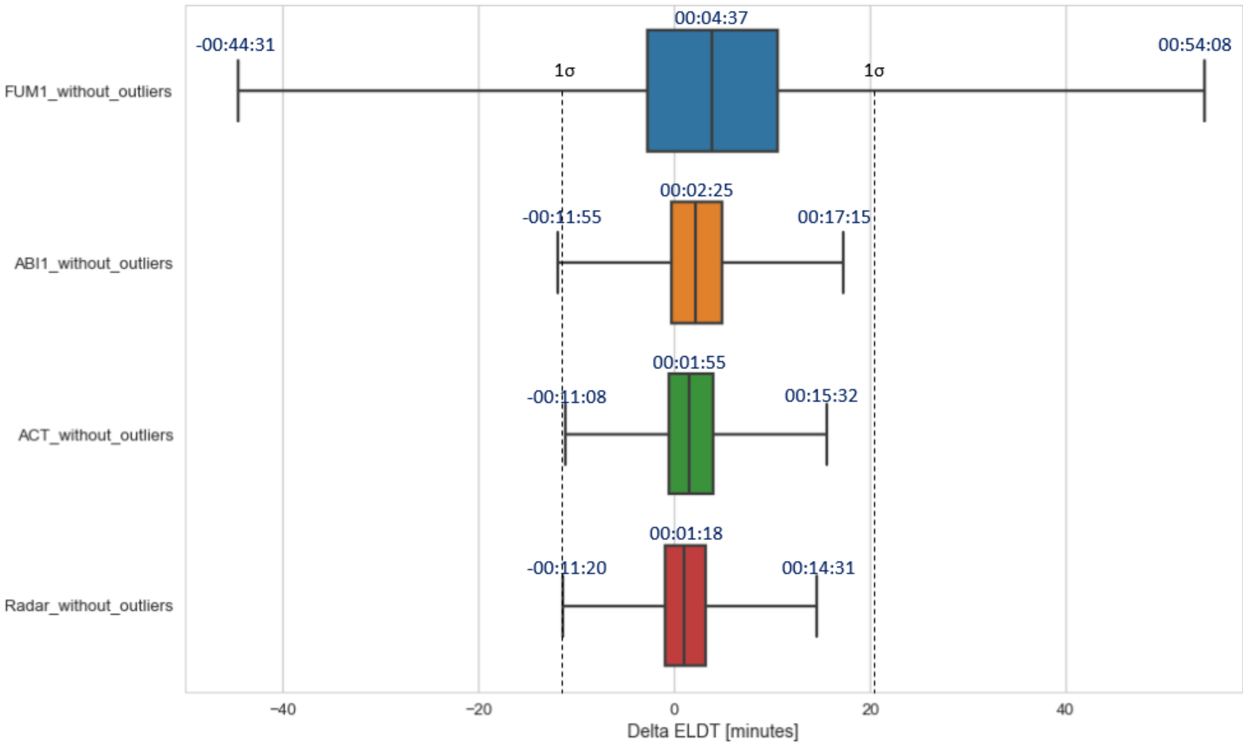

Figure 40 - Graphical comparison quality ELDT first FUM, ABI, ACT and radar without outliers AAA

ASAP first ABI-message

Table 15a presents the measures of central tendency and spread of the quality of the calculated landing time, using the first ABI-message from ASAP as source for the complete set of data, while Table 15b presents the analysis of the data without outliers. It can be seen that the quality of the ELDT is on average 2 minutes, however, it is also possible that the estimation using the first ABI-message is 58 minutes earlier than the ELDT, and even -29 minutes later than the ALDT, which means that the quality of the estimation of the landing time has an interval of 1 hour and 27 minutes. The standard deviation (represented by the sigma 'σ') of the quality of the calculated landing time using the first ABI-message from ASAP is 4 minutes and 33 seconds. This means that for 68.2% of the flights, the quality of the first ABI-message ELDT is between 6 minutes and -2 minutes, for 95.4% of the flights, the quality of the ELDT is between 11 minutes and -6 minutes, and for 99.6% of the flights, the quality of the ELDT is between 16 minutes and -11 minutes. The 50% percentile of the quality of the first ABI-message ELDT is 1 minute and 48 seconds. Because the mean and median only differ 35 seconds, it can be concluded that the outliers do not influence the quality of the first ABI-message ELDT of the ASAP system.

Table 15 - Quality first ABI-message ELDT winter ASAP a) with outliers b) without outliers

a) with outliers

	w_ABI_ALDT	w_std_time_ABI_ALDT
mean	143	00:02:23
std	274	00:04:33
min	-1775	23:30:25
50%	108	00:01:48
max	3482	00:58:02

b) without outliers

	w_ABI1_ASAP_without_outliers	w_ABI1_ASAP_std_time
mean	128	00:02:08
std	234	00:03:53
min	-677	23:48:43
50%	104	00:01:44
max	964	00:16:04

Figure 41 displays the difference between the quality of the calculated landing time for the first ABI-message with and without the outliers on a more graphical manner, where the '0' is the point where the difference between the ALDT and ELDT is equal to 0. The data without the outliers decreases its interval from 58 minutes to 16 minutes and increases its interval from -26 minutes to -11 minutes. However, these outliers only represent 0.4% of the complete data set (353 out of 85,481). It can also be noticed that most of the outliers are positive values; this indicates that the estimation of the landing time is often earlier than the actual landing time. Further research on why the estimation is often earlier is interesting. The difference between the average estimation of the landing time with and without outliers is 15 seconds. Therefore, as stated before, the outliers do not influence the overall analysis's further presented on the quality (Department of Education, 2015).

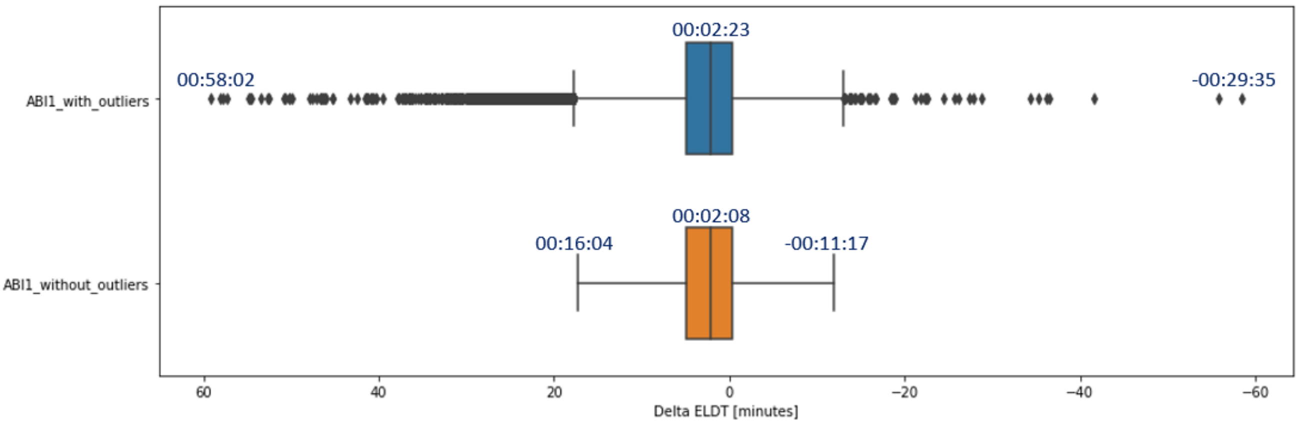

Figure 41 - Graphical comparison quality ELDT first ABI-message with & without outliers ASAP

ASAP ACT-message

Table 16a presents the measures of central tendency of the quality of the calculated landing time, using the ACT-message from ASAP as source for the complete data set, and Table 16b presents the one excluding the outliers. It shows that the quality of the ELDT is on average 2 minutes, however, it could also happen that the estimation using the ACT-message is 58 minutes earlier than the ELDT, but also -38 minutes later than the ALDT, which means that the quality of the estimation of the landing time has an interval of 1 hour and 36 minutes. The standard deviation (σ) of the quality of the calculated landing time using the ACT-message from ASAP is 3 minutes and 30 seconds. This means that for 68.2% of the flights, the quality of the ACT-message ELDT is between 6 minutes and -2 minutes, for 95.4% of the flights, the quality of the ELDT is between 11 minutes and -6 minutes, and for 99.6% of the flights, the quality of the ELDT is between 15 minutes and -11 minutes. The median of the quality of the ACT-message ELDT is 1 minute and 37 seconds. Due to the fact that the mean and median only differ 36 seconds, it can be concluded that the outliers do not influence the quality of the ACT-message ELDT of the ASAP system (Department of Education, 2015).

Table 16 - Quality ACT-message ELDT winter ASAP a) with outliers b) without outliers

a) with outliers

	w_ACT_ALDT	w_std_time_ACT_ALDT
mean	133	00:02:13
std	271	00:04:30
min	-2316	23:21:24
50%	97	00:01:37
max	3482	00:58:02

b) without outliers

	w_ACT_ASAP_without_outliers	w_ACT_ASAP_std_time
mean	118	00:01:57
std	230	00:03:50
min	-677	23:48:43
50%	94	00:01:34
max	945	00:15:45

Figure 42 shows the difference between the quality of the calculated landing time for the ACT-message with and without the outliers on a graphical manner, where the '0' is the point where the difference between the ALDT and ELDT is equal to 0. It can be seen that the data without the outliers decreases its interval from 58 minutes to 15 minutes and increases its interval from -38 minutes to -11 minutes. However, these outliers only represent 0.4% of the complete data set (473 out of 117,224). It can also be noticed that most of the outliers are positive values; this indicates that the estimation of the landing time is often earlier than the actual landing time. Further research on why the estimation is often earlier is interesting. The difference between the average estimation of the landing time with and without outliers is 16 seconds; therefore, as stated before, the outliers do not influence the overall analyses further presented on the quality.

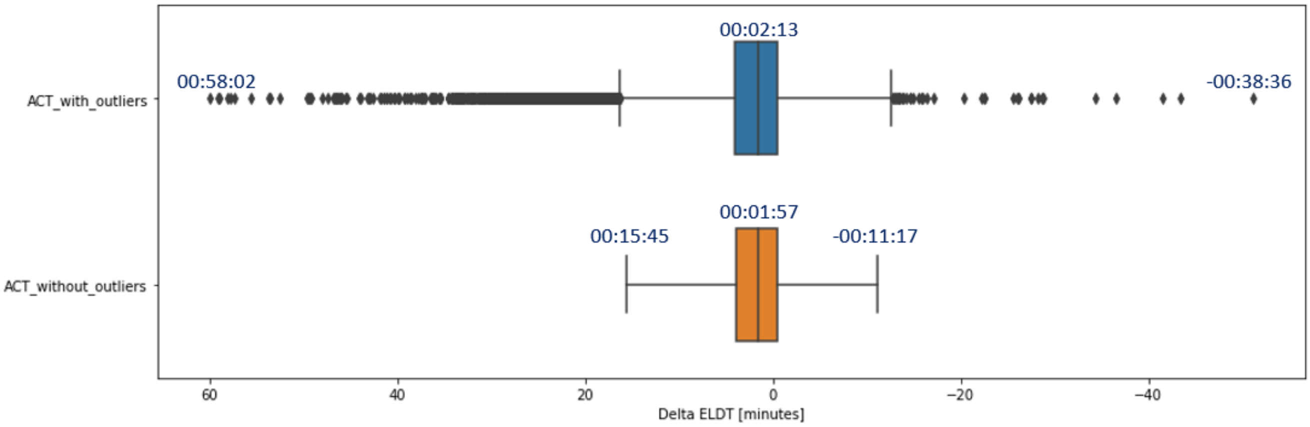

Figure 42 - Graphical comparison quality ELDT ACT-message with & without outliers ASAP

ASAP Frozen planning time

Table 17a presents measures of central tendency and spread of the quality of the calculated landing time, using the frozen planning time from ASAP as source for the complete set of data, while Table 17b presents the analysis of the data without outliers. It can be seen that the quality of the ELDT is on average 1 minute, however, it is also possible that the estimation using the frozen planning time is 59 minutes earlier than the ELDT, and even -25 minutes later than the ALDT, which means that the quality of the estimation of the landing time has an interval of 1 hour and 24 minutes. The standard deviation (σ) of the quality of the calculated landing time using the frozen planning time from ASAP is 3 minutes and 37 seconds. This implies that for 68.2% of the flights, the quality of the frozen planning time ELDT is between 5 minutes and -1 minutes, for 95.4% of the flights, the quality of the ELDT is between 9 minutes and -5 minutes, and for 99.6% of the flights, the quality of the ELDT is between 12 minutes and -8 minutes. The median of the quality of the frozen planning time ELDT is 1 minute and 16 seconds. Because the mean and median only differ 40 seconds, it can be concluded that the outliers do not influence the quality of the frozen planning time ELDT of the ASAP system (Department of Education, 2015).

Table 17 - Quality frozen planning time ELDT winter ASAP a) with outliers b) without outliers

a) with outliers

	w_slot_ALDT	w_std_time_slot_ALDT
mean	116	00:01:56
std	218	00:03:37
min	-1551	23:34:09
50%	76	00:01:16
max	3558	00:59:18

b) without outliers

	w_slot_without_outliers	w_slot_std_time
mean	100	00:01:40
std	176	00:02:55
min	-533	23:51:07
50%	73	00:01:13
max	769	00:12:49

Figure 43 presents the difference between the quality of the calculated landing time for the frozen planning time with and without the outliers in a more graphical way, where the '0' is the point where the difference between the ALDT and ELDT is equal to 0. The data without the outliers decreases its interval from 59 minutes to 12 minutes and increases its interval from -25 minutes to -8 minutes. However, these outliers only represent 0.4% of the complete data set (467 out of 117,224). It can also be noticed that most of the outliers are positive values; this indicates that the estimation of the landing time is often earlier than the actual landing time. Further research on why the estimation is often earlier is interesting. The difference between the average estimation with and without outliers is 16 seconds. Therefore, the outliers do not influence the overall analyses further presented on the quality.

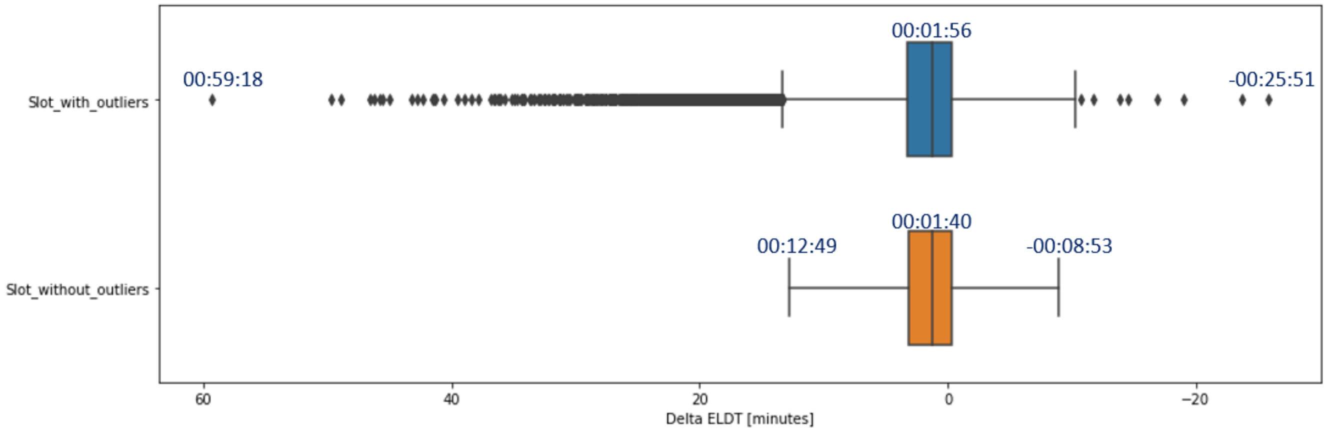

Figure 43 - Graphical comparison quality ELDT frozen planning time with & without outliers ASAP

Conclusions ABI, ACT and slot ASAP

Figure 44 presents a graphical comparative representation of three sources of information, used in the ASAP system, to determine the landing time, where the '0' is the point where the difference between the ALDT and ELDT is equal to 0. As it can be seen, the first boxplot represents the quality of the estimated landing time produced by AAA using the first ABI-message as source of information; the second boxplot represents the quality using the ACT-message as source of information, while the third representing the frozen planning time (slot time).

If the spread of the ELDT is too high, then the accuracy of the ELDT decreases. The first ABI-message and the ACT-message are almost similar, however, the spread of the frozen planning time ELDT has a difference of around 3 minutes with the remaining sources. Therefore, it can be concluded from this figure, based on the spread of the source of information, the frozen planning time ELDT is the most accurate.

If the average ELDT of the input sources decreases, the quality of ELDT increases. As it can be seen, the average ELDT from the first ABI-message decreases with 26 seconds to the ACT-message, then the average of the ACT-message decreases with 17 seconds. Therefore, it can be concluded from this figure that the frozen planning time ELDT is the most accurate.

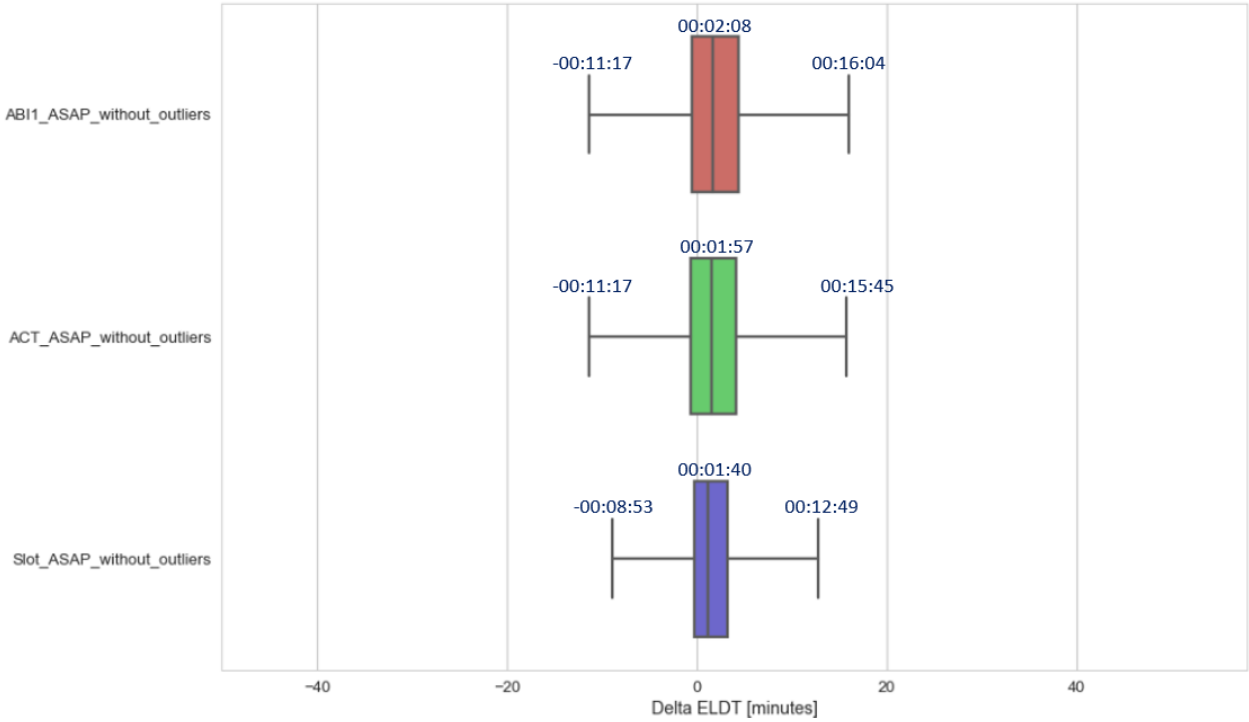

Figure 44 - Graphical comparison quality ELDT first ABI, ACT and slot without outliers ASAP

4.4 Comparison between the AAA ELDTs and the ASAP ELDTs

Figure 45 presents a graphical comparative representation of four sources of information, used in the AAA and ASAP system, to estimate the landing time, where the '0' is the point where the difference between the ALDT and ELDT is equal to 0. As it can be seen, the first boxplot represents the quality of the estimated landing time produced by AAA using the first ABI-message as source of information; the second boxplot represents the quality of the estimated landing time produced by the ASAP system using the first ABI-message, while the third and fourth boxplots represents the quality of estimated landing time using the ACT-message produced by respectively AAA and ASAP.

If the average ELDT of the input sources decreases, the quality of the ELDT increases. As it can be seen, the difference between the average of the first ABI-message from the AAA and ASAP system is 17 seconds. The difference between the average of the ACT-message from the AAA and ASAP system is 2 seconds. In addition, the difference of the spread of all the sources is around 1 minute. Therefore, it can be concluded from this figure, that the estimations of the landing time produced by the AAA and ASAP system are almost equal in quality. In addition, the differences between ELDTs from AAA and ASAP have a maximum of 30 seconds. Therefore, it can be concluded that the AAA ELDTs and the ASAP ELDTs are almost equal, and therefore, it would not make a difference if the ASAP ELDTs would be used in the CDM platform.

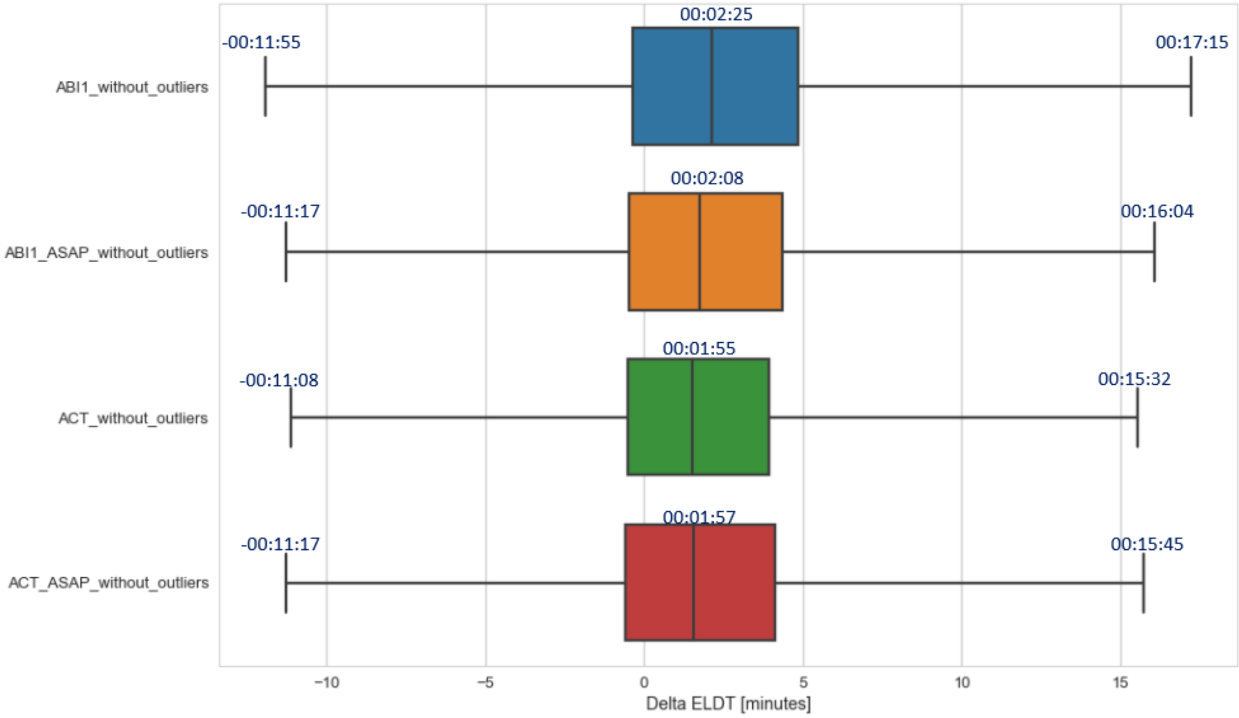

Figure 45 - Graphical comparison quality ELDT ABI, ACT AAA & ASAP

5 Research findings

The research findings describe the most important results of the carried-out data analysis, which is explained in the previous chapter. However, only the results of the analysis are stated, no conclusions or opinions are given. The first research finding clarifies how frequent the sources of information arrive during the winter and summer period, the second research finding presents the time window of the arrival of these sources, while the final research findings explains which source of information and system provides the most accurate landing time.

Results of the frequency of reception of the inbound sources of information

The first research finding, analyzed in Chapter 4.1, explains the results of the following research question:

How frequent does the sources of information arrive?

This question focusses on the frequency of the reception on four inbound sources of information: ABI, ACT, radar and FUM. The first source of information is the ABI-message, which is send by an adjacent center. For the winter and summer period, the frequency of reception is 72,95% and 71,95%, respectively. The second source of information is the ACT-message, which is also send by an adjacent center. Since the ACT-message is a mandatory message, the frequency of reception for the analyzed flights is 100%. In addition, radar correlation always occurs when the aircraft is in radar range, therefore, the frequency of reception for the analyzed flight is also 100%. The final source of information is the FUM, which is a message from Eurocontrol. The first FUM is received, for the winter and summer, 99,69% and 99,60%, respectively. For the second FUM, this has been decreased for the winter and summer to 91,65% and 91,31%, respectively. Finally, for the third FUM, the frequency of reception for the winter and summer is respectively, 72,54% and 75,61%.

Results of the time window of the reception of the inbound sources

The second research finding, described in Chapter 4.2, presents the results of the follow research question:

What is the time window of the arrival of these sources of information?

This question focusses on the time window of the arrival of the input information, described in the previous section. The initial approach fix (IAF) is used as coordination point to determine this time window. The first FUM is the earliest available source of information, with an average of 2 hour and 54 minutes before the IAF, while the second updated FUM arrives with an average of 2 hour and 54 minutes before the IAF. Finally, a third FUM can arrive with an average of 1 hour and 29 minutes prior to the IAF. The next source arrives with an average of 39 minutes before the IAF, which is the ABI-message; following is the ACT-message, which arrives with an average of 25 minutes before the IAF, and finally, the radar correlation occurs on average 22 minutes prior to the IAF.

Results of the quality of generated landing times

The final research finding, presented in Chapter 4.3, explains the results of the following research question:

"Which source of information provides the most accurate landing times on AAA and ASAP?"

This question focusses on the quality of the calculated landing times, which is measures by subtracting the ELDT from the ALDT. It is possible that the results of this analysis are less than zero; these outcomes mean that the actual time the aircraft has landed on the runway, is earlier than the landing time that has been calculated. For the AAA system, these sources are: ABI, ACT, radar and FUM; for the ASAP system, these are: ABI, ACT and the frozen planning time. The quality of the first FUM ELDT, from AAA, is on average 4 minutes and 37 seconds, while the quality of the ELDT from the second updated message is on average 4 minutes and 47 seconds. Finally, the quality of the third FUM is on average 4 minutes and 7 seconds. Furthermore, the quality of the ELDT from AAA using the first ABI-message as source is 2 minutes and 25, the following ELDT has a quality of 1 minute and 55 seconds, which is the ACT-message, while the final source from the AAA system is the radar ELDT, with an average quality of 1 minute and 18 seconds. In addition, the quality of the first ABI-message ELDT from the ASAP system, is on average 2 minutes and 23 seconds. The ACT-message ELDT from ASAP, is on average 1 minute and 57 seconds, while the quality of the final ELDT from ASAP, using the frozen planning time as source, is on average 1 minute and 40 seconds.

6 Conclusions and discussions

This chapter presents the conclusion of the thesis that answers the sub-questions and, therefore, the main research question. In addition, the discussion discusses the interpretations of the results and what the researcher could have done better. The information has been retrieved by means of desk research on the CDM manuals from Eurocontrol and Schiphol (Eurocontrol Airport CDM Team, 2017)(Schiphol Group, 2019) and the data analysis. In addition, several meetings, conversation and presentation has been conducted to get more information. This was due the fact that not all information was written in the manuals.

6.1 Conclusions

The aim of this research was to understand which system of the LVNL, Amsterdam Advanced Air traffic control system (AAA) or Advanced Schiphol Arrival Planner (ASAP), calculates the most accurate landing times. Therefore, to solve this problem the following main research questions has been formulated:

"Which system calculates the most accurate landing time to improve the outbound planning process of mainport Schiphol, the Amsterdam Advanced Air traffic control system (AAA) or the arrival manager called ASAP?"

The research started with a desk research on what the different sources of information were to calculate the landing time. The first result of this part of the main research question is Figure 46, where all the generated landing times are shown in the scope of this project, which is the moment of the reception the first ABI-message to the frozen planning time of ASAP. As shown in table, the various ELDTs have different colors, except the ELDTs from ASAP, they are all black. In addition, it is possible to receive more ABI's and FUMs, therefore, to distinguish the ELDTs from the same source and system, the letter 'X' is added to the ELDT. Because not all information is written in the manuals and to find out which organizations or persons are interesting to interview, and which stakeholders are involved in the CDM arrival process, a stakeholders analysis is performed, The most important stakeholders are LVNL, Schiphol and KLM, which are also one of the members and founders of the Knowledge and Development Centre (KDC). Additionally, to understand the relation between the different ELDTs and to see how flows through the systems, a cross-functional flow chart is made; this is the second result of this part of the main research question. The complete cross-functional flow chart is shown in appendix VI.

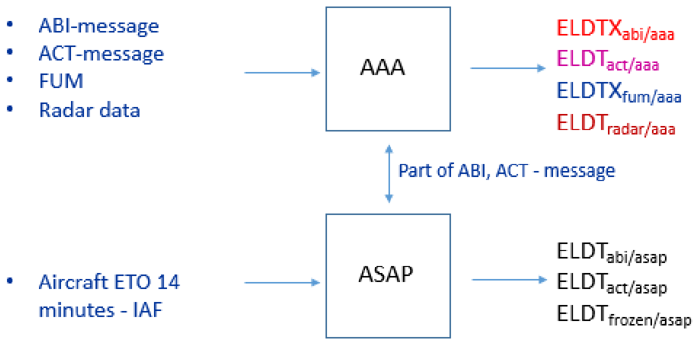

Figure 46 - Generated ELDTs

The second step of the main question is answered by means of a quantitative analysis. There have been 273,008 flights analyzed and these have been carried out in the period between October 1st, 2018 and October 31st, 2019. The data have been divided into a winter period and a summer period. The winter period commences at October 1st, 2018 and ends at March 31st, 2019 with 117,224 flights, and the summer period starts at April 1st, 2019 and ends at October 31st, 2019 with 155,784 flights.

The analysis has been divided into four main parts, the first one aims to provide a frequency analysis on four inbound sources of information: ABI, ACT, radar and FUM. The reception of the ABI-message depends on the agreements the LVNL has with the adjacent centers. The sending of a FUM could depend on various reasons, such as change of flights status or if the ELDT changes more than +-5 minutes. This analysis shows that the frequency of the ABI-message is 72,92% for the winter period, and the frequency of the first, second and third FUM are respectively 99,96%, 91,65% and 72,54%. Finally, the frequency of the ACT-message and radar correlation is 100%. In addition, an analysis on the frequency of reception per arriving sector of the first ABI-message and FUM has been conducted. The results of this analysis concluded that aircraft enter the Dutch airspace via sector 3, has the lowest frequency of reception for the first ABI-message, namely 4,27%; the other sectors are almost 100%. Therefore, it can be concluded that LVNL has less agreements with the adjacent centers in sector 3, than in the other sectors. In addition, the frequency of reception of the FUM is still almost 100% for each sector. Therefore, it could be concluded that the sector does not influence the sending of the FUM.

The second part of the quantitative analysis provides an analysis on the time window of the arrival of the same four inbound sources of information. The coordination point, that is used to determine the time window, is the Initial Approach Fix (IAF). The measures of central tendency and spread are determined for four sources of information. The first FUM is the earliest available source of information to estimate the landing time, with an average of 2 hours and 54 minutes before the IAF, while the second updated FUM arrives with an average of 1 hour and 52 minutes before the IAF. Finally, a third FUM can arrive with an average of 1 hour and 29 minutes before the IAF. The next source arrives with an average of 39 minutes before the IAF, which is the ABI-message; following is the ACT-message, which arrives with an average of 25 minutes before the IAF, and finally, radar correlation occurs on average 22 minutes prior to the IAF. Therefore, it can be thought that between the first FUM and the first ABI-message, there is a gap of new information to estimate with more accuracy the landing time. However, it can be concluded that within this period, updated of FUMs can be used to estimate the landing time.

The next part of the analysis aims to provide an analysis on the quality of the generated landing times of five inbound sources of information. For the AAA system, these sources are: ABI, ACT, radar and FUM; for the ASAP system, these are: ABI, ACT and the frozen planning time. The measures of central tendency and spread are determined for all these different sources of information. It is possible that the results of this analysis are less than zero; these outcomes mean that the actual time the aircraft has landed on the runway, is earlier than the landing time that has been calculated.

The quality of the fist FUM ELDT is on average 4 minutes and 37 seconds, while the quality of the ELDT second updated message is on average 4 minutes and 47 seconds. Finally, the quality of the third FUM is on average 4 minutes and 7 seconds. The FUMs are updates for the same flight, and therefore, the three FUMs behave in a similar way. The quality of the ELDT from the AAA and ASAP system using the first ABI-message is on average 2 minutes and 25 seconds and 2 minutes and 8 seconds, respectively. The quality of the ELDT from the AAA and ASAP system using the ACT-message is on average 1 minute and 55 seconds and 1 minute and 57 seconds, respectively. The quality of the radar ELDT produced by the AAA system is on average 1 minute and 18 seconds, while the frozen planning time ELDT, produced by the ASAP system is on average 1 minute and 40 seconds. First, if the spread of the ELDT is too high, then the accuracy of ELDT decreases. The difference between the maximum and minimum of the first FUM and the remaining sources from AAA is almost 30 minutes. Thus, the accuracy of the FUM is spread with more than 30 minutes, and therefore, the first FUM is less accurate than the other sources. In addition, if the average ELDT of the input sources decreases, the quality of the ELDT increases. It was found that the difference between the average ELDTs of the FUMs and the other input sources differ around 2 minutes. However, the FUM arrives earlier in time than the other sources, and therefore, it could be a reason the quality is less accurate.

So, it was found that the radar correlation is most interesting as ELDT source for the outbound planning process. The availability of this source is 100% and the accuracy of the arrival time estimate is 1 minute and 18 seconds.

Finally, the last part of the analysis provides a comparative analysis between the ELDTs generated by the AAA system and the ELDTs generated by the ASAP system. It was found that the differences between ELDTs from AAA and ASAP have a maximum of 30 seconds, therefore, it can be concluded that the quality of the estimation of the landing from both systems is almost equal.

6.2 Discussion

The challenge for this research was that it was not clear from the beginning how many updates of the ELDT there were in the inbound phase of the flight. Therefore, to determine a scope for this project was an issue. In addition, the quality of these updates was unclear. These problems resulted in the following main research question:

"Which system calculates the most accurate landing time to improve the outbound planning process of mainport Schiphol, the Amsterdam Advanced Air traffic control system (AAA) or the arrival manager called ASAP?"

The results indicated that there are five different sources of the ELDT in the scope of this project. From all these updates of the ELDT, the landing time generated due to the radar correlation is the most accurate ELDT. Also, the landing times generated by AAA and the landing times generated by ASAP are almost equal. The results of the data analysis were in line with the expectations made before the hand, because the later the source of information is received, and therefore, the calculation is made, the more accurate the calculation of the landing time can be.

The first limitation of this research is the size of the data set. Due to the many updates of the ELDT, there is chosen for a data set of one year. It is possible that a better indication of the quality of the ELDTs could be given, if a longer period would be analyzed. However, because most flights happen more than one time a year, it is most likely that this is not the case.

The second limitation was that there is only chosen to analyze the ELDTs generated by the systems of LVNL. Therefore, ACARS data was not included. It could be possible that the ACARS ELDT is more accurate, but for the analysis on what the most accurate source is of the LVNL, ACARS data is not relevant.

The final limitation is the fact that the analysis is only based on descriptive statistics. If the question was if the generated ELDTs has a significant difference to each other, hypotheses testing and a significance test would be interesting. However, to form a proper conclusion on what source and system calculates the most accurate landing time, descriptive statistics was enough.

7 Recommendations

The final chapter of this thesis is the recommendation. These recommendations are mainly meant for students or colleagues that wish to further analyze the different ELDTs and their quality. Additional recommendations are based on the results of the data analysis.

1. Perform further analysis on the outliers of the analyzes

These outliers are interesting, because the outliers determine whether there is a possibility for delay in the outbound planning process. Therefore, it is interesting to know what the characteristics are of these outliers, so these can be filtered out. This would improve the performance of the ELDT data source. So, the first recommendation is to further analyze the outliers of the data sets, to find a solution to prevent that these outliers occur in the future.

2. Further analysis on the quality of the ACARS ELDT

As mentioned in the discussion and the scope of this project, there is another potential data source that has not been considered: ACARS. ACARS is a digital form of radio communication between aircraft and ground stations. ACARS could be interesting to analysis, because it is another source of information that could be used to determine the ELDT. Therefore, it might be interesting to conduct an analysis on ACARS data as well.

3. Further analysis on sector 3 for the sending of the ABI-message

As shown in the analysis on the arriving sector of the first ABI-message, sector 3 is the sector where the LVNL receive the lowest amount of ABI-message. This could be caused, by the amount of agreements the LVNL has with the adjacent centers in that sector. Therefore, further analysis on which adjacent centers in sector 3 does not send the ABI-message is recommended.

4. Further research on the runway assignment at the moment of the ABI-message

The final recommendation is based on one of the possible causes of the outliers, namely the change of the runway. In the current ASAP system, the runway assignment occurs at the moment when the ABI-message is received, instead of when the ACT-message is received. Therefore, due to the fact that the ABI-message is received earlier in time, the quality of the assignment of the runway is still unclear. Thus, the next recommendation is to conduct further research on the quality of the runway assignment of ASAP at the moment of the ABI-message.

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Appendix I - Notes CDM experts meeting 24-09-2019

ELDT is not received from an adjacent center, ELDT is calculated based on the information from the adjacent center (ABI-message). ABI-message triggers the assignment of the runway. (used to be on ACT-message, now its assigned-on ASAP's ABI message)
CISS receives the ACARS
The cutover from switching from the ACARS source to the LVNL source is FIR boundary. It depends if you received an ACARS message or not.
ACARS is only available by KLM

There are other sources. If its ATC activated according to Eurocontrol, it has a higher priority than the messages from the airports. So LVNL is usually used until we use the ACARS messages and then it comes to the FIR boundary and then we use LVNL again. Unless there are no ACARS messages, then you use the LVNL.

ATC Activated is a FUM flight state field in the message from LVNL to AAS. That is used to define that is a higher priority message from LVNL. FUM flight state is communicated to the CISS.

We can receive the data earlier within that timeframe, so we must make the comparison. Make the comparisons with the ALDT.

There is the new ASAP data and the old data, what is still available in the tower system or within the LVNL. It depends what the LVNL has available, before ASAP was in place, there was other data.
The ETA's (ELDT) communicated to CISS are still AAA based, Ferdinand knows.

We currently use the calculated ELDT, which are used in operations. Hans liked to know what benefits we find if we start using this new information. It's a predictability issue. Liked the current data with the data that is available.

Between the ABI moment and the ACT, you have 3 potential sources. Source from the ABI-message, source from the ACT-message and ACARS. In addition, there is are the FUM messages, it updates the AAA ELDT. In that timeframe of ABI and ACT, the FUMs are still processed by AAA. The FUM will overwrite the ABI. At the ACT, AAA will stop processing the FUM. We have a better view of the world than the ETFMS = Enhanced Tactical Flow Management System.

FUM source can be used to evaluate in between the ABI and the ACT. There are two sources, AAA by itself or an external agency. FUM do influence until ACT. Accuracy of the ETFMS 10 years ago was bad, however it has been improved. We want to know where we are in terms of accuracy.

On the ACT you expect the predictability to be the best, improving, most current. From the ACT onwards, there are two sources that updates the ELDT. Could be that ACARS is better than the ACT. The current business rule is until FIR arrival ACARS messages are high priority.

In this period (probably between ABI and ACT) ABI message as a source, FUM as a source and ACARS as a source. In next period (probably between ACT and frozen planning time), you have ACT as a source and ACARS as a source. And after FIR boundary only ASAP as a source.

Ferdinand thinks it is not wise to use ACARS after the frozen planning, because you ignore the FIR delay, and that's not a good idea. Frozen planning time will be move upwards to 18 min hopefully in the coming year.

FUM messages in integral part of the LVNL data. It is simulated in the LVNL data.

You have ABI and ACT versus (E)ALDT. ELDT is always a moment in time, associated with a horizon. If we can have a conclusion on the predictability or the quality of the current system or calculation of the ELDT -ALDT versus what there might be. It might be as we start using ABI messages.

Catya thought the objective was to compare the two data sets in between the time span of ABI and (ACT) frozen planning time. And mainly to choose the most accurate source, so that would be like the accuracy of the data.

David said what you want to know if you would use ASAP from ABI onwards and only ASAP, if that is given a better predictability of the ALDT then using ACARS in the middle. You want to compare it to what the current output of CISS was and compare it to what if. What we are looking in is what is the best input for final ATC or LVNL procedures to get the aircraft on the ground.

It is like general CDM, that starts 3 hours in advance, where sequence information is only included 14 minutes before TOBT. But before that there is also a whole area of things that can happen on TOBT or flight plans. And that is already part of the predictability. And for landing you want to have a similar.

(We do two important assumptions; one we have the IBP system and ASAP. They are both constructed internally in a very equal manner, because of something change in this software. You have all the reasons for a different output. So, we are assuming they are completely the same. If we are looking at the accuracy of the output data, just look at the output. We must consider that there are other factors that also could have effect such as the performance of the system.)

There are two differences between ASAP and IBP. We have a new trajectory predictor, that makes the estimated times that come out of it different, because it's a different trajectory predictor. And there is a new planning algorithm. However, only the use from the planners has changed, how they modify and manipulate the planning. The ELDT are different from the systems. The output will be influenced by it. So, the input would be in link with the output, they are similar assumption.

We are looking at the accuracy of the data in this time. But also, it is important, attached to that, to make some other questions. If all the aircraft receive the ABI and ACT message. All the aircraft receive the ACT message, because it is mandatory, however not all the aircraft receive an ABI message. Only one ACT-message is received for each flight. For which flights we receive and ABI? Because the aircraft doesn't receive it! ABI's are optional.

What determines if you receive an ABI message? Those are based on agreements with each individual upstream sector, London, Brussel, Maastricht, Dusseldorf. And depending on which agreement you have with those sectors you will get that some centers will not be sent it. An ABI is a message from another ACC. They establish it through a letter of agreement, and they can agree not to send it. So, it changes from direction what you get for certain information and with which accuracy. So, the ABI are on or off on certain sectors, whether there is an agreement with an ACC. It's about 70/80% that they do send an ABI message
There are more qualitative questions, like how these process starts, who has the information, how many data sets are there. Which one in which moment they are used. Like more qualitative in order to say what's happening with the process at the beginning. Later all the information is put into ASAP, we compare the data and we came out with an accuracy. KLM receive ACARS information from the aircraft.

KLM is interested in the sector ELDT. What could we benefit for this new data source? The one is he is talking about is that we need to include ACARS. Because that is used on the airport side to determine the ELDT for the landing process. However, the first step is to look at the LNVL data and compare that and find a conclusion with the LVNL data. In a second step you could compare the results of the LVNL comparison with ACARS.

Yiannis would expect that ACARS would be more accurate early on. ASAP doesn't know necessarily about which runway there is and less the in-FIR delay. In case you don't have an ABI message, the runway assigned comes with the ACT message.

How do I compare the data if there is not an ABI message? In that case you have a late ELDT, at the ACT message, which will become known on the reception of the ACT. But the coverage has improvement very much. It's more like an exception than a rule.

A sub result could be a plot on how good the coverage of the ABI message is. How many flights receive them? If we have this basic information, we could have followed up studies for other students. If we have the ABI and its brilliant information and it would improve predictability, but its i.e. a coverage of 50% of the flights. How good is that we could move to a system with that. Hans thinks this is not a problem because if we know by the study that the data is better, then there we just must put it in the business rules of the calculation with the ELDT. So just give it a higher priority. So, if we receive it, we use it. In the end is the business rule in CDM that determine what data to use at what time. If it's available by ABI then you take it in, otherwise you go along the old way. Hans is interested in if this is better information that we should want, you use the data to give it a higher priority.

Appendix II - Explanation per stakeholder

1. [LVNL] LVNL is one of the initiators of the CDM program at Schiphol. They have a great influence on the CDM arrival process, because their systems are used in the process. Their systems generate specific times, e.g. ELDT, EIBT and TOBT, needed for the arrival process. In addition, LVNL has a significant interest in the arrival process, because they want this process to be as efficient as possible to avoid disruptions.

2. [AAS] AAS is also one of the initiators of the CDM program. Their facilities and systems on the airport are used by the airlines and ground handlers. Therefore, they have a great influence and interest in the CDM arrival process.

3. [KLM] KLM is the home carrier of Schiphol. KLM is one of the initiators of the CDM program as well. Their interest and power in the CDM arrival process is high, because they have many aircraft arrive at Schiphol. Therefore, KLM wants the arrival process to be as efficient as possible, to keep the costs as low as possible.

4. [GH] The ground handlers are responsible to make sure that the ground handling processes are finished at TOBT and to keep the TOBT accurate during the turnaround process. The ground handlers have little power in the arrival process. However, they do have interest in the arrival process, because in order to plan their work, they need to know when the aircraft will arrive at the gate.

5. [EC] Airport CDM is a program developed by Eurocontrol. It was developed because of the increasingly busy European Airspace. Therefore, Eurocontrol has power in how the process should be implemented. However, their interest on the arrival CDM process at Schiphol is limited, because they do not benefit from it directly.

6. [OA] The other airlines have a lot of interest in the CDM arrival process, because they benefit from an efficient process. However, their power is small, because they cannot adjust the process itself and have less aircraft than KLM arrive at Schiphol.

7. [IATA] IATA stands for International Air Transport Association. They created the Airline A-CDM Coordination Group (AACG). The task of the AACG is to support the global roll-out of Airport Collaborative Decision Making (A-CDM). It was created in response to the difficulties encountered by airlines with non-harmonized processes and procedures that had developed in the European A-CDM. Therefore, their power in the CDM arrival process is large. However, their interest in the CDM process of Schiphol is less, because they do not benefit from it directly.

8. [ICAO] ICAO is the abbreviation for International Civil Aviation Organization. ICAO helps to explain the general A-CDM process, but they do not explain how to implement it. Therefore, ICAO have little interest and power in the CDM arrival process at Schiphol.

9. [GOV] The government has little interest in the CDM arrival process, because they do not benefit from this process. On the contrary, their power is high, because can establish certain rules and limits my means of legislation.

Appendix III - CDM Procedure 1.3 – ELDT

Title	CDM@AMS procedure 1.3 – Update of A-CDM ELDT
Effective since	11 May 2011
Information Element	Estimated Landing Time (ELDT)
Description	The information sharing platform CISS uses various sources and events to determine the CDM estimated landing time (ELDT). This source priority sequence is used to update the ELDT: Source Prio 1: • LVNL ELDT for airborne flights with assigned landing runway Source Prio 2: • ELDT from Aircraft (Acars) received from Ground Handler KLM (Firda) Source Prio 3: • LVNL ELDT for airborne flights with no assigned landing runway (based on FUM with airborne indicator) • ELDT originating from departure at outstation (movement) received from Ground Handler KLM (Firda) • ELDT received from other Ground Handler than KLM Source Prio 4: • LVNL ELDT for non-airborne flights (based on FUM with non-airborne indicators) • ELDT originating from delay at outstation received from Ground Handler KLM (Firda) Special events: • In case of a diversion message received from LVNL the ELDT (and its source) is blanked to enable updates of new ELDT information by the Ground Handler • In case of a flight disruption such as an en-route diversion or flight return to the departure airport the information sharing platform CISS shall accept ELDT updates with non-airborne status entered by the Ground Handler in the CISS GUI. These updates will overwrite any other ELDT information except source prio 1. • In case of a flight cancellation received from the Ground Handler the ELDT (and its source) is blanked to indicate that the flight is no longer planned to arrive at Schiphol • In case of system-to-system interface failure AAS APC can manually enter an ELDT in CISS. This ELDT will overwrite any previously known ELDT.
Work Sequence	In case a new ELDT is received • If new ELDT source has higher or equal priority than current ELDT source than the current ELDT information is updated. If new ELDT source has lower priority than current ELDT source than the current ELDT information is not updated. If the flight state is DIV or CNX (current ELDT is blanked/empty) then only ELDT's from ATC with assigned landing runway (source prio 1) or ELDT updates from the GH will be accepted to update the ELDT. In case of flight state DIV • If CDM flight state DIV received from LVNL or flight state DIV set by AAS than ELDT (and its source) shall be blanked (empty) In case non-airborne ELDT from GH via CISS GUI • If ELDT update with non-airborne status is received from the GH via the CISS GUI then the ELDT (and its source) shall overwrite any other ELDT except ELDT from source prio 1. In case of flight status CNX

	• If CDM flight state CNX received from the ground handler, then ELDT (and its source) shall be blanked (empty) In case of system-to-system failure • Manually entered ELDT by AAS APC (Koepel) in CISS shall overwrite any previously known ELDT. If the CDM ELDT is updated, then it shall be distributed to relevant partners & systems
Additional Information	Clarification for identification of ELDT source 1, 3 and 4: • ELDT received from LVNL is considered source prio 1 if the inbound flight has an assigned landing runway. • ELDT received from LVNL is considered source prio 3 if the inbound flight has no assigned landing runway and FUM flight state is AA. • ELDT received from LVNL is considered source prio 4 if the inbound flight has no assigned landing runway and FUM flight state is not AA.

Appendix IV - Preview of the data set

Figure 47 presents a preview of the first five flights of the complete data set. Each row represents a different flight. The ELDTs are in a unit called: Unix Epoch. The Unix epoch is the number of seconds that have elapsed since January 1st, 1970. This method allows systems to understand time correctly (EpochConverter, 2019).

	Date	EOBT	Acid	Airline	ADEP	ADES	A/C_type	WTC	Entry_sector	STAR_id	IAF_name	Time_IAF	Time_ABI1_AAA	ELDT_ABI1_AAA
0	20181001	1538320200	KLM894	KLM	ZSPD	EHAM	B789	H	1	EEL1A	ARTIP	1538359777	1538357620	1538360924
1	20181001	1538320800	KLM810	KLM	WMKK	EHAM	B772	H	2	NKU2A	ARTIP	1538364856	1538362502	1538365777
2	20181001	1538322900	KLM808	KLM	RCTP	EHAM	B77W	H	1	EEL1A	ARTIP	1538366353	1538363920	1538367208
3	20181001	1538322900	KLM856	KLM	RKSI	EHAM	B744	H	1	EEL1A	ARTIP	1538361366	1538359133	1538362429
4	20181001	1538322900	SIA324	SIA	WSSS	EHAM	A359	H	2	NKU2A	ARTIP	1538368589	1538366100	1538369367

	Time_ABI2_AAA	ELDT_ABI2_AAA	Time_ABI3_AAA	ELDT_ABI3_AAA	Time_ABI4_AAA	ELDT_ABI4_AAA	Time_ABI5_AAA	ELDT_ABI5_AAA
0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0

	Time_ABI6_AAA	ELDT_ABI6_AAA	Time_ACT_AAA	ELDT_ACT_AAA	Time_FUM1_AAA	ELDT_FUM1_AAA	Time_FUM2_AAA	ELDT_FUM2_AAA
0	0	0	1538358298	1538360864	1538349542	1538360292	0	0
1	0	0	1538363301	1538365881	1538354510	1538365290	0	0
2	0	0	1538364760	1538367326	1538354659	1538367304	1538356281	1538367338
3	0	0	1538359878	1538362492	1538351359	1538362033	0	0
4	0	0	1538366934	1538369487	1538357667	1538368919	0	0

	Time_FUM3_AAA	ELDT_FUM3_AAA	Time_radar_AAA	ELDT_radar_AAA	Time_slot_AAA	ELDT_slot_AAA	ALDT	ELDT_ABI_ASAP
0	0	0	1538358454	1538360932	1538359049	1538360867	1538360685	1538361022
1	0	0	1538363610	1538365880	1538364030	1538365840	1538365820	1538365853
2	1538359227	1538367026	1538365060	1538367510	1538365500	1538367303	1538367316	1538367251
3	0	0	1538359981	1538362544	1538360643	1538362460	1538362308	1538362472
4	0	0	1538367203	1538369504	1538367680	1538369352	1538369346	1538369462

	ELDT_ACT_ASAP	Predicted_rwy	Actual_rwy
0	1538361022	6	6
1	1538365853	6	6
2	1538367251	6	6
3	1538362472	6	6
4	1538369462	6	36R

Figure 47 - Complete data set

Appendix V - Data analysis tables summer

4.2 Analysis on the accuracy of the sources of information arriving

First ABI-message

Table 18 - Time window ABI-message summer a) with outliers b) without outliers

a) with outliers

	Time_window_ABI1	Time_window_std_time
mean	2341	00:39:01
std	341	00:05:40
min	351	00:05:51
50%	2368	00:39:28
max	10757	02:59:17

b) without outliers

	Time_window_ABI1	Time_window_std_time
mean	2372	00:39:31
std	225	00:03:44
min	1787	00:29:47
50%	2379	00:39:39
max	2942	00:49:02

ACT-message

Table 19 - Time window ACT-message summer a) with outliers b) without outliers

a) with outliers

	s_Time_window_ACT	Time_window_std_time
mean	1507	00:25:07
std	250	00:04:10
min	230	00:03:50
50%	1516	00:25:16
max	9986	02:46:26

b) without outliers

	Time_window_ACT	Time_window_std_time
mean	1505	00:25:04
std	204	00:03:23
min	889	00:14:49
50%	1516	00:25:16
max	2107	00:35:07

Radar correlation

Table 20 - Time window radar correlation summer a) with outliers b) without outliers

a) with outliers

	Time_window_radar	Time_window_std_time
mean	1415	00:23:35
std	538	00:08:57
min	53	00:00:53
50%	1375	00:22:55
max	13995	03:53:15

b) without outliers

	Time_window_radar	Time_window_std_time
mean	1391	00:23:10
std	206	00:03:25
min	784	00:13:04
50%	1373	00:22:53
max	2003	00:33:23

First FUM

Table 21 - Time window FUM1 summer a) with outliers b) without outliers

a) with outliers

	Time_window_FUM1	Time_window_std_time
mean	10831	03:00:30
std	1116	00:18:36
min	-785	23:46:55
50%	10689	02:58:09
max	13922	03:52:02

b) without outliers

	Time_window_FUM1	Time_window_std_time
mean	10822	03:00:22
std	862	00:14:22
min	8460	02:21:00
50%	10675	02:57:55
max	13148	03:39:08

Second FUM

Table 22 - Time window FUM2 summer a) with outliers b) without outliers

a) with outliers

	Time_window_FUM2	Time_window_std_time
mean	7575	02:06:15
std	2993	00:49:53
min	-952	23:44:08
50%	8326	02:18:46
max	12374	03:26:14

b) without outliers

	Time_window_FUM2	Time_window_std_time
mean	7575	02:06:15
std	2993	00:49:53
min	-952	23:44:08
50%	8326	02:18:46
max	12374	03:26:14

Third FUM

Table 23 - Time window FUM3 summer a) with outliers b) without outliers

a) with outliers

	Time_window_FUM3	Time_window_std_time
mean	5972	01:39:31
std	2953	00:49:13
min	-1284	23:38:36
50%	5754	01:35:54
max	11996	03:19:56

b) without outliers

	Time_window_FUM3	Time_window_std_time
mean	5972	01:39:31
std	2953	00:49:13
min	-1284	23:38:36
50%	5754	01:35:54
max	11996	03:19:56

4.3 Analysis on the quality between the generated landing times and the ALDT

First ABI-message AAA

Table 24 - Quality first ABI-message ELDT summer AAA a) with outliers b) without outliers

a) with outliers

	s_ABI1_ALDT	s_std_time_ABI1_ALDT
mean	135	00:02:15
std	283	00:04:42
min	-3600	23:00:00
50%	113	00:01:53
max	3539	00:58:59

b) without outliers

	s_Diff_ABI1_ALDT	s_diff_ABI1_ALDT_std_time
mean	118	00:01:57
std	237	00:03:56
min	-531	23:51:09
50%	107	00:01:47
max	773	00:12:53

First ABI-message ASAP

Table 25 - Quality first ABI-message ELDT summer ASAP a) with outliers b) without outliers

a) with outliers

	s_ABI_ALDT	s_std_time_ABI_ALDT
mean	131	00:02:10
std	259	00:04:18
min	-1981	23:26:59
50%	102	00:01:42
max	2811	00:46:51

b) without outliers

	s_Diff_ABI1_ASAP	s_diff_ABI1_ASAP_std_time
mean	111	00:01:50
std	214	00:03:34
min	-478	23:52:02
50%	96	00:01:36
max	706	00:11:46

ACT-message AAA

Table 26 - Quality ACT-message ELDT summer AAA a) with outliers b) without outliers

a) with outliers

	s_ACT_ALDT	s_std_time_ACT_ALDT
mean	121	00:02:01
std	247	00:04:07
min	-3600	23:00:00
50%	89	00:01:29
max	3539	00:58:59

b) without outliers

	s_Diff_ACT	s_diff_ACT_std_time
mean	99	00:01:38
std	195	00:03:15
min	-441	23:52:39
50%	82	00:01:22
max	647	00:10:47

ACT-message ASAP

Table 27 - Quality ACT-message ELDT summer ASAP a) with outliers b) without outliers

a) with outliers

	s_ACT_ALDT	s_std_time_ACT_ALDT
mean	120	00:01:59
std	254	00:04:13
min	-2700	23:15:00
50%	90	00:01:30
max	3084	00:51:24

b) without outliers

	s_Diff_ACT_ASAP	s_diff_ACT_ASAP_std_time
mean	99	00:01:39
std	207	00:03:27
min	-474	23:52:06
50%	83	00:01:23
max	678	00:11:18

Radar correlation

Table 28 - Quality radar correlation ELDT summer AAA a) with outliers b) without outliers

a) with outliers **b) without outliers**

	s_radar_ALDT	s_std_time_radar_ALDT
mean	88	00:01:27
std	247	00:04:07
min	-2559	23:17:21
50%	56	00:00:56
max	3576	00:59:36

	s_Diff_radar	s_diff_radar_std_time
mean	65	00:01:04
std	188	00:03:07
min	-451	23:52:29
50%	49	00:00:49
max	589	00:09:49

First FUM

Table 29 - Quality first FUM ELDT summer AAA a) with outliers b) without outliers

a) with outliers

	s_FUM1_ALDT	s_std_time_FUM1_ALDT
mean	282	00:04:41
std	984	00:16:23
min	-7177	22:00:23
50%	208	00:03:28
max	7196	01:59:56

b) without outliers

	s_Diff_FUM1	s_diff_FUM1_std_time
mean	188	00:03:08
std	619	00:10:18
min	-1489	23:35:11
50%	185	00:03:05
max	1911	00:31:51

Second FUM

Table 30 - Quality second FUM ELDT summer AAA a) with outliers b) without outliers

a) with outliers

	s_FUM2_ALDT	s_std_time_FUM2_ALDT
mean	249	00:04:08
std	891	00:14:51
min	-7127	22:01:13
50%	207	00:03:27
max	7193	01:59:53

b) without outliers

	s_Diff_FUM2	s_diff_FUM2_std_time
mean	199	00:03:18
std	486	00:08:06
min	-1125	23:41:15
50%	197	00:03:17
max	1547	00:25:47

Third FUM

Table 31 - Quality third FUM ELDT summer AAA a) with outliers b) without outliers

a) with outliers

	s_FUM3_ALDT	s_std_time_FUM3_ALDT
mean	207	00:03:26
std	844	00:14:04
min	-7187	22:00:13
50%	193	00:03:13
max	7200	02:00:00

b) without outliers

	s_Diff_FUM3	s_diff_FUM3_std_time
mean	191	00:03:11
std	419	00:06:59
min	-979	23:43:41
50%	189	00:03:09
max	1368	00:22:48

Frozen planning time ASAP

Table 32 - Quality frozen planning time ELDT summer ASAP a) with outliers b) without outliers

a) with outliers

	s_slot_ALDT	s_std_time_slot_ALDT
mean	117	00:01:56
std	205	00:03:24
min	-1230	23:39:30
50%	82	00:01:22
max	2403	00:40:03

b) without outliers

	s_Diff_slot	s_diff_slot_std_time
mean	93	00:01:32
std	156	00:02:36
min	-343	23:54:17
50%	74	00:01:14
max	537	00:08:57

Appendix VI - Cross functional flow chart

Objective per process

D1 - Aircraft departs outside Dutch FIR? To determine whether the aircraft departs inside or outside the Dutch FIR to expect or not an ABI & ACT message according to previous agreements.

P1 - In FIR departure: To verify the aircraft has departed from inside the Dutch airspace.

P2 - Agreement ABI-reception: To verify that the adjacent centers have agreements with the LVNL for sending the ABI-message.

D2 - Agreement to send ABI-message? To send or not send the ABI-message for calculating the ELDT.

P3 - Send ABI-message: To send the ABI-message to the LVNL (AAA) from the adjacent center for generating the ELDT.

P4 - Receive ABI-message: To receive the ABI-message from the adjacent center.

+ generate $ELDT_{abi/aaa}$: To generate the $ELDT_{abi/aaa}$, using the information received from the ABI-message, for determining the estimated landing time of the aircraft.

P5 - $ELDT_{abi/aaa}$ distributed: To distribute the $ELDT_{abi/aaa}$, received from the AAA system, to the CDM system, called CISS.

P6 - Apply business rules + show $ELDT_{abi/aaa}$: To determine which ELDT is used at what moment in time, using specific business rules implied into CISS. If the incoming $ELDT_{abi/aaa}$ has the highest or same priority as the previous ELDTs, the new ELDT is displayed in the CDM platform.

P7 - Receive specific ABI information + assign runway + generate $ELDT_{abi/asap}$: To generate the $ELDT_{abi/asap}$ and assign a runway, using a certain part of the information received from the ABI-message, for determining the used runway and estimated landing time of the aircraft.

P8 - Send runway: To send the assigned runway to the AAA system for generating a new ELDT based on the runway.

P9 - Generate $ELDT1_{rwy/aaa}$: To generate the $ELDT1_{rwy/aaa}$ based on the runway information received from ASAP, for the estimated landing time of the aircraft on that runway.

P10 - $ELDT1_{rwy/aaa}$ distributed: To distribute the $ELDT1_{rwy/aaa}$ received from AAA to the CDM system, called CISS.

P11 - Apply business rules + show $ELDT1_{rwy/aaa}$: To determine which ELDT is used at what moment in time, using specific business rules implied into CISS. If the incoming $ELDT1_{rwy/aaa}$ has the highest or same priority as the previous ELDTs, the new ELDT is displayed in the CDM platform.

P12 - Send ACT-message: To send the ACT-message to the LVNL (AAA) from the adjacent center for generating the ELDT.

P13 - Receive specific ACT information + generate $ELDT_{act/asap}$: To generate the $ELDT_{act/asap}$, using a certain part of the information received from the ACT-message, for determining the estimated landing time of the aircraft.

D3 - Runway already assigned? To determine whether the flight already received a runway for determining a new ELDT.

P14 - Assign runway + send runway: To assign and send the runway to the AAA system, in the case there is not already assigned a runway, for generating a new ELDT.

P15 - Generate $ELDT2_{rwy/aaa}$: To generate the $ELDT2_{rwy/aaa}$, based on the runway information from ASAP, for the estimated landing time of the aircraft.

P16 - $ELDT2_{rwy/aaa}$ distributed: To distribute the $ELDT2_{rwy/aaa}$ received from AAA to the CDM system, called CISS.

P17 - Apply business rules + show ELDT2$_{rwy/aaa}$: To determine which ELDT is used at what moment in time, using specific business rules implied into CISS. If the incoming ELDT2$_{rwy/aaa}$ has the highest or same priority as the previous ELDTs, the new ELDT2 is displayed in the CDM platform.

P18 – Generate ELDT$_{act/aaa}$: To generate the ELDT$_{act/aaa}$, using the information received from the ACT-message, for determining the estimated landing time of the aircraft.

P18 - Receive ACT & SSR code + generate ELDT$_{act/aaa}$: To generate the ELDT$_{act/aaa}$, using the information received from the ACT-message, for determining the estimated landing time of the aircraft. Within the ACT-message, an SSR code is provided to correlate the radar. With the SSR code and the correlation of the radar, the location of the aircraft can be determined.

P19 - ELDT$_{act/aaa}$ distributed: To distribute the ELDT$_{act/aaa}$ received from the AAA system to the CDM system, called CISS.

P20 - Apply business rules + show ELDT$_{act/aaa}$: To determine which ELDT is used at what moment in time, using specific business rules implied into CISS. If the incoming ELDT$_{act/aaa}$ has the highest or same priority as the previous ELDTs, the new ELDT$_{act/aaa}$ is displayed in the CDM platform.

P21 – SSR code received + send radar tracks: To receive the SSR code from the AAA system and send radar tracks back to the ASAP system.

P22 – Radar correlated + ELDT$_{radar/aaa}$ generated: To correlate the radar and to generate ELDT$_{radar/aaa,}$ based on the information from the correlation of the radar, for the estimated landing time of the aircraft.

P23 - ELDT$_{radar/aaa}$ distributed: To distribute ELDT$_{radar/aaa}$ received from AAA to the CDM system, called CISS.

P24 - Apply business rules + show ELDT$_{radar/aaa}$: To determine which ELDT is used at what moment in time, using specific business rules implied into CISS. If the incoming ELDT$_{radar/aaa}$ has the highest or same priority as the previous ELDTs, the new ELDT$_{radar/aaa}$ is shown in the CDM platform.

D4 – Difference ELDT +- 1 minute: To determine if the incoming new ELDT has a difference of +-1 minute to its predecessor. If so, to send it to CISS.

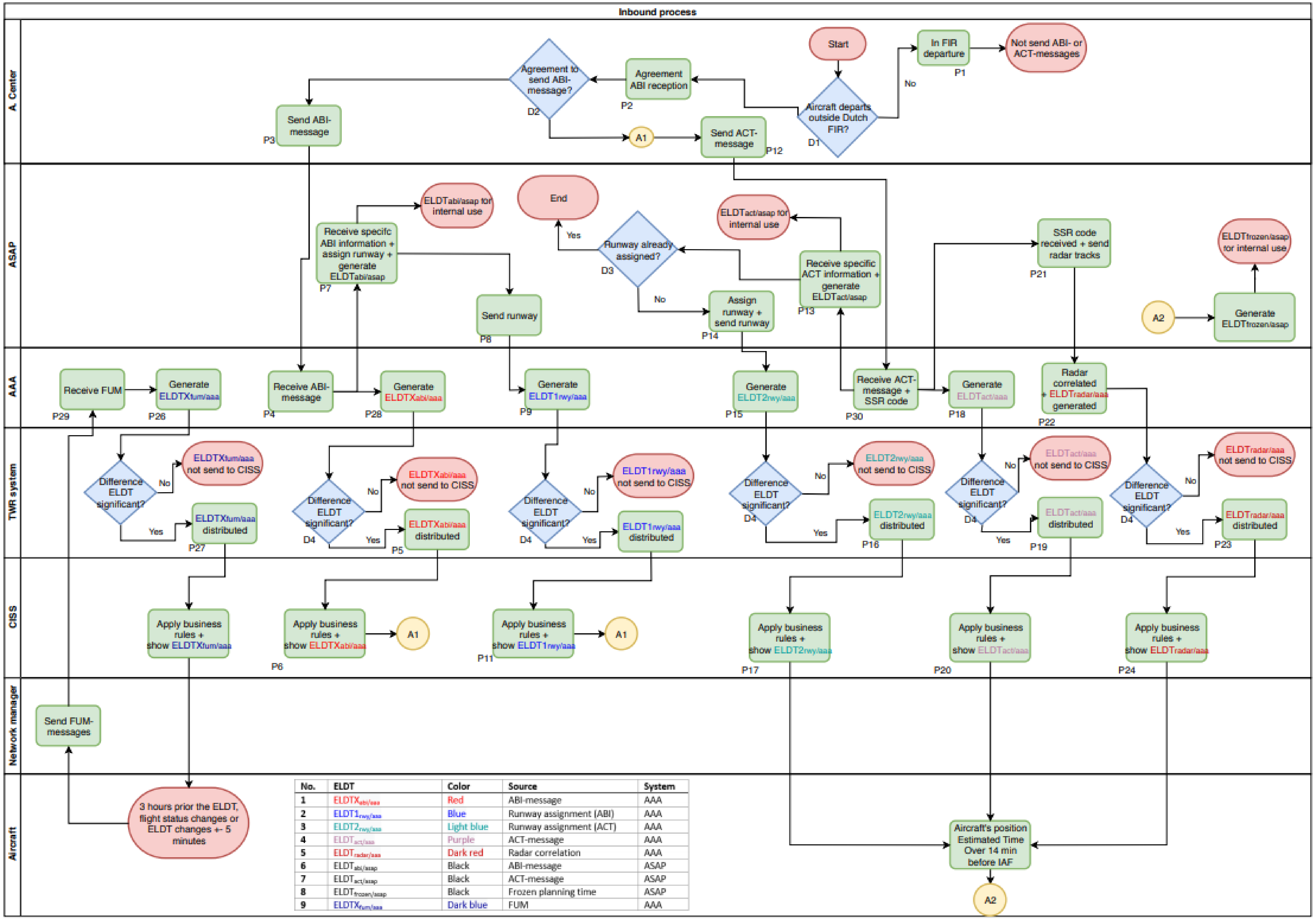
P25 - Send FUM: To send the FUM to the LVNL (AAA) from the network manager for generating the ELDT.

P26 – Receive FUM: To receive the FUM from network manager.

P27 – ELDTX$_{fum/aaa}$ generated: To generate the ELDTX$_{fum/aaa,}$ based on the information from the FUM, for the estimated landing time of the aircraft.

P28 – ELDTX$_{fum/aaa}$ distributed: To distribute the ELDTX$_{fum/aaa}$ received from the AAA system to the CDM system, called CISS.

P29 - Apply business rules + show ELDTX$_{fum/aaa}$: To determine which ELDT is used at what moment in time, using specific business rules implied into CISS. If the incoming ELDTX$_{fum/aaa}$ has the highest or same priority as the previous ELDTs, the new ELDT$_{radar/aaa}$ is displayed in the CDM platform.
P30 – Receive ACT-message + SSR code: To receive the ACT-message and SSR code from the adjacent center
P31 – Aircraft's position ETO 14 minutes before IAF: To determine whether the aircraft's position is ETO 14 minutes before the IAF
P32 – Generate ELDT$_{frozen/asap}$: To generate the ELDT$_{frozen/asap}$ based on the frozen planning time of ASAP.



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 48 - Complete cross-functional flow chart