

# Operational plan stability at Schiphol Airport

## *Analysing the causes and effects of instability in the operational plan*

Thesis



KDC Mainport Schiphol

A collaboration with the Aviation Academy, Amsterdam University of Applied Sciences

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Thesis

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## Preface

This research has been performed for the Knowledge and Development Centre – Mainport Schiphol, a collaboration of Air Traffic Control the Netherlands (LVNL), Amsterdam Airport Schiphol and KLM in collaboration with Dutch Universities such as the Amsterdam University of Applied Sciences. I have executed the research from February 2019 until July 2019. Within the research an analysis is made of the current plan stability of the airport airside ground operational system.

It turned out to be a real challenge to work in such a versatile environment in which the academic purpose of the research had to function within the business environment of the KDC stakeholders. At the same time was this challenge one of the biggest lessons in my personal development.

Overcoming the challenges would probably not have been possible without the help of Frenchez Pietersz, helping me to focus my research and getting to know all of the different structures and procedures around and inside the complex aviation environment. Not only helping me to understand but also how to communicate complex problems to others.

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Last but surely not least, I want to thank all of my fellow KDC student researchers; Anouk Hollebeek, Flore Wassenberg, Femke Mollema and Kyara Metz, for all the times you; were available to help me, listen to me, think with me and made me laugh realizing that the most important thing in life are your family and friends.

Sybrén Kuiper

## Abstract

Over the last years Schiphol has grown in the amount of movements. As a side effect of the current capacity limit, the ratio of narrow-body to wide-body aircraft has changed with a higher amount of wide-body aircraft. The combination of more and different aircraft has increased the pressure on the airside ground operation capacity.

Due to the lack of free capacity during the peak hours, Schiphol only grew in movements during their off-peaks moments. With most of the off-peak moments filled up; Schiphol has lost the ability to accommodate any last-minute changes to the planning. In the complex aviation system last minute changes are unwanted but seem unavoidable. When changes take place, other flights are affected to accommodate them causing a domino effect in the ground operations planning. Within this research influences that cause the changes in the system are analysed by combining an analysis of the current situation and the knowledge of experts from within all the KDC partners.

The analysis of the current situation delivered two important results. Firstly, there is too little overarching standardisation on the methods used to determine and manage plan stability. Stakeholders influence the plan stability of other stakeholder by managing their own system. However, they are not enough aware of the consequences.

Secondly, influences causing system instability are; Eurocontrol ATFM delays, too early arrivals and outbound bunching. The influences were individually analysed to determine, the causes and effects of the influences on the airside ground operation of the airport. Understanding the influences creates possibilities to prevent the last-minute changes and their effects. From the analysed influences the following recommendations are applicable:

- Create an overarching uniform method of analysing plan stability covering all the stakeholders.
- Restructure current procedures to prevent the increasing effects of ATFM slots on plan stability.
- Create a better communication for early arrivals between airport and airlines.
- Work with smaller outbound planning brackets when outbound stability is needed.
- APOC will create cooperation to accommodate the measures and should be made in charge of the measures.

To conclude, to increase the system plan stability more cooperation will be needed in the plan stability management. Instability in the airport airside ground operation still occurs due to external influence. The effect influencing the ground operation are created by other stakeholders in the aviation industry to optimise their own operation, In some cases this delivers more instability at the ground operations than the added value for the own operation. An overarching system registering the effects could prevent the unwanted external influences. This system could be a cooperation of the APOC and Network Manager in which the Eurocontrol Network Operations Plan and the Schiphol Airport Operations Plan could be better aligned.

Keywords: Capacity, Plan stability, stakeholders, airport airside ground operations, APOC, Network Manager, external influences, alignment.

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## List of Abbreviations

AAS	Amsterdam Airport Schiphol
AC	Aircraft
ACDM	Airport Collaborative Decision Making
ACNL	Airport Coordination Netherlands
AIBT	Actual In-Blocks Time
ALDT	Actual LanDing Time
ANSP	Air Navigational Service Provider
AOP	Airport Operations Plan
APC	Apron Controller
APOC	AirPort Operation Control
ARDT	Actual ReaDy Time
ATC	Air Traffic Controller
ATFCM	Air Traffic Flow Capacity Management
ATFM	Air Traffic Flow Management
ATOT	Actual Take-Off Time
AUAS	Amsterdam University of Applied Sciences Collaborative Pre-Departure Sequence Planner
CPDSP	
CTOT	Calculated Take-Off Time
ECAC	European Civil Aviation Conference
EXOT	Estimated TaXi Out time
FIR	Flight Information Region
FMP	Flow Management Position
GC	Ground controller
HCC	Hub Control Centre
KDC	Knowledge and Development Centre
KLM	Koninklijke Luchtvaart Maatschappij
KPI	Key Performance Indicator
LVNL	Luchtverkeersleiding Nederland
NM	Network Manager
NOP	Network Operations Plan
OCC	Operations Control Centre
OTP	On Time Performance
RWY	Runway
SIBT	Scheduled In-Blocks Time
TOBT	Target Off-Blocks Time
TSAT	Target Start-up Approval Time
TTOT	Target Take-Off Time

## Summary

Over the last years Schiphol has experienced a growth in aircraft traffic movements and exchange of narrow body aircraft for wide body aircraft. The infrastructure has been unable to change at the same pace increasing the pressure on the ground operations capacity and forcing the growth into the off-peaks moments where unused infrastructural capacity was available. By growing in the off-peaks a new challenge arose. The unused capacity was of essential value in the system's plan stability. It offered flexibility that could be used to recuperate from planning deviations. The situation created, could cause a deviation from the plan to trigger a domino through the day that cannot be halted because there is no recuperation possibility. To stop this effect, it was essential to perform research into the current situation of the plan stability, and the exact causes that started or continued the domino effect. To do this the research has answered the following research question:

**“What are the opportunities for Amsterdam Airport Schiphol and the other KDC stakeholders to improve the airside ground operational plan stability of the airport?”**

After performing a system analysis focussed on planning and stability, differences are found in the plan stability definitions, responsibilities and KPIs. Every stakeholder has focused the KPIs on their own part of the operational chain, without covering the whole system. This creates inefficiencies if a stakeholder improves the plan stability within their own system while creating instability in the system of a different stakeholder.

To understand the situation that has developed over the past years a problem analysis into the current plan stability was performed. The analysis indicated differences between the plan stability during the summer and winter. Confirming the expectation that the plan stability is related to the free recuperation capacity within the system. Where during the winter more space is available compared to the summer period. During the summer the snowballing effect is clearly indicated, when the OTP and consequently the plan stability drops, the system is unable to restore and the plan stability stays low during the rest of the day.

When combining the results of the analysis with the experiences of experts, three external influences on the ground operation on the plan stability were found and analysed based on the expected impact. All the influences were studied in the analysis of the operation of the summer 2018 and winter 18/19.

Starting with the influence of the ATFM slots allocated by the Eurocontrol Network Manager. The results of this analysis indicated an influence of the ATFM slots on the stability of the airside ground operations. The current procedures of Eurocontrol create instability in the output flow of the airport. Clogging up the system and influencing the input stability. To minimize the impact, the airport, ANSP and airlines could cooperate in a procedure to minimize the effects on the stability. However, the current procedures are not covering the majority of the affected flights and due to the complex practicability, the flights that meet the requirements, are often deliberately excluded by the responsible persons during the operation.

The second influence is that of too early arrivals of aircraft. When arriving much earlier than planned the flights use more capacity from the ground operations than originally scheduled. Due to the growth during off-peak moments the unused capacity has become scarce and the ground operation is less capable of handling this kind of instability. Because the early arrivals are an added value to the stakeholders and its customers it is important to facilitate it when possible. To make this happen clear procedures and communication is important. Currently the airlines and airport do not communicate enough during the planning phase of a flight about the possibility of the airport system to accommodate an early arrival. As a consequence, flights unnecessarily arrive too early in a peak moment causing instability at moments the system needs stability to perform.

The third and last influence is the outbound bunching that results from the current method of producing the outbound schedule. The schedule is produced by assigning an outbound slot to a flight, in the form of a departure bracket of 20 minutes. The only restriction is the amount of flights allowed to depart within the bracket. Creating the possibility that all the flights are planned at the exact same time instead of equally spread over the bracket. As a consequence, the first outbound schedule made is already unrealistic and will most probably be unreliable and unstable during the operation.

Currently the airport ground operations system does not have the procedures in place to prevent the mentioned influences from happening or prevent them from affecting the system. In all cases the problems resulting from the influences only occur when plan stability is under pressure. Without the pressure, the influences add value to the customer by using the system flexibility.

To prevent the recommended measures from causing further instability they need to be structural, however, they need to be able to offer the added value of flexibility when possible. An opportunity could be within adaptive structures. These structures change in predetermined ways to achieve set objectives, depending of the circumstances it must operate in. The new AirPort Operations Control (APOC) could play a big role in this adaptive structure. It is advised for the KDC stakeholders to develop adaptive structures to offer flexibility when possible but stability when the system needs to operate at maximum capacity. More stability can be achieved by introducing the following adaptive structure variables:

- When the outbound ATFM delays are high, effective outbound buffer procedures could minimizing the effects of the ATFM delays on the airside ground operation stability. To effectively change the outbound buffer system a cooperation of all the airside ground operation stakeholders and Eurocontrol is required.
- The airport should communicate to airlines if early arrivals can be accommodated for the time of the day the flight is scheduled. This can be changed by the AAS by adding more communication possibilities to all airlines about expected ground capacity.
- If the airport airside ground operation is needed to run at full capacity, outbound bunching should be prevented by scheduling with smaller brackets. Airport Coordination Netherlands and the airlines are mostly involved in this measure. The airlines because they should give up some of their rights and ACNL needs to change the slot allocation procedure.

When the recommendations will be followed this will most likely result in a more stable execution of the airside ground operations plan. All of the recommendations can be implemented in different timelines. The ATFM outbound buffers are very complex to organize while the extra communication flow between airport and airline could easily be achieved by next year.

Another recommendation is to use the implementation of APOC and the Airport Operating Plan to align the definitions and importance of plan stability of all the stakeholders within the airport ground operations. Collaborating with the Eurocontrol Network manager would mean that even the Network Operational Plan can become part of the alignment. In this case a complete overarching system is created in which plan stability can effectively be reduced.

# 1 Introduction

This chapter introduces the problem that initiated this research and the parties facing the problem. Next the main research question, sub questions and background questions that will be answered are introduced. Afterwards, using the research questions, the research scope, indicating what is included in and explicitly excluded out of the research, are described. The chapter ends with a short depiction of the rest of the research.

## 1.1 Problem statement

While running a complex operation it is important to do this according to the way it is planned to create plan stability. When you are forced to deviate from this planning, changes are required to accommodate the deviation. This normally causes a decrease in efficiency, when more resources are needed for the same amount of production. The problem faced in aviation is that it is impossible to run an operation, influenced by so many factors, without any deviations. This results in the need for a system that is resilient to the effects of deviations and minimizes them to return to the original planning quickly, making sure the planning afterwards is no longer affected by the deviation that happened before.

Schiphol Airport has experienced a rapid growth in aircraft movements over the last years. This growth was mostly realized in their off-peak moments where there was infrastructural capacity left. By filling the last gaps of unused capacity, the airport is now working with almost continuous peaks. During the off-peaks the amount of free capacity has severely decreased. Without the free capacity there is barely opportunity to accommodate and recover from deviations that occur during the peak moments. Deviations from planning can now create a domino effect throughout the day effecting the flights that originally, with more recover capacity, would not be affected by the deviation. In the current structure the airport and its stakeholders are no longer able to minimize the effects and are forced to keep adjusting the planning as a result of a deviation from planning earlier during the day. With more flights effected the plan has become more unstable and thus unpredictable.

One of the key selling points for an airport and airline to their customer, the passenger, is there on-time performance (OTP). When more deviations to the planning occur, stability decreases. One of the consequences is a decrease in OTP. Which is something the Dutch aviation stakeholders want to prevent from happening to minimize the risk of losing customers. Especially because the competitor airports and airlines in other countries do not necessarily face the same problems. This could cause Schiphol and the airlines to lose terrain on their competitors who will have a better on-time performance, which they use as a selling a point.

Concluding, a decrease in plan stability due to the lack of capabilities to resolve the effects of plan deviations causes instability in the ground operation and decreases the on-time performance. This decrease in stability causes a loss of efficiency to all the stakeholders and comes with the risk of losing crucial terrain on competitors. Because the problem is relatively new there is no deep understanding of the problem of instability and the influences causing this. It is necessary to find opportunities that could benefit the plan stability.

## 1.2 Research relevance/significance

In January 2019 the management of Amsterdam Airport Schiphol has announced that they have made their OTP one of their top priorities. The management has put the OTP target on at least 71%. A high OTP is a direct result of a stable operation. Indirectly they want to stabilize the execution of their planning. Increasing the relevance of this research. By putting it in their top priorities the Schiphol management regards this problem as one of the biggest threats to their operation. An interesting factor is the relevance of the research for the other KDC stakeholders (KLM and LVNL). Especially because they are not all equally influenced with the plan stability of the airports ground operation. Nevertheless, all stakeholders profit from a stable airport ground operation. Schiphol as the operator, KLM as the biggest user and LVNL as the connection between airside infrastructure of Schiphol and the airlines. But there is also one other stakeholder at the airport that is often forgotten: the passenger. The passenger will profit from a more stable plan, decreasing the amount of delays and unexpected changes that could affect the passenger, improving the overall experience and the product value delivered to the customer.

## 1.3 Research Questions

This paragraph will further specify the research subject by formulating a research question that will be answered. The main question is divided into sub questions that will help to answer the main question. Then the sub questions are divided into background questions to make sure all the information is available to answer the sub questions and eventually the main question.

The main research question of the research is:

**“What are the opportunities for Amsterdam Airport Schiphol and the other KDC stakeholders to improve the airside ground operational plan stability of the airport?”**

The question is build-up out of the following parts, each explaining part of the research:

- **What are the opportunities:** The research is mainly focused on advising what can be done to improve. Opportunities is not necessarily something new but can also be focused on something that already exists but is not used to its potential.
- **For Amsterdam Airport Schiphol and the other KDC stakeholders:** The operational plan stability is a consequence of decisions made by all the KDC stakeholders. For this reason, the research focusses on the roles of all stakeholders instead of only the airport.
- **To improve the airside ground operational plan stability of the airport:** This is the main goal of the project of improving plan stability within the airside ground operations of Schiphol.

The following sub-questions help answer the main question:

1. *What defines a stable planning?*
2. *What are the responsibilities and options of the KDC stakeholders in maintaining a stable airport operation?*
3. *How stable is the current planning at Amsterdam Schiphol airport?*
4. *Are there and if so, what are the influences of external effects on the on-time performance of Amsterdam Schiphol?*

Per sub question background questions have been made. These background questions are answered in the findings before the sub questions and consequently the main question can be answered correctly.

1. *What defines a stable planning?*
  - *What is in this research defined as a planning?*
  - *What are the requirements for a stable planning?*
2. *What are the responsibilities and options of the KDC stakeholders in maintaining a stable airport operation?*
  - *What are the roles of the KDC stakeholders in the airport planning?*
  - *Which stakeholder can make which decision in the planning process?*
  - *How is each of the stakeholders influenced by an instable airport operation?*
3. *How stable is the current planning at Amsterdam Schiphol airport?*
  - *How can we measure stability?*
  - *How can you express robustness and resilience of an operation?*
4. *Are there and if so, what are the influences of external effects on the on-time performance of Amsterdam Schiphol?*
  - *What are the external effects?*
  - *In what way do the effects influence the on-time performance?*
  - *Is there a relation between the external influence and the effect within the airport system?*

## 1.4 Research scope

The research will focus on all the processes and procedures that might have a significant influence on the plan stability of the airport's airside ground operations system. These processes are expected to be found within the operations of all the KDC stakeholders. Resulting in a scope that covers all the daily airside operations at Schiphol airport and the short and long-term planning of both ground and flight operations.

Because the airport is part of a bigger European aviation system, the influences from this system need to be considered. Explicitly the influences of Eurocontrol Network Manager on the ground processes of the airport and its stakeholders are included within the research.

Important to mention is the goal of this research: finding opportunities within the current operation that could structurally improve the plan stability. Out of scope will be the micro-management level where the performance per individual flight is analysed and influenced. The aim is to find opportunities that benefit the whole system instead of one flight.

The structural changes aimed for can be achieved within the strategic planning phase of an operational plan. Where procedures and the plans are made that influence the system performance on the tactical plan level.

The analysis should result in the areas where problems with plan stability arise and where there is still room for structural improvement. The opportunities could lay within plans already implemented but currently not used to the full potential.

## 1.5 Thesis structure

This thesis consists of multiple chapters each covering a certain phase or subject of the research. Starting with the methodology, where will be explained which methods have been used per research sub part. Followed by the literature review that is used to perform the research and needed to perform the following analysis. During this analysis the background information is combined with the obtained data using the methods described in the methodology phase. After the analysis, all the results are given in the research findings answering the main research question using the answers to the sub research questions. At the end the research findings are merged into recommendations to the stakeholders covering possible points of improvement.

## 2 Methodology

This chapter contains more detail about the structures of the research and the tools and methods used to perform the research. Starting with the research structure, continuing with information about the data samples and collection methods. The paragraph after the collection methods states the most important definitions of the research. Finishing with the methods used to analyse the data and information gathered during the research.

### 2.1 Research Design & Instruments

The research follows the design structure in table 1. Which indicates the research phases from left to right. Starting with the orientation into the main subject: Plan stability, and then spreading over the subtopics. The sub-topics are created during the orientation phase with the help of experts, who indicated that these topics might be of interest to the research because of their influence on the airport operational plan stability. One topic that will be analysed is the Schiphol Airport Operations Control Centre (APOC) because many experts explained the relevance of APOC in the future of airport ground operations plan stability. Without an operational APOC, it is impossible to perform a current situation analysis.

Eventually all the analysed topics are combined in the chapters of results and recommendations.

<b>Orientation</b>	<b>Instruments</b>	<b>Analysing topics</b>	<b>Instruments</b>	<b>Deliverable</b>
<i>Plan Stability</i> <i>*Sub question 1</i>	<i>-Literature</i> <i>-Interviews</i>	<i>Schiphol / KLM / LVNL OTP</i> <i>*Sub question 2, 3</i>	<i>-Data</i> <i>-Interviews and observations</i> <i>-Literature</i>	<i>Results and recommendations</i>
		<i>Eurocontrol CTOT, Outbound delays</i> <i>ATFM</i> <i>*Sub question 4</i>	<i>-Data</i> <i>-Interviews and observations</i> <i>-Literature</i>	
		<i>Early arrivals</i> <i>*Sub question 4</i>	<i>-Data</i> <i>-Interviews and observations</i> <i>-Literature</i>	
		<i>Schiphol APOC</i> <i>*Sub question 4</i>	<i>-Interviews and observations</i> <i>-Literature</i>	

Table 1: Research structure timeline  
\* = sub questions covered

The analysing topics and instruments in detail:

<p>Plan Stability *Sub question 1</p>	<p>-Literature: - Research in other sectors</p> <p>-Interviews and observations: - Airport operations analyst, Amsterdam Airport Schiphol - Airport Council International Liaison Officer, Eurocontrol - Duty Hub Manager, KLM</p>
<p>Schiphol / KLM / LVNL OTP *Sub question 2, 3</p>	<p>-Data: Schiphol ACDM outbound data summer/winter 18/19</p> <p>-Interviews and observations: - Gate planner, Amsterdam Airport Schiphol - Airport operations analyst, Amsterdam Airport Schiphol - Airport Council International Liaison Officer, Eurocontrol - Flow controller, LVNL - Approach supervisor, LVNL - Duty Hub Manager, KLM</p> <p>-Literature: - AAS/KLM/LVNL manuals, procedures and reports concerning On-Time Performance</p>
<p>Eurocontrol CTOT, Outbound ATFM delays *Sub question 4</p>	<p>-Data: Schiphol ACDM outbound data summer/winter 18/19</p> <p>-Interviews and observations: - Ground controller, LVNL - Gate planner, Amsterdam Airport Schiphol - Airport Council International Liaison Officer, Eurocontrol - Flow controller, LVNL - Duty Hub Manager, KLM</p> <p>-Literature: Reports, manuals and procedures regarding the Eurocontrol Network manager.</p>
<p>Early arrivals *Sub question 4</p>	<p>-Data: Schiphol ACDM inbound data summer/winter 18/19</p> <p>-Interviews and observations: - Gate planner, Amsterdam Airport Schiphol - Flow controller, LVNL - Flow controller, KLM - Gate controller, KLM - Duty Hub Manager, KLM</p> <p>-Literature: AAS manuals and procedures around early arrivals</p>
<p>Schiphol APOC *Sub question 4</p>	<p>-Interviews and observations: AirPort operations Centre Manager, Amsterdam Airport Schiphol</p> <p>-Literature: APOC related literature, APOC manuals of Schiphol and Eurocontrol</p>

Table 2: Analysing topics and instruments

## 2.2 Data Collection and Sample

During the research two data samples have been obtained from the ACDM database of Schiphol. This chapter will give information about the data sets. Both datasets have been used to answer sub-question 3, by analysing the stability of the system in the summer season of 2018 and the winter season of 2018/19.

### 2.2.1 Outbound ACDM data

The first data set contains the ACDM milestones of all outbound flights during the summer season of 2018 and almost the complete winter season of 2018/2019. Stated in table 3 are the general information about the data set, in table 4 a data sample of the whole data set and in table 5 a legend of the information within the data set.

Name	Outbound ACDM Data
Provided by	Schiphol Capacity Management & Operational Intelligence
Period	01/05/2018 until 10/03/2019
N (amount of flights)	217804
Remarks	All times are Amsterdam local times [LT]

Table 3: Data set outbound ACDM information

SDATE	FLTNR	TSAT	SDATETIME	TOBT	AOBT	ATOT	CTOT	TTOT_TARGET	EXOT
1-5-2018	EZY7997	1-5-2018 08:06	1-5-2018 07:45	1-5-2018 08:05	1-5-2018 08:08	1-5-2018 08:22	1-5-2018 08:19	1-5-2018 08:18	00:13:00
1-5-2018	KL0933	1-5-2018 08:06	1-5-2018 07:45	1-5-2018 07:45	1-5-2018 08:06	1-5-2018 08:14		1-5-2018 07:52	00:07:00
1-5-2018	BA423	1-5-2018 08:07	1-5-2018 07:45	1-5-2018 07:45	1-5-2018 08:06	1-5-2018 08:18		1-5-2018 07:55	00:10:00
1-5-2018	KL1413	1-5-2018 08:09	1-5-2018 07:50	1-5-2018 07:50	1-5-2018 08:08	1-5-2018 08:19		1-5-2018 07:59	00:09:00
1-5-2018	KL1071	1-5-2018 08:11	1-5-2018 07:55	1-5-2018 07:55	1-5-2018 08:09	1-5-2018 08:20		1-5-2018 08:05	00:10:00

Table 4: Sample of outbound ACDM data set

The outbound data set, of which the above figure 3 is a sample, includes the following data:

Abbreviation	Meaning
SDATE	Date the flight was planned to depart
FLTNR	Flight number of the specific flight
TSAT	Target Start up Approval Time
SDATETIME	Date and time the flight was scheduled to go off-blocks Scheduled Of Blocks Time
TOBT	Target Off-blocks Time
AOBT	Actual Off-blocks Time
ATOT	Actual Take Off Time
CTOT	Calculated Take Of Time
TTOT_Target	Target Take Off Time
EXOT	Estimated TaXi Out Time [in minutes]

Table 5: Legend of outbound ACDM data set

## 2.2.2 Inbound ACDM data

The second data sample covers the same time period, only this time it is the ACDM milestones of inbound flights. Again, table 6 indicates the general information about the data set, table 7 a data sample of the whole data set and table 8 a legend of the information within the data set.

Name	Inbound ACDM Data
Provided by	Schiphol Capacity Management & Operational Intelligence
Period	01/05/2018 until 10/03/2019
N (amount of flights)	215900
Remarks	All times are Amsterdam local times (LT)

Table 6: Data set inbound ACDM information

FLTNR	Airline	Schedule	ALDT	AIBT	SIBT	AC_registr	AC_type	ramp_POS	rwy_desc
KL0434	KLM	1-5-2018	1-5-2018 06:17	1-5-2018 06:20	1-5-2018 06:25	PHBQO	B772	E09	Buitenveldertbaan
KL0692	KLM	1-5-2018	1-5-2018 06:13	1-5-2018 06:16	1-5-2018 06:30	PHBHM	B789	E05	Buitenveldertbaan
CZ0307	China Sou	1-5-2018	1-5-2018 06:34	1-5-2018 06:37	1-5-2018 06:35	B1063	A333	F04	Buitenveldertbaan
CX271	Cathay	1-5-2018	1-5-2018 06:26	1-5-2018 06:30	1-5-2018 06:40	BKQE	B77W	G04	Buitenveldertbaan
KL0537	KLM	1-5-2018	1-5-2018 06:38	1-5-2018 06:42	1-5-2018 06:55	PHAKD	A333	E24	Buitenveldertbaan

Table 7: Sample of inbound ACDM data set

Abbreviation	Meaning
FLTNR	Flight number of the specific flight
Airline	Airline that performed the flight
Schedule	Date the flight was scheduled to go off-blocks
ALDT	<b>A</b> ctual <b>L</b> an <b>D</b> ing <b>T</b> ime
AIBT	<b>A</b> ctual <b>I</b> n <b>B</b> locks <b>T</b> ime
SIBT	<b>S</b> cheduled <b>I</b> n <b>B</b> locks <b>T</b> ime
AC_registr	Registration of the aircraft that performed the flight
AC_type	Aircraft type used
Ramp_pos	Stand that was used to handle the aircraft
Rwy_desc	Runway the flight landed on

Table 8: Legend of inbound ACDM data set

## 2.2.3 Interviews and observation

During the research multiple interviews are held with experts about their views and opinions about the problems analysed within research. Interviews are held with:

- **Ground controller, LVNL**  
The ground controllers at LVNL re responsible for all movements of aircraft on the ground of the airport. They experience the instability of ground operational plan the most within the LVNL organisation. When they need to guide aircraft from their gate to the runway and the other way around.
- **Gate planner, Amsterdam Airport Schiphol**  
The gate planners at Schiphol airport are responsible for the planning of the gates one day before operation and the adjustment of the planning during the operation. They experience instability by constantly having to adjust the planning to make it match the new circumstances.
- **AirPort operations Centre Manager, Amsterdam Airport Schiphol**  
The manager of the, to be implemented, APOC is currently responsible for the implementation and development of the APOC. She is interviewed to understand the proposed structures and working of the APOC.
- **Airport operations analyst, Amsterdam Airport Schiphol**  
The operational analysts of Schiphol are tasked with the post-operational analysis of the operation. For this research he was interviewed to align the data analysis definitions with the definitions used by Schiphol.

- **Airport Council International Liaison Officer, Eurocontrol**

The liaison officer has a very special position within the Eurocontrol organisation. He represents the airports within Eurocontrol. By doing so he both understands the system of Eurocontrol and the airports. For this reason he was interviewed about the relation between both and the development of the relation.

Next to the interviews the research also includes observations during the work done by experts directly experiencing the problems. During the observations most of the time there was also the possibility to ask about some further elaboration about the problems the research focussed on. Observations were done during the work of:

- **Flow controller, LVNL**

The flow controller controls the throughput of aircraft through the LVNL systems. When limited capacity the flow controller will limit the input of the system to prevent under capacity. His work was observed to understand the influence on the plan stability.

- **Approach supervisor, LVNL**

The approach supervisor, supervises the approach and departure airspace around the airport. Trying to use the airspace as efficient as possible, by changing runway usage and assigning different runways to inbound flights. His work was also observed to understand his influence on the plan stability.

- **Flow controller, KLM**

A flow controller at KLM is responsible for the flow of aircraft through the airspace. The controller adjusts the flight plans to create most efficient flow of aircraft, hereby striving for the best balance between cost and quality. When instability occurs the flow controller decides how much effort is made to overcome the instability.

- **Duty Hub Manager, KLM**

Within the Hub Control Centre the duty hub manager holds the end responsibility of the whole KLM hub operation, both on land and airside. Hereby managing all the sub-processes such as: baggage, passengers, maintenance, etc. When plan stability in the airside operations occurs, the Duty Hub Manager has the responsibility for the whole KLM system to accommodate it.

- **Gate controller, KLM**

The Gate Controller at KLM works closely together with the gate controllers at Schiphol. When changes in the gate planning occur the gate controller has the responsibility to minimize the impact on the gate planning and maintain the stability. He is the link between the airside instability of the airport on the airline.

## 2.3 Data Definitions

To analyse the data sets both the data analysis programs, Microsoft Excel and Tibco Spotfire haven been used. Each of the programs has its own pros and cons, for this reason a combination of both is used. As example, Excel is an excellent program to quickly make minor adjustments, while Tibco Spotfire is far better in sorting, filtering, visualising and analysing data sets. The data samples provided contain all the necessary data, however, the data still needs to be manipulated into the data needed to perform this research. The following methods are used to shape the data into the required forms. All the following is done according to the definitions used by Eurocontrol ACDM and Amsterdam Airport Schiphol.

### 2.3.1 Off-blocks Delay

The delay definition of Amsterdam Airport Schiphol has been used during this research. If a flight has an Actual Off-Blocks Time before or until 15 minutes and 59 seconds after the Scheduled Off-blocks Time according to the flight plan, the flights is regarded as an on-time departure. If the flight leaves later than 15 minutes and 59 seconds after the Scheduled Off-Blocks Time the flight is regarded as delayed. Figure 1 illustrates this on a timeline.

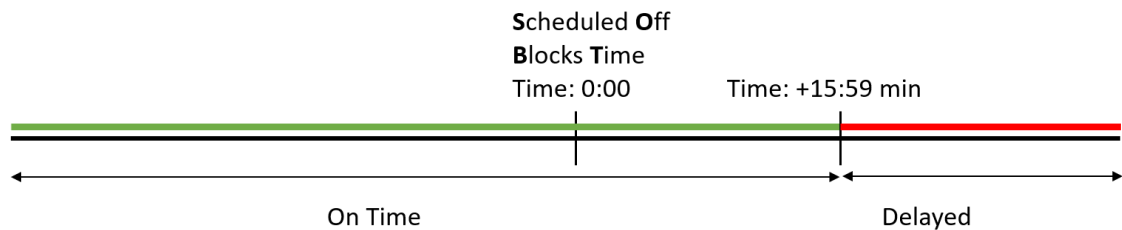


Figure 1: Visualisation of delayed definition

To calculate the off-blocks delay the following formula (1) per flight is used:

$$AOBT\ delay = AOBT - SOBT \quad (1)$$

When the result is a negative time/number it indicates that the flight left before the SOBT and is regarded as on-time. If the number is between 0:00 minutes and 15:59 minutes, the flight's AOBT is on-time. All flights with an AOBT delay above 15:59 minutes are regarded as delayed while calculating the off-blocks OTP.

### 2.3.2 Off-blocks On-Time Performance

The off-blocks on-time performance is currently monitored by Schiphol per flight and the average of all flights per day. The average OTP per day is an indicator of the performance of the whole system. However, for the level of detail of this research it is not detailed enough.

To increase the detail, the average over a smaller time period is required. To do this the average on-time performance of brackets per hour is calculated. Where the bracket starts at the whole hour (08:00:00) and ends at the last minute (08:59:59). This creates the possibility to analyse the OTP in detail.

To calculate the average off-blocks OTP per day the following formula (2) is used:

$$Avg\ off\ blocks\ OTP\ day = \frac{Amount\ of\ on\ time\ AOBT\ of\ flights\ with\ SOBT\ on\ the\ day}{Amount\ of\ flights\ with\ SOBT\ on\ the\ day} \times 100\% \quad (2)$$

To calculate the average off-blocks OTP per hour the following formula B (3) is used:

$$Avg\ off\ blocks\ OTP\ hour = \frac{Amount\ of\ on\ time\ AOBT\ of\ flights\ with\ SOBT\ within\ bracket}{Amount\ of\ flights\ with\ SOBT\ within\ bracket} \times 100\% \quad (3)$$

### 2.3.3 CTOT Calculations

Whether an outbound flight received a CTOT or not is indicated in the column “CTOT” of the outbound data file. If a flight has a CTOT restriction, the time of the restriction is indicated in this column. In table 9, presenting a sample of the inbound data, the first flight (flight number EZY7997) has received a CTOT. The other flights do not have a CTOT, leaving the field empty. In this specific sample it means that flight EZY7997 has a take-off window from 08:14 until 08:29

SDATE	FLTNR	TSAT	SDATETIME	TOBT	AOBT	ATOT	CTOT	TTOT_TARGET	EXOT
1-5-2018	EZY7997	1-5-2018 08:06	1-5-2018 07:45	1-5-2018 08:05	1-5-2018 08:08	1-5-2018 08:22	1-5-2018 08:19	1-5-2018 08:18	00:13:00
1-5-2018	KL0933	1-5-2018 08:06	1-5-2018 07:45	1-5-2018 07:45	1-5-2018 08:06	1-5-2018 08:14		1-5-2018 07:52	00:07:00
1-5-2018	BA423	1-5-2018 08:07	1-5-2018 07:45	1-5-2018 07:45	1-5-2018 08:06	1-5-2018 08:18		1-5-2018 07:55	00:10:00
1-5-2018	KL1413	1-5-2018 08:09	1-5-2018 07:50	1-5-2018 07:50	1-5-2018 08:08	1-5-2018 08:19		1-5-2018 07:59	00:09:00
1-5-2018	KL1071	1-5-2018 08:11	1-5-2018 07:55	1-5-2018 07:55	1-5-2018 08:09	1-5-2018 08:20		1-5-2018 08:05	00:10:00

Table 9: Sample of outbound ACDM data set

To be able to analyse at the impact CTOTs have on the plan stability, the CTOT and OTP data need to be in the same format. OTP is divided in brackets per hour, so the CTOTs will be in brackets per hour as well. To analyse the system performance, the percentage of flights with a CTOT per day and per hour is calculated using the following formulas:

Per day (formula 4):

$$\text{Percentage of flights with CTOT day} = \frac{\text{Amount of CTOT effected flights with SOBT within the day}}{\text{Amount of flights with SOBT within the day}} \quad (4)$$

Per hour (formula 5):

$$\text{Percentage of flights with CTOT hour} = \frac{\text{Amount of CTOT effected flights with SOBT within the hour}}{\text{Amount of flights with SOBT within the hour}} \quad (5)$$

To calculate the CTOT/ATFM delay of a flight the following formula (6) is used. Where the CTOT indicates the window in which the flight can take-off and the TTOT\_Target indicates the moment the flight would have been able to take-off without CTOT:

$$\text{ATFM delay} = \text{CTOT} - \text{TTOT\_Target} \quad (6)$$

### 2.3.4 Early Arrivals

Next to delayed outbound flights the research also focusses on early arrivals. Currently there is no definition for an early flight, apart from the definition of early: before planned. However, if looked at the definition of a delayed flight; more than 15:59 min later than planned, this is not the exact definition of delayed. While creating a definition for an early arrival the same standards are applied as with delays. This means that the 15:59 minutes, are in front of time point zero. This resulted in the timeline as in figure 2. All the flights arriving more than 15:59 minutes earlier than the SIBT are considered as too early arrivals.

To match the data with the OTP formats the early arrivals are calculated per hour using the same

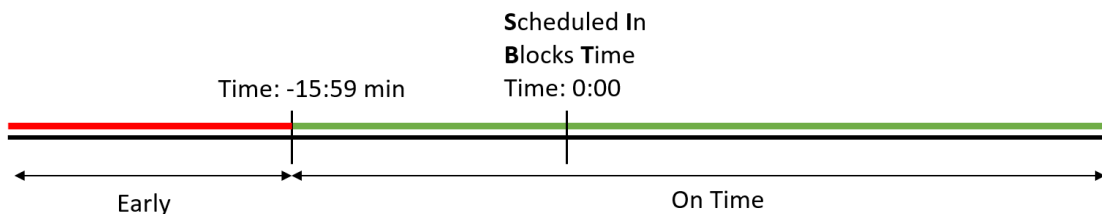


Figure 2: Visualisation of early arrival definition

hour brackets as the OTP calculations. The percentage of flights arriving early within the hour bracket are compared to the OTP percentage. The problem arises that the SIBT is not the time the flight actually arrived at; this causes that the data does not represent the real percentage of flights that arrived too early in that bracket. What it does represent is the impact the early arrivals have on the plan stability.

To explain with an example (figure 3): A flight that was planned to arrive at 11:15, arrives at 10:55. The flight is more than 15:59 minutes earlier than planned and is considered as too early. The flight was planned in the bracket of 11:00:00 until 11:59:59 but arrived in the bracket of 10:00:00 – 10:59:59. With 15 minutes in the SIBT bracket, the flight impacted this bracket more than the AIBT bracket.

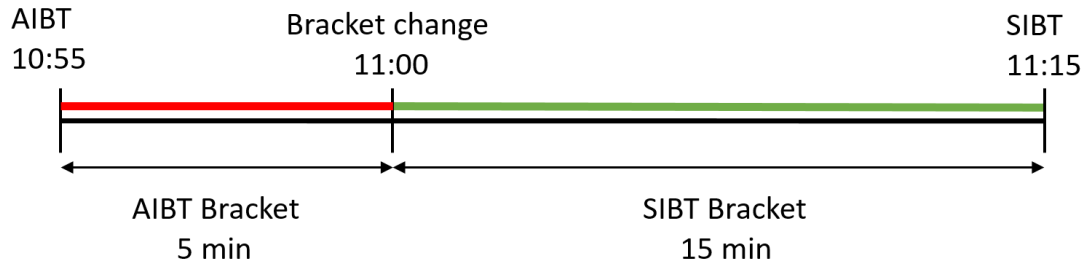


Figure 3: Visualisation of early bracket definition

Nevertheless, if the flight had an SIBT of 11:05 and an AIBT of 10:45 it would have had more impact on the bracket the AIBT is in. Concluding there is no accurate way of comparing early arrivals in the system with the OTP. The used method in this research will give a close approximation of the reality. Where one flight impacted the earlier bracket, another flight impacted more of the later bracket.

The formula (number 7) used to calculate the percentage of early arrivals is the following:

$$\text{Avg early arrivals} = \frac{\text{Amount of early arrivals of flights with SIBT within the hour}}{\text{Amount of flights with SIBT within the hour}} \times 100\% \quad (7)$$

## 2.4 Data Analysing Methods

During the research two types of data are collected and analysed, quantitative and qualitative data. For both data types the analysis is done differently, which is explained in this paragraph.

### 2.4.1 Quantitative Data Analysing Methods

After the collection and adjustment of data using Excel, the data is analysed using Tibco Spotfire. This computer program analyses and visualizes data. When analysing the quantitative data, the main target is to look for patterns. To do this, the data needs to be put into graphs that can visualize patterns over longer periods of times. Boxplots can be used to achieve this. The Boxplots can take the OTP data of all the days or hours and visualize the averages and the deviation from average for a whole year in one figure, visualizing the patterns within the data. Multiple boxplots will visualize the OTP of each day of the week, the OTP of each hour of the day and the percentage of flights with a CTOT restriction per hour. The boxplots will visualize the average of all the days/hours and the quartiles to get an understanding of the deviation of the values from the median.

All the boxplots will be statistically substantiated, and all values used should be statistically sufficient. The boxplots used during the research can be found in the appendixes, including all their statistical data.

To analyse the relation between CTOTs and OTP and too early arrivals and OTP, the correlation coefficient (Pearson Rho) is calculated. This will indicate if there is a linear relation between the variables and if so, the strength of the relation. The Pearson Rho, has coefficient between -1 and 1. Where the following terms apply:

- 0.00 < r < 0.30: none too weak correlation
- 0.30 < r < 0.50: weak correlation
- 0.50 < r < 0.70: moderate correlation
- 0.70 < r < 0.90: strong correlation
- 0.90 < r < 1.00: very strong correlation

The negative coefficients follow the same pattern: -0.30 < r < 0.00 is none to barely. However, a negative coefficient indicates an opposite relation. As example, in this research, if the OTP is high and has a negative correlation with the CTOT this would mean that the percentage of CTOTs is low.

The Pearson rho can be calculated using the following formula (8):

$$r = \frac{\sum(X-\bar{X})(Y-\bar{Y})}{\sqrt{\sum(X-\bar{X})^2} \sqrt{\sum(Y-\bar{Y})^2}} \quad (8)$$

where,

$X$  =  $X$  coordinate of data point

$Y$  =  $Y$  coordinate of data point

$\bar{X}$  = mean of  $X$  sample

$\bar{Y}$  = mean of  $Y$  sample

It is important to understand that a relation does not necessarily imply causality. Especially in the cases of this research where many factors influence the off-blocks on-time performance. It is not possible to prove causality between the performance of the airport system and the performance of the network system.

#### 2.4.2 Qualitative Data Analysing Methods

The interviews are recorded and afterwards transcribed when they are used as a source for the research. The transcriptions are afterwards validated by the interviewees to make sure the colloquial language is correctly transformed to written language, using the right context. The interviews are analysed by comparison to data, literature and other interviews. Analysing if inconsistencies exist between the interviews themselves, the quantitative analysis and the literature. The interviews are mainly used as a source to cover future possibilities that could not be validated by any other sources.

#### 2.4.3 Process analysis

A model used to analyse processes is the SIPOC method. This is a Lean Six Sigma method that helps to understand models of processes. The model describes the following steps:

- **Supplier:** Organisation or person delivering information, goods, etc. needed within the process.
- **Input:** Where does the process start?
- **Process:** How does the process work?
- **Output:** what is the result of the process?
- **Customer:** Who receives what from the process?

The method is particularly of use to create models of complicated processes in which many stakeholders are involved. For many of the processes analysed in this research, the SIPOC model has been used.

### 3 Literature Review

The research is a response to a problem that has grown over the previous years. Many of the influences and causes of the problem have already been analysed and procedures have been made. Important for the quality of the analysis is the understanding of all the current information available. This chapter describes all relevant information available beforehand that is used in the research.

#### 3.1 Plan stability

The definition of plan stability used within the research is the capability of a plan to be executed according to the way it was originally planned. One of the first results of the literature review into this definition is the lack of research by the aviation industry done into system plan stability. Especially overarching research including all the airport system stakeholders is lacking. One of the problems is the lack of plan stability definitions between all stakeholders.

To describe the system stability two important terms are used: resilience and robustness.

- Resilience, the easier you can return to stable after a disruption effected the system causing deviations from the planning, the more resilient the system.
- Robustness, the definition of system robustness slightly differs from the system resilience. The more robust the system, the lesser a deviation influences your system.

Comparing the two, robustness indicates how much effect a deviation has on the system, resilience indicates how easily the system can recover from a deviation.

To put it in line, the best option is to have no disruptions that could cause deviations at all, however, this is not always possible. In that case a system needs to be robust to stop the deviations from effecting your operation and if the system is unable to stop the deviation from effecting your operation, the system must be resilient to overcome the effects as quickly as possible.

An example for robust systems is an adaptive structured system. Compared to normal system structures where no adaption to environmental influences takes place, adaptive systems change their structures and procedures dependent to the influences out of their environment. If a change in the environmental influences, an adaptive systems changes to prevent and minimize the impact of the changed influences. Under which circumstances a structure adaption takes place is predetermined and the same applies to the way the system adapts. (Sastry & Bodson, 2011)

The functioning of an adaptive structure is depicted in figure 4. The system constantly compares the objectives determined for the system and the model of the current and future state of the system. The current and future model are made using sensors (KPIs) within the system, measuring the performance of smaller subsystems and all of the influences from the environment on the system. In combination with predictions of the executing systems and environmental influences.

When the system deviates from the planned objectives the system corrects by changing the original planning to comply with the objectives. The changeable variations for the system are predetermined and should bridge the gaps between the objectives and the execution. The corrections on the variables, are put into the system using commands to the operational subsystems. When the system operations or the environmental influences change, the adaptive system controller automatically corrects the system. (Müller, Pezzè, & Shaw, 2008)

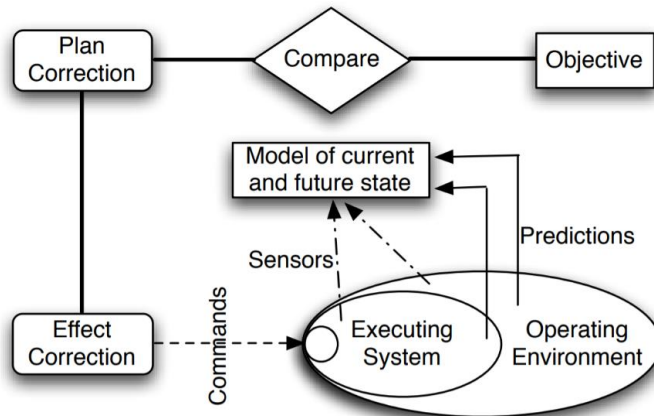


Figure 4: Adaptive system process (Müller, Pezzè, & Shaw, 2008)

When an adaptive system is self-learning the system learns from patterns in the sensors (KPIs) and predictions. The patterns are used to increase the predictability of the system performance. The more predictable the performance, the better the system is able to adapt to situations.

When a system is not robust enough and has to deviate to comply with the objectives, two options are available to return to a stable operation: replanning and plan repair. Replanning means completely letting go of the old plan and create a new plan, mostly used when the new situation differs that much from the originally planned situation that the old planning has become unrealistic. The other option, plan repair, is mostly used in case most of the original plan is still functioning and changing parts of the original planning can solve the deviations from further effecting the planning. Plan repair is mostly used in complex operational plans. In complex plans there is no possibility to make a new plan because there are too many stakeholders involved that have based their resources on the old planning. This is also the case at Schiphol. The system is based on a planning and when deviated from the plan, the planning is adjusted until it becomes workable again. (Fox, Gerevini, Long, & Serina, 2006)

The plan stability is extremely important to all the airport stakeholders. When the plan is stable it is possible to create an efficient planning and minimize the margins needed for unplanned changes. By minimizing the margins, assets can be used more efficiently. As example, when an aircraft flies according to plan, less margin is needed in the schedule, which could create more space for an extra flight per day. More flights with the same amount of aircraft means more efficiency.

### 3.1.1 Planning phases

The planning of the operations is divided in different phases up to the moment of operation of the plan. The exact time periods of the phases may differ per organisation. These phases are in chronological order:

- Strategic planning: Until 7 days before the day of operations. In this phase structures, methods and responsibilities to create the planning in the pre-tactical phase are determined.
- Pre-tactical planning: 6 to 1 day before the day of operations. In this phase the plan is made according to the structures agreed on in the strategic phase. While creating the plan it is adjusted for the short-term expectations of the actual circumstances during the tactical phase.
- Tactical planning: day of operations, the plan is only fine-tuned. The broad lines are already made in the earlier phases and no major changes should be necessary when the plan is executed stably. (Eurocontrol, 2017)

### 3.1.2 In- and output stability

Two important points in the performance of a system are the input and output. Especially the input can heavily influence the system stability. If the input is unstable the system will automatically have a disadvantage and needs resilience to regain stability. When the system is unable to regain stability over the input, the output will become instable as well.

This also applies the other way around. If the output capacity is unstable because of an unexpectedly low demand on the output side, the system production will get congested causing under capacity in the system, influencing the system input. This is an example of the bottleneck theory. There is too much system output compared to output capacity, clogging up the system. Capacity is used to hold the clogged-up output flow, while the capacity is needed for the input flow. These effects are visualised in figure 5. (Klug, 2013)

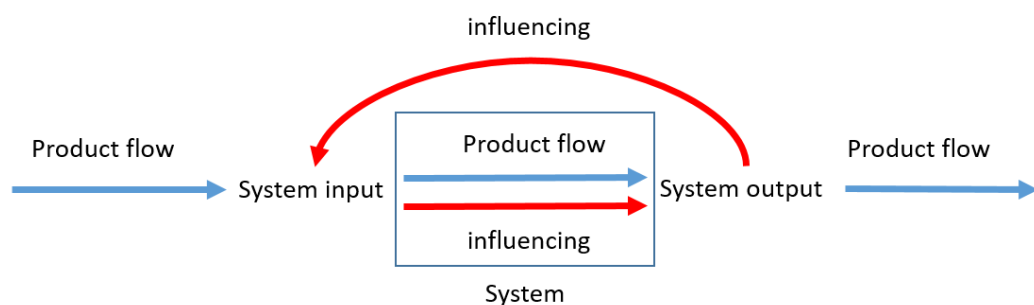


Figure 5: Visualisation input - output influence

When systems are connected, the system input is the result of the output of another system. When the output of the first system is unstable, your system input becomes unstable. The same applies to system output. When the output is the input for another system, the system input stability of the other system can cause instability in the output stability. Due to the domino effect within the system, output instability can affect the input stability. Causing the input to become instable creating a vicious cycle.

The results of a system influencing another system are often unnoticed by the responsible party that caused the instability. Especially when the communication between the systems is inadequate. Figure 6 visualizes the system influences in a simplified way.

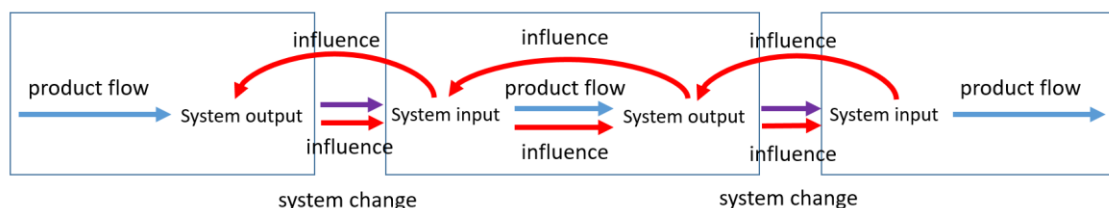


Figure 6: Visualisation influence chain of systems

### 3.1.3 Outbound Bunching

Schiphol is a slot-controlled airport. Departure flights need a departure slot. These slots are brackets of 20 minutes in which a flight should be scheduled to depart. The maximum amount of scheduled flights allowed to depart within such a bracket is predetermined. To determine if a slot is available the total of departures must not be above the maximum amount of flights allowed within that departure bracket and the airline must have the right to claim that slot. (Airport coordination Netherlands, 2018)

### 3.1.4 Capacity

An important factor within plan stability, is the capacity available to run an operation. A system can easily cope with changes in planning when a system runs while offering over capacity. In airport example, if an aircraft arrives too late but there is no aircraft scheduled behind it, the effects are minimal. Currently gate capacity is limited at Schiphol. This forced the airport to put a maximum on the amount of wide-body aircraft that can be on the ground during the morning peak, to stabilize their planning. This regulation has started in the summer season of 2019. Schiphol has announced that in the future with the lacking capacity more of these measures can be expected. (Landex, 2007) (Airport coordination Netherlands, 2018)

### 3.1.5 Airport Collaborative Decision Making

The added value of a stable plan is the predictability it delivers. Even though a stakeholder strives for the perfect execution of a plan it is impossible within the complexity of the aviation system to do this. Knowing that changes will exist, it is important to be aware of changes as quickly as possible, to create time to act on them. For this reason, Airport Collaborative Decision Making is created, letting all stakeholders easily communicate deviations with each other. Within ACDM all the ACDM milestones are continuously updated/predicted and made available to the stakeholders. (Eurocontrol, 2017)

### 3.1.6 Reasons for turnaround delays

During earlier research done by the KDC into the effects of airline business model on the gate occupancy an Ishikawa diagram was created of the causes for delays in the turnaround process (figure 7). A flight with a delayed turnaround causes instability at the output of the ground operation. Other result from the research was that there appears to be no difference in the causes for a turnaround delay between different airline business models. (Ringelberg, 2018)

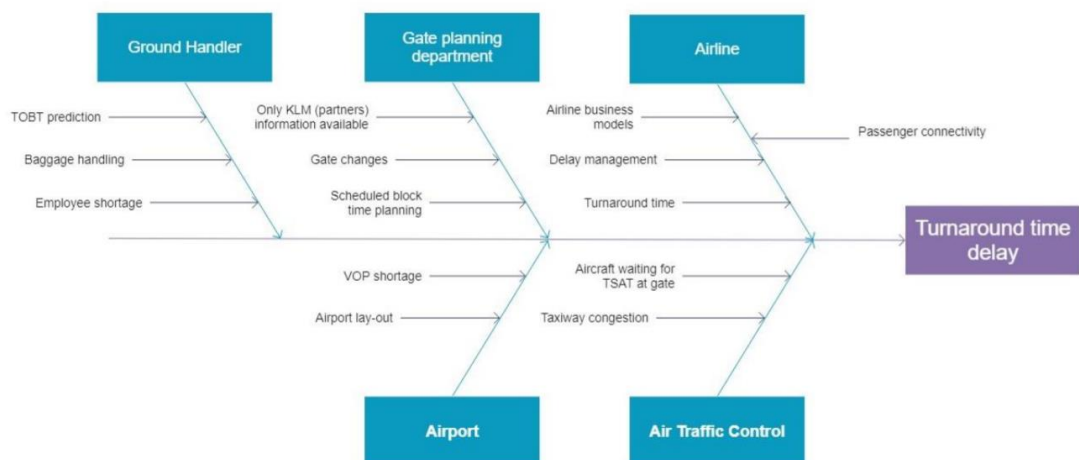


Figure 7: Fishbone diagram different causes for turnaround delay (Ringelberg, 2018)

### 3.2 Eurocontrol Network Manager

Since May 2018 Schiphol is fully connected to the Eurocontrol network manager. (Royal Schiphol Group, 2018) This means that all the airport stakeholders now, not only share departure data with each other, but also with the Eurocontrol Network Manager Operations Centre (NMOC). The Network Manager permanently monitors the air traffic flow and capacity management of the European airspace with as objective: “Optimise traffic flows according to air traffic control capacity while enabling airlines to operate safe and efficient flights.” (Eurocontrol, 2019)

The medium- and short-term planning of air traffic flow and capacity management until the day of operation is divided in the same three phases as most other plans:

- Strategic: “During this phase the NMOC helps the air navigation service providers (ANSPs) to predict what capacity they will need to provide in each of their air traffic control centres. A routing scheme is prepared. This also includes avoiding imbalances between capacity and demand for events taking place a week or more in the future (large-scale military exercises, major sports events, etc.).”
- Pre-tactical: “During this phase the NMOC coordinates the definition of a daily plan, the initial network plan and informs air traffic control (ATC) units and aircraft operators about the ATFCM measures that will be in force in European airspace on the following day by publishing the agreed plan for the day of operations.”
- Tactical: “During this phase the NMOC monitors and updates the daily plan based on the current situation and continuous capacity optimisation according to real time traffic demand. When aircraft are affected by a regulation, the centre offers alternative solutions to minimise delays.” (Eurocontrol, 2017)

Figure 8 visualizes the planning phases. Added are the long-term capacity assessment, planning and the post-ops analysis of the performance, which is used in the future planning. Underneath the phase is indicated what tasks are executed during the phase. Going from left to right with each phase the plan becomes more detailed when more information about the day 0 being available.

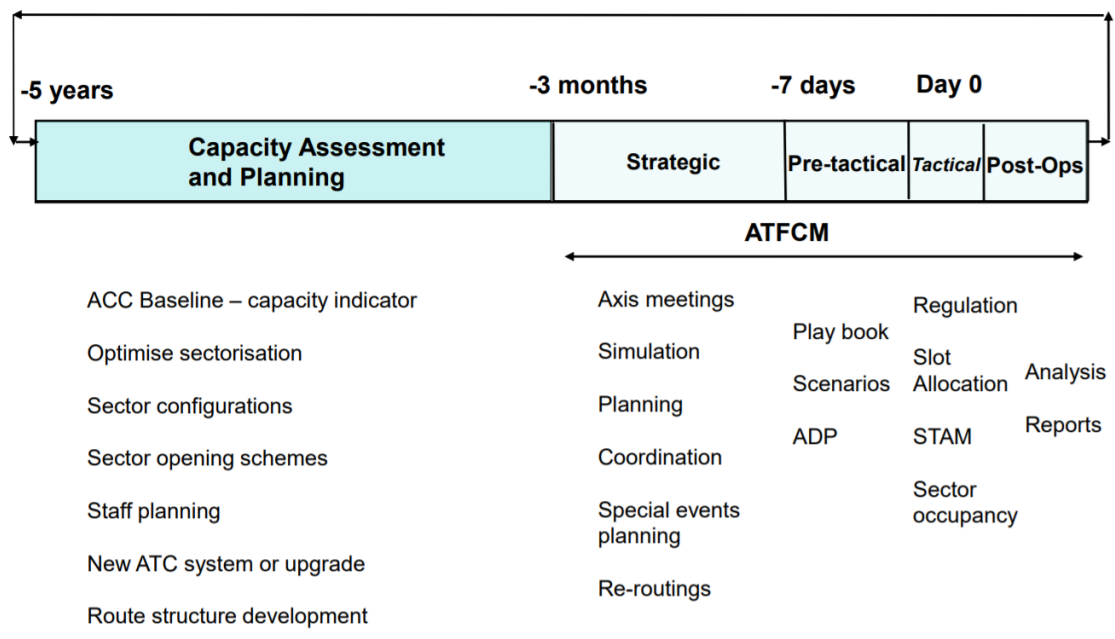


Figure 8: Eurocontrol Network Operational Plan planning phases (Eurocontrol, 2016)

During the tactical phases an important task of the network manager is to regulate on airspace capacity. The airspace capacity is calculated according to the fishbone diagram of figure 9. The airspace capacity is calculated for every piece of airspace (sector) by the responsible Air Navigation Service Provider.

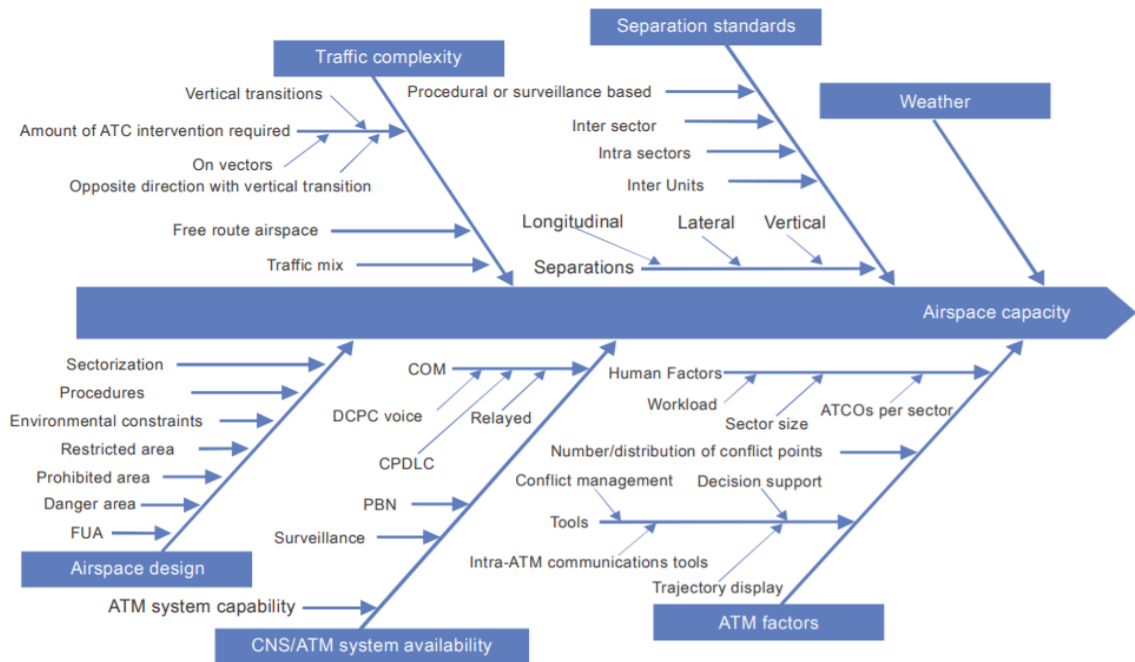


Figure 9: Fishbone diagram influences on airspace capacity (ICAO, 2018)

The amount of influences complicates the process to determine the airspace capacity. Only one of the influences must differ from planned to drastically change the airspace capacity. This means that the determined capacity in the strategic planning can be completely different from the tactical phase of execution. When the capacity changes during the tactical phase in a negative way, allowing less flights through a sector compared to scheduled, the Network Manager may be forced to reroute flight around the affected sector or delay flights to distribute the peaks within the sector over a longer period. Limiting the amount of flights to be within the restricted capacity. The flights that get delayed are chosen at random to make sure all airlines are as equally affected as possible.

Flights are delayed on the ground until they can be guaranteed a direct flight to the destination to increase efficiency. Delaying flights while in the air has disadvantages: fuel usages and CO2 emissions. When a flight needs to be delayed, the network manager assigns the flight a take-off time at which it can take-off and continue through the European airspace without significant delays in the air. This take-off slot is called a Calculated Take-Off Time (CTOT). The slot is a window of 15 minutes in which the flight can take off, starting 5 minutes before the CTOT and ending 10 minutes after the CTOT (The name ATFM slot is used as well for this window).

Figure 10 is an example of this system. Due to a strike at the French air traffic control, severe capacity restrictions occurred in French airspace. Many sectors under French ANSP supervision are affected. These sectors are indicated as red or orange. If the sector is red it means that a flight planned to fly through the sector has to wait for at least 45 minutes compared to flight plan, until the flight can enter the sector. For Schiphol this day will have resulted in heavy delays for flights that needed to go through those sectors, for example flights to France, Spain and Portugal will have been affected. They had to wait at the ground until they can get a slot for those airspaces or had to fly around the affected sectors, decreasing efficiency. (Eurocontrol, 2018)

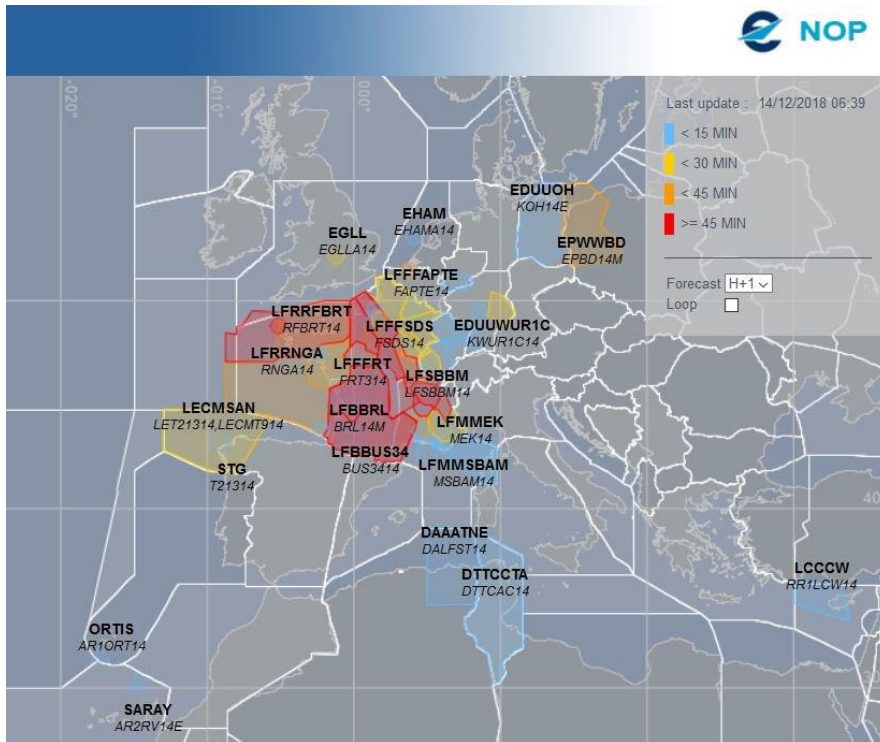


Figure 10: Map indicating restricted sectors at 14/12/2018 06:39 (Eurocontrol , 2018)

By delaying flights on the ground, the CTOTs affect the Schiphol ground processes. To understand the effect, the effects of the CTOT are put in the ACDM milestone timeline. In the figure below all the ACDM milestones are visualized on a timeline. Milestone number 1 represents the activation of the flight plan 3 hours prior to the estimated off-blocks time. Informing all stakeholders, the flight is about to depart. Milestone number 2 represents the moment the Network Manager can assign a CTOT or/and suggest an alternative flight plan to a flight when there is an under capacity in one of the sectors within the flight route filed in the flight plan. The Network manager can assign a CTOT from 2 hours prior to Estimated Off-Block Time until the Actual Off-blocks Time. When the flight has received a CTOT the flight will wait on the ground until it can take off within the ATFM slot.

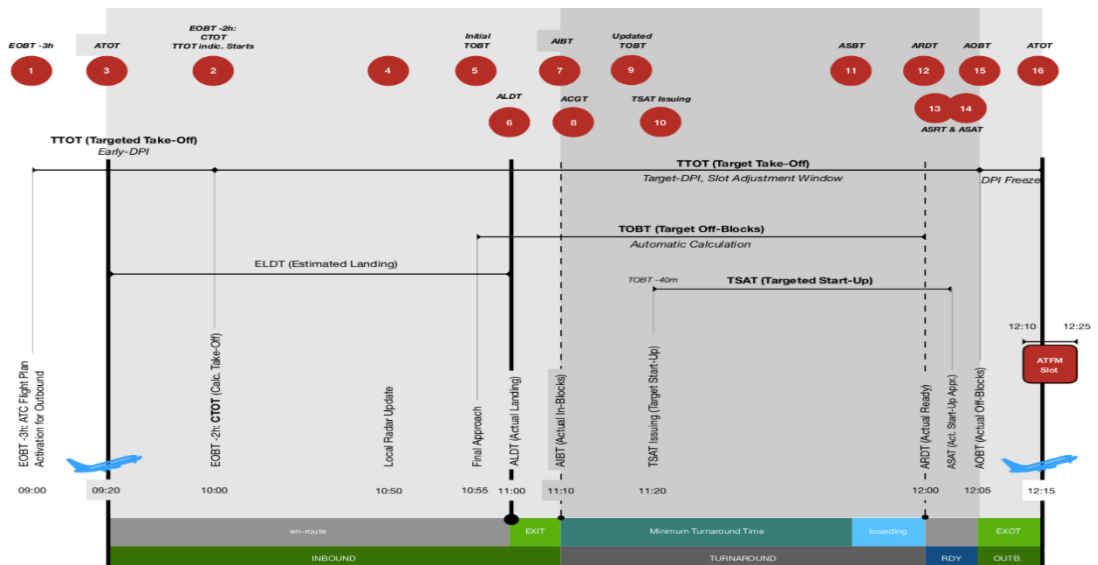


Figure 11: Flight timeline with ACDM milestones (Eurocontrol , 2019)

### 3.2.1 Departure planning

Schiphol uses a system to calculate the departure sequence of aircraft called the Collaborative Pre-Departure Sequence Planner (CPDSP). This sequence planner uses ACDM data to support air traffic controllers to determine when flights should leave the stand (The TSAT, milestone 10) to get at the take-off runway in a distributed way and, if a flight has one, within the ATFM window.

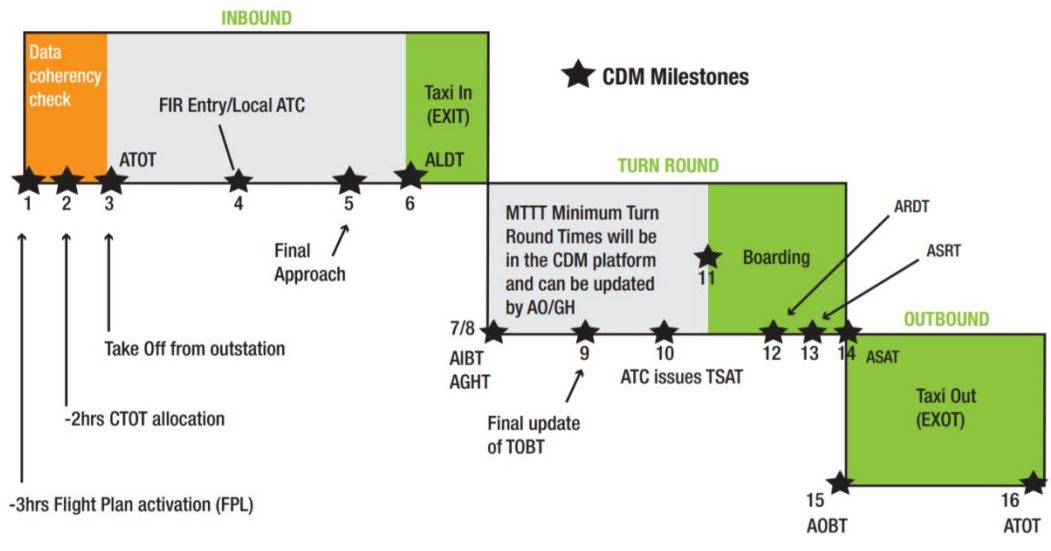


Figure 12: ACDM milestone in flight process (Eurocontrol, 2017)

In figure 13 the process of the CPDSP is further elaborated. The sequencer starts with the final update of the Target Off-blocks Time (milestone number 9). The TOBT indicates the time that the ground handling expects the aircraft to have completed the turnaround and is ready to depart. The TOBT is used to calculate the earliest possible TTOT by adding the estimated taxi time. The earliest TTOT is compared to all the restrictions the flight has, among other the CTOT a flight might have. This leads to a TTOT that is realistic and complies to all restrictions. The TTOT minus the taxi out time is used to calculate the TSAT.

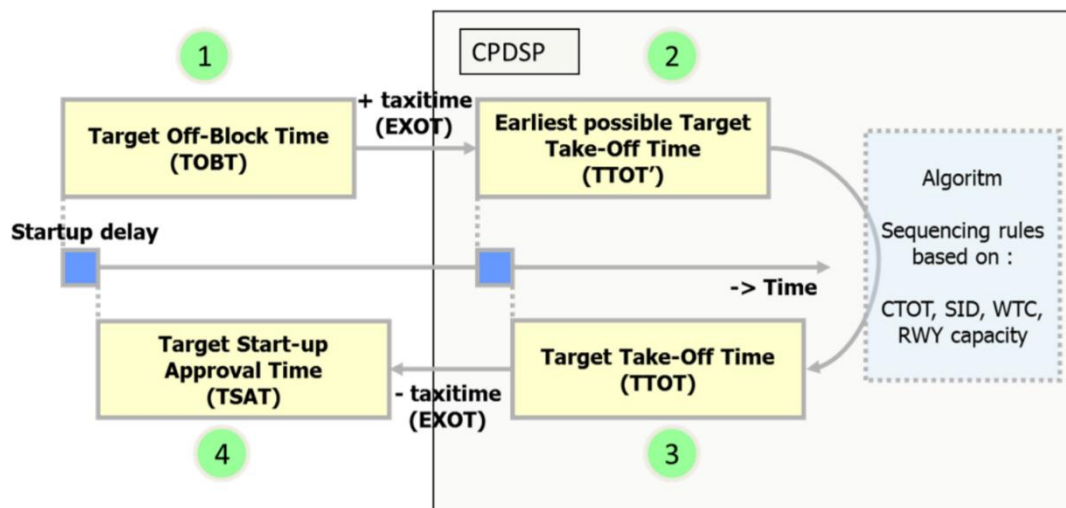


Figure 13: Process flow departure sequencer (Schiphol, 2018)

The TSAT has a window of -5/+5 minutes in which the pilots from the aircraft reports ready for departure to the ATC, who will give start up approval or with a slight delay depending on the operational circumstances. When the ground controller gives start up clearance this is also the moment the aircraft can leave the gate and is equal to the Actual Off-blocks Time.

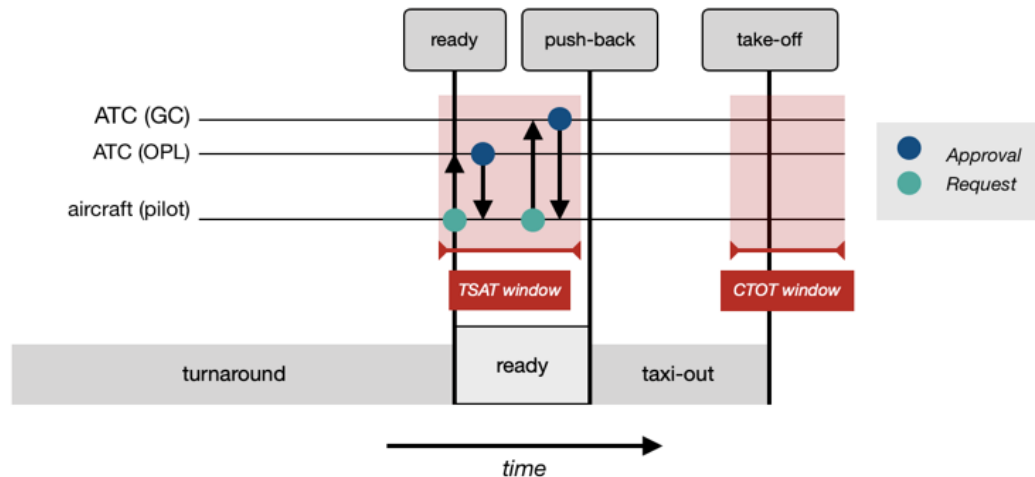


Figure 14: Start-up request process (Voogt, 2019)

When a flight is delayed due to a CTOT and the flight is already in the departure sequence, the sequencer creates a new TSAT to prevent the situation that an aircraft is unable to depart after start up approval has been given. As a result, the flight has to wait longer until he is finally in his TSAT window. Resulting in the situation that it can happen that a completely ready aircraft needs to wait at the airport until they can depart. Due to an under capacity in an airspace, thousands of kilometres away.

If the airport is congested and the free gate capacity is low, the CTOTs can cause problems in the inbound flow of the airport, because arriving flights are unable to go to their assigned stands and start their ground processes. When this situation occurs there are some options to minimize the unwanted effects on the inbound flow:

- ATFM delay longer than 20 minutes:  
*“In the event that an arrival aircraft has to wait for a prolonged period of time (usually more than ca 20 minutes) for its parking position becomes available, ATC coordinates with the pilot of the departure flight which is blocking the parking position. When pilot is fully ready but is not within TSAT window yet, ATC shall coordinate with APC to tow the departure flight to a temporarily parking position. APC shall change the parking position and coordinate the movement towards the new temporary parking position. In this situation the departure flight still remains ready for improvement for any TTOT/CTOT updates.”* (Schiphol, 2018)
- ATFM delay less than circa 20 minutes:  
*“In the event that an arrival aircraft has to wait for a shorter period of time (usually less than ca. 20 minutes) for its parking position becomes available, ATC shall coordinate with the pilot of the departure flight which is blocking the parking position. When pilot is fully ready but is not within TSAT window yet, ATC shall plan the flight within the take-off sequence and coordinates taxiing towards a temporary parking position. In this situation no TTOT/CTOT improvements are possible.”* (Schiphol, 2018)

### 3.2.2 CTOT forecast

In the past five years the amount of airport ATFM delays has experienced an impressive growth. Growing from about 4 million airport delay minutes in 2013 to about 6.5 million minutes in 2018, as indicated in figure 16. The expectation is that this growth will continue in the next coming year, with a bigger growth in air traffic movements than capacity. The growth in regulations is visible when analysing the Schiphol specific departure data. Indicated in figure 15, in 2014 during the most regulated days about 15% of the departure flights has a CTOT, in 2018 this has risen to more than 40% (indicated by the blue arrow).

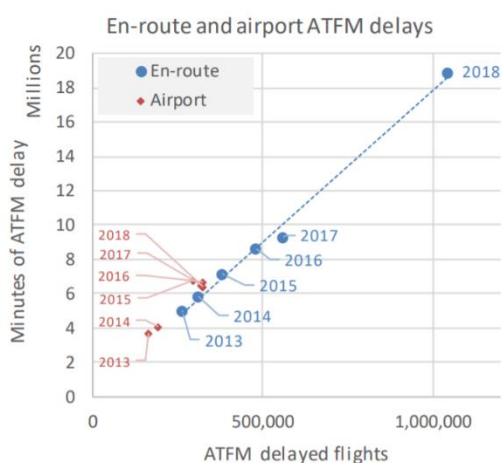


Figure 16: Development of ATFM delay minutes

AMS

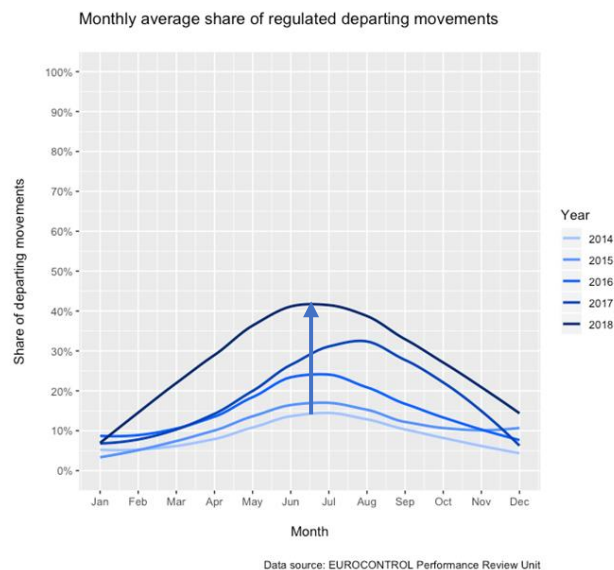


Figure 15: Development of the percentage of flights at Schiphol affected by CTOT

### 3.3 Early arrivals

During the flight planning phase of airlines, they use block times to plan flight schedules. These times are the time scheduled for the time from Scheduled Off-Blocks Time until Scheduled In Blocks Time. Because it is very important for an airline to arrive on-time, they use the following measures to ensure their on-time arrival performance:

- The planned flight time is based on the average time it takes to fly a route over the last years. A typical standard is the time that is needed by 80% of the flights to arrive earlier or on-time.
- To accommodate for delays, they add a time margin based on historical and predicted delays and add it to the scheduled block times.

These measures ensure a high probability for a flight to arrive in time. However, a side effect is that when the wind is favourable and there are no delays, the flight arrives far before the actual scheduled arrival time. (IATA, 2014) (Eurocontrol, 2005)

### 3.4 Airport operations control centre

Currently Schiphol is developing their AirPort operations Control Centre (APOC). The definition Eurocontrol uses for an APOC is:

*“A coordination arrangement at an airport, whereby operational stakeholders (actors) collaborate for the effective/efficient establishment and execution of an agreed operational plan, in a structured manner with agreed processes, either through physical or virtual interaction or a combination thereof. The APOC is the prime interface between the Airport and the Network Manager Operations Centre (NMOC) established in the States within, and adjacent to, the ECAC area.”* (Eurocontrol, 2018)

One of the responsibilities of the APOC will be the development and management of the Airport Operational Plan. This is a rolling plan containing all the necessary data, contextual information, scenarios and KPIs to enable decision making in a collaborative manner. The development of this plan will work according to the same principles used by Eurocontrol to build their Network Operational Plan. However, the definitions and exact timeline used are different. A detailed overview of the development of an AOP can be found in Appendix II.

With all the airport stakeholders involved in the APOC it should result in an AOP in which all the stakeholders’ interests are taken into account. Delivering the most optimal plan, balancing all the stakeholder interests with the system performance. Benefitting the system performance by increasing the system predictability and stability.

Six days before the day of operation the AOP starts to get shape, all the latest information is integrated and possible scenarios of the day of operations are created. One day before the day of operation, depending on the development of circumstances, a plan based on the scenarios is chosen as the actual plan. The other plans stay on standby and can always be used if the circumstances unexpectedly change.

During the day of operation (D-0), the APOC will manage the AOP and when needed, change the planning according to predetermined structures. These changes should be made in cooperation between all the stakeholders. One of the added values of APOC are the short communication lines between the stakeholders benefitting quick decision making. Cooperating on the decisions should create a better overview of the effects a change within the operations of one stakeholder has on the other stakeholders.

Another responsibility of the APOC is the coordination between the APOC stakeholders, the Network Manager Operation Control and the Airlines Flow Managers. Hereby making sure that all the plans are aligned, and all the airport stakeholders are aware of the network operations and the airline operations. These relations are visualized in figure 17. (Eurocontrol, 2018)

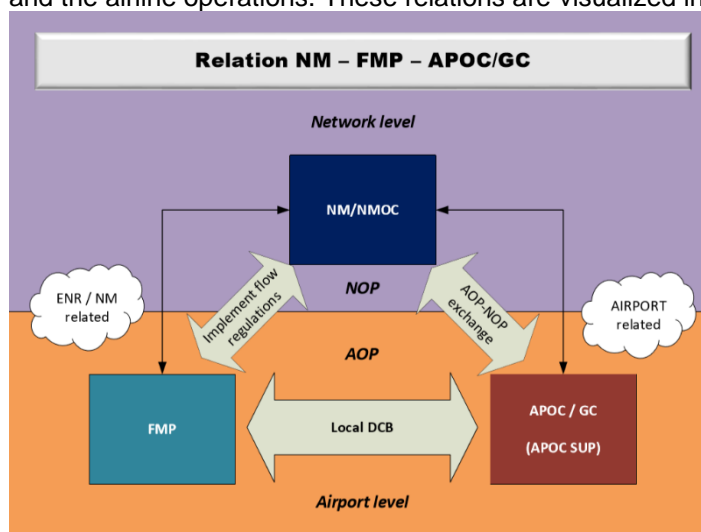


Figure 17: Relations around APOC (Eurocontrol, 2018)

## 4 System Analysis

To understand the procedures and structures enabling the system to operate (stably), the system and stakeholders are analysed.

Currently every stakeholder makes their own operational plan based upon the filed flight plans of the airlines. Every stakeholder shares their operational plan with the other stakeholders and adjusts it cooperatively until realistic and/or optimal. During the execution phase of the plan every stakeholder stays responsible for their own planning and execution. ACDM is the catalyst between all the plans keeping all the stakeholders up to date with the latest information about the operation, aligning the operations after changes occurred. The ACDM plan can be considered as the overarching plan, where all the stakeholders deliver a part of the input planning. The stakeholders hold periodic sector meetings to keep each other up to date of their own tactical execution of the plan. During the meetings the stakeholders discuss events that could influence them and the system and align the measures taken in response.

Figure 18 visualizes the chain of systems an aircraft progresses through when performing flights arriving and departing Schiphol and the stakeholders involved within each system. Each of the stakeholders has the following responsibilities.

- Airline: responsible for filing flight plan and executing the flight
- Eurocontrol: plans European (including Dutch) airspace according to flight plans
- LVNL: plans the Dutch airspace infrastructure and use of runways at Schiphol.
- Amsterdam Airport Schiphol: responsibility over airport operations and its planning.
- Ground handler: contracted by airline to perform turnaround

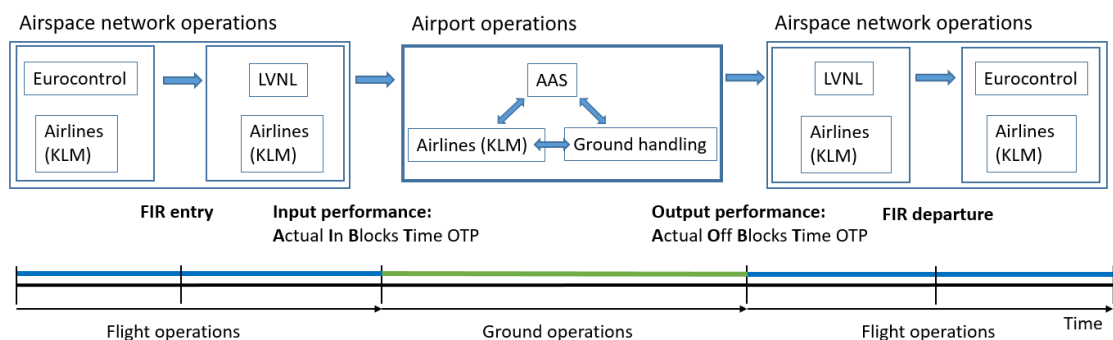


Figure 18: Flight process systems chain

Following the timeline from left to right every system box is described. In which the output of a process, is the input of the following process.

- The flight first enters European airspace and network. The control of the European Network is the responsibility of Eurocontrol, and the execution of the flight is the responsibility of the airline. The airline has submitted a flight plan that Eurocontrol allowed. Eurocontrol has now become responsible to offer enough facilities to the airline to execute the flight plan.
- When the flight enters the FIR of LVNL (LVNL controlled airspace) the responsibility over the guidance of the flight is handed over to LVNL. LVNL is responsible to offer the right infrastructure. The planning of the amount of aircraft in the FIR of LVNL is done by restricting the amount of incoming flights through the Eurocontrol Network Manager. The airline is still responsible for the execution of the flight. LVNL guides the flight from the FIR entry point towards the assigned parking position on the airport. When on the ground the infrastructure becomes the responsibility of AAS.
- When the aircraft has reached its position, the responsibility is passed through to Amsterdam Airport Schiphol to offer the airline the right facilities and infrastructure to execute the turnaround process they submitted a request for at the airport. The responsibility of the actual execution stays with the airline and the contracted ground handler.

- If the flight is within the TSAT window after completion of the turnaround process, which is calculated according to the flight plan filed with Eurocontrol and afterwards shared with LVNL, the flight can request start up approval. When the start-up approval is given the flight leaves the parking stand and enters the outbound process. The LVNL is responsible for the guidance of the flight and the air infrastructure from the moment of take-off. Schiphol is responsible for the ground infrastructure. The execution of the flight is the responsibility of the airline.
- At the FIR boundary the guidance of the departure flight is handed over to Eurocontrol. Eurocontrol will guide the flight to the responsible ANSP of the arrival airport or the edge of the European airspace. During this phase Eurocontrol is responsible for the guidance of the flight, sufficient air infrastructure and planning and management of the airspace.

The influences on the plan stability differ greatly between the stakeholders and are dependent on the place in the process where the stakeholder is responsible over the flight. All the stakeholders hold the responsibility of their own planning of their system in the chain during the strategic, pre tactical and tactical phase. Even though the plans are aligned, the goals differ. Each stakeholder has planned to execute their system box as efficient as possible and uses its own adaptive structures to manage the operation efficiently. Within the adaptive structures the systems of the other stakeholders are seen as environmental influences. While with cooperation these influences could be prevented.

#### 4.1 Ground operations system

Within the ground operations the same patterns appear, each stakeholder has its own planning and responsibilities. A visualization per stakeholder elaborates on the responsibilities of the three biggest (and KDC) stakeholders of the ground operations at Schiphol: KLM, AAS and LVNL.

- **KLM:** KLM measures the plan stability at the OTP of the Actual In Blocks Time. An important milestone because passengers expect to arrive on-time. Thereby is the AIBT the milestone that determines if passengers are entitled to claim delay compensation when the flight arrives more than 3 hours too late without force majeure. This creates a big financial trigger for KLM to make sure their flights always have an on-time AIBT. Even without the financial trigger the off-blocks OTP is still an important stability KPI to the airline. The off-blocks OTP can strongly influence the in blocks OTP of arriving flights. With Schiphol as their home base and hub in their system, KLM wants to prevent delays at the airport that might cause the Schiphol stability to severely decrease. (KLM, 2019) KLM has split up their operational processes and responsibilities between ground and flight operations. This is visualized in figure 18 and 19. The flight operations are managed from the Operations Control Centre (OCC) and the ground operations at Amsterdam Schiphol from the Hub Control Centre (HCC). The transfer of responsibility over a flight/aircraft between the two systems occurs at the in/off-blocks moments. The output of the flight operations (OCC) and most important plan stability KPI to KLM is the Actual In Blocks Time OTP. The stability of the ground operations is measured using the off-blocks OTP. However, this KPI is of less importance to the KLM. In figure 19 the blue box indicates the control of the OCC. The blue dotted line indicates how the OCC flight operations experiences the ground process. When the flight has gone in blocks their work is done and the flight is ended. The HCC takes over and unloads the aircraft. During the turn around the aircraft changes from inbound to outbound flight and is loaded again. After the turnaround the outbound flight becomes the responsibility of the OCC from the off-blocks moment.

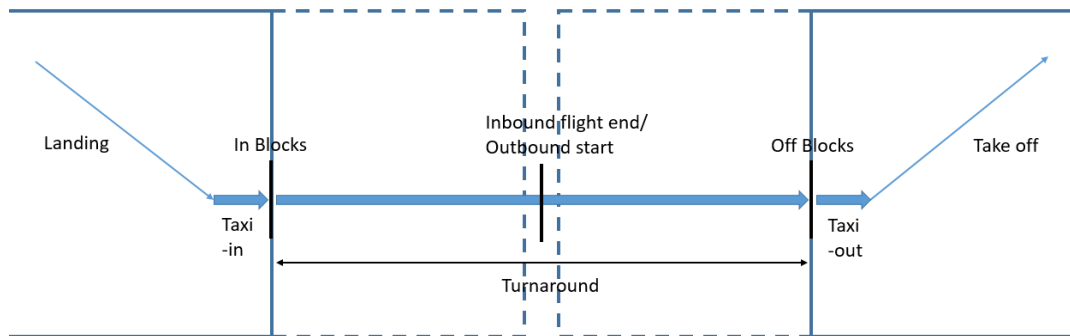


Figure 19: KLM flight operations process (OCC)

The HCC experiences the process differently. They are responsible for and control an aircraft from the moment it has gone in blocks until off-blocks. This is visualized in figure 20 with the blue box. The blue dotted line indicates the responsibility of the OCC.

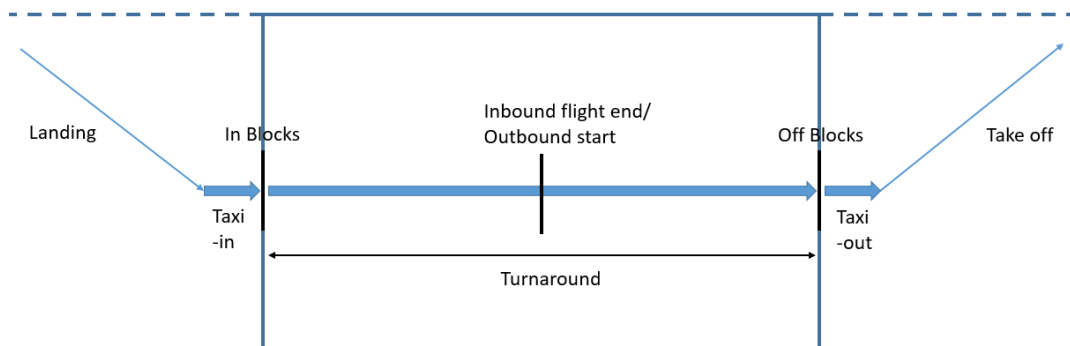


Figure 20: KLM ground operations process (HCC)

The structure of the organization is very similar to the structure of the APOC (ground) and the network manager (flight). An interesting observation is that within the KLM between the HCC and OCC sometimes communicational problems exist. When the OCC makes a decision, it is not always clearly communicated to the HCC and vice versa. The people working in the HCC and OCC are aware of the risks of the miscommunications and do their best and have systems to prevent them.

The same could happen with the APOC and Network manager, where two sides could be created. Ground and Flight operations. Where the APOC works closely together with the KLM HCC, the Network Manager works closely together with the OCC.

- **Amsterdam Airport Schiphol:** The airport is focused on the OTP of the Actual Off-blocks Times. Being the output of the ground operations system the OTP of the AOBT creates the most representable KPI of the airports' airside ground operations. The output is the deliverable to the customers of the airport: airline and passenger. (Royal Schiphol Group, 2019)

Note: Amsterdam Airport Schiphol is assigned as airport operator. They are responsible to deliver all the required infrastructure for a safe and efficient operation of the airport.

Figure 21 indicates the influence and responsibility of AAS on the ground operations. The airport is responsible for the ground infrastructure within the blue box. However, during the taxi-in and taxi-out phase the responsibility over the flight is with LVNL. When in blocks the responsibility changes to AAS, indicated by the red dotted lines. After the off-blocks moment, the responsibility of AAS ends and is transferred to LVNL. This transfer is the output of the AAS system and the measurement point of their OTP.

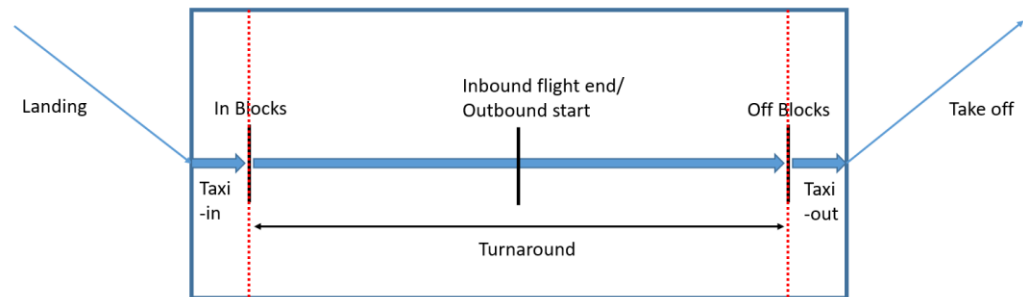


Figure 21: AAS ground process priorities

- **LVNL:** The LVNL organisation has, compared to the other two organizations, the least interest in the plan stability KPIs used by the other stakeholders. This is mainly due to the relative simplicity of the operation. Applying the first come, first serve principle, the LVNL is relatively independent from plan instability. When a flight approaches their airspace, the goal is to guide it safely and efficient to the parking stand. In normal operation the amount of entries of the airspace should not exceed the output to the airport by regulating the amount of inbound flights through the Eurocontrol Network manager.

The same applies to the departure process. When a flight leaves the parking space and becomes input in the process it is assured of an output of the LVNL system into the Eurocontrol airspace, through the Eurocontrol Network Manager. The most important for LVNL is the throughput capacity. The more flights that can go through the system, the lesser the delays.

Within ground capacity it is important to the LVNL that there are enough aircraft stands available to guide the traffic to. If an aircraft must wait on a taxiway until his stand is available, the workload of air traffic controllers and the risk of an incident increases. To stop this from happening the LVNL can choose to restrict inbound flights to create take off capacity for outbound flights, decreasing the amount of aircraft on the ground. By doing this they can greatly influence the plan stability to ensure capacity.

Note: The LVNL is tasked with guarding the safety of all the air traffic at the airport. So, if anything appears to be unsafe or might become unsafe then the LVNL can shut everything down.

The blue box in figure 22 indicates the responsibility area of LVNL. The responsibility starts when the flight enters the Dutch air space at the FIR boundary and ends when the flight has gone in blocks at its parking space. The ground infrastructure used during taxi is the responsibility of Amsterdam Airport Schiphol, indicated by the red dotted line. When the turnaround is completed, and the flight has gone off-blocks the responsibility transfers to LVNL again. Guiding the aircraft from the parking stand towards the runway to the

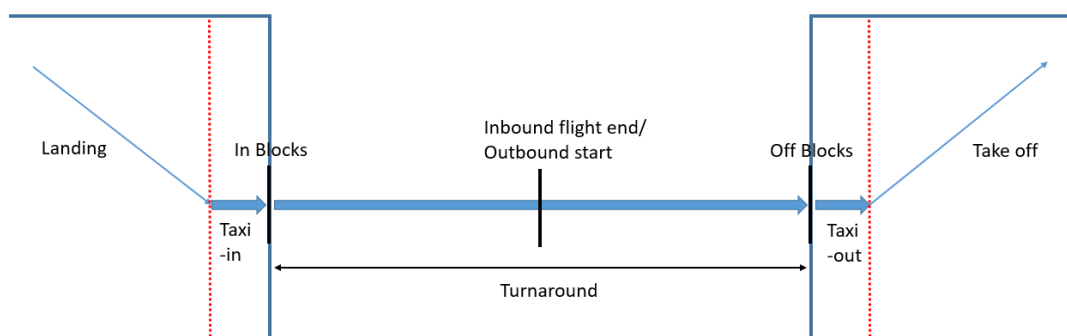


Figure 22: LVNL ground process priorities

In short, the stakeholders focus on different KPIs, based on their own process and incentives, when determining plan stability. LVNL: peak hour throughput capacity, Schiphol: Off-blocks OTP, KLM: In blocks OTP. With the following incentives:

- KLM uses in blocks on-time performance as a selling point to their passengers and wants to prevent paying compensation.
- Schiphol wants maximum efficiency where flights have the shortest time at their gates.
- LVNL wants to use their capacity restricted airspace to the full potential.

Figure 23 visualizes the responsibilities of all the stakeholders within the ground operation. Combining the visualizations of figure 18, 19, 20 and 21. The coloured lines in the bottom indicate the responsibility. The figure creates an effective overview of the involvement of stakeholders and the common ground within the operation.

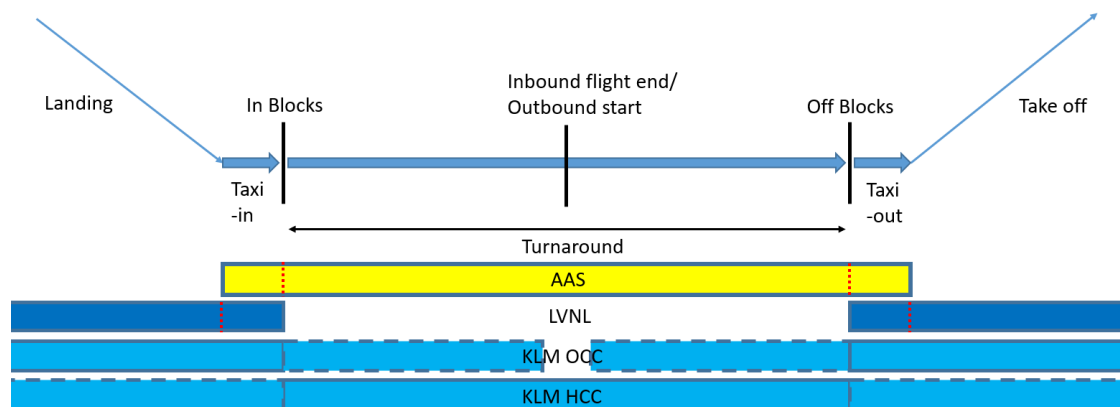


Figure 23: Overview ground operations processes KLM, LVNL and AAS

The biggest common ground on plan stability is the need to execute the operation as efficient as possible. However, with all the different responsibilities and KPIs to measure stability within the ground operations, it becomes difficult to create cooperation to increase the overall system stability.

## 4.2 Off-blocks process

The current stability of the ground operations at the airport is measured by Schiphol using the off-blocks OTP KPI. To understand the performance indicated by the off-blocks OTP a SIPOC diagram is created (table 10).

Airport off blocks process				
Supplier	Input	Process	Output	Customer
<p>AAS, responsible for:</p> <ul style="list-style-type: none"> <li>Sufficient ground infrastructure: Taxiways, Runways, ground holdings</li> </ul> <p>Eurocontrol, responsible for:</p> <ul style="list-style-type: none"> <li>Planning of air infrastructure</li> <li>Assigning take-off time</li> </ul> <p>LVNL, responsible for:</p> <ul style="list-style-type: none"> <li>Departure sequence and take-off time adherence</li> <li>Aircraft guidance from parking stand to runway to FIR boundary</li> <li>Sufficient air infrastructure</li> </ul> <p>Airline:</p> <ul style="list-style-type: none"> <li>Responsible for execution of the flight: aircraft, passengers, crew, etc.</li> </ul> <p>Ground handler:</p> <ul style="list-style-type: none"> <li>Delivers aircraft ready for push back</li> </ul>	Flight ends turnaround	<ul style="list-style-type: none"> <li>LVNL sequences makes start up sequence based on flight plan (airline), TOBT (ground handling) and ATFM slot(Eurocontrol)</li> <li>Flight (airline) requests start up approval at LVNL depending on sequence</li> <li>Flight can leave within TSAT window created by LVNL sequencer</li> <li>Ground handler performs push back</li> </ul>	flight goes off blocks	<p>Airline:</p> <ul style="list-style-type: none"> <li>Ability to perform their flight according to flight plan and departure slot</li> </ul> <p>LVNL:</p> <ul style="list-style-type: none"> <li>Start of guidance to FIR boundary (input of departure system)</li> </ul> <p>Eurocontrol:</p> <ul style="list-style-type: none"> <li>Flight enters network operation plan (input of network operation)</li> </ul> <p>AAS:</p> <ul style="list-style-type: none"> <li>End of use of gate capacity (output of ground operations)</li> </ul> <p>Ground handler:</p> <ul style="list-style-type: none"> <li>Finishes turn around (end of turnaround)</li> </ul>

Table 10: SIPOC flight off-blocks process

Interesting to notice in the SIPOC model is the supplier input. All the stakeholders: KLM, AAS, Ground handlers, LVNL and Eurocontrol are present. Ultimately Eurocontrol determines the moment a flight can go off-blocks. They stabilize the input to their network by only allowing flights to go off-blocks when the network system can accommodate the flight. Unable to go off-blocks the flight stays in ground operations while the turnaround, except for the pushback, is completed. As a result, the KPI of off-blocks OTP is not causally linked with the ground operations but can be a result of the input of the Network operations as well. Concluding, the off-blocks OTP is not necessarily indicating the stability of the ground operation. What it does indicate is the output stability of the ground operations. An important KPI because usually the output stability influences the whole system stability.

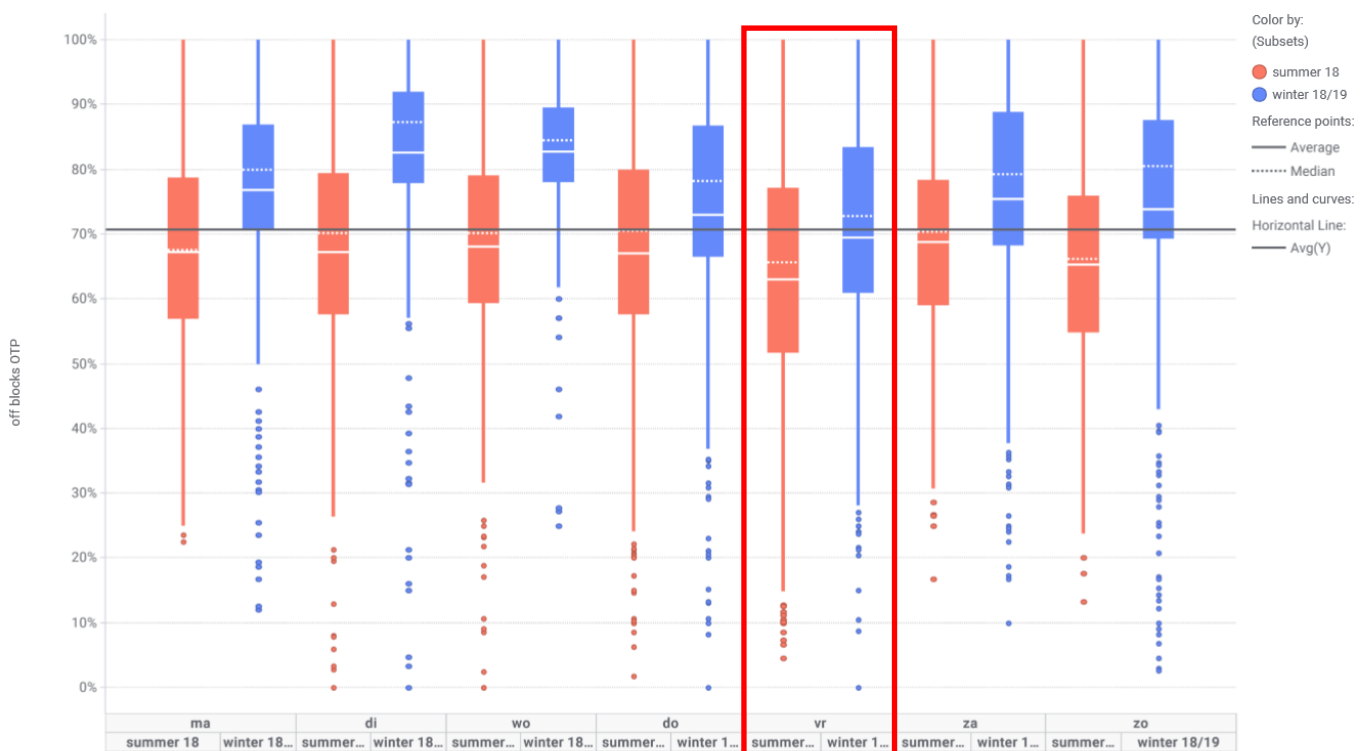
## 5 Current (output) stability

To find points of improvement, the current stability of the airport ground operational plan is analysed using the Amsterdam Airport Schiphol KPI for stability. AAS measures the ground operational stability at the output of the system, the off-blocks OTP. However, the off-blocks OTP KPI does not indicate the system stability, it does indicate the output stability. For the goal of this research the difference is irrelevant because by improving the output stability, the system stability is improved as well.

The first off-blocks OTP data analysis is a boxplot (graph 1, Appendix III) of all the flights leaving from Schiphol during the summer and winter season of 2018/2019 grouped over the days of the week. The OTP indicates the percentage of the flights that left the gate according to their schedule, which is created during the strategic planning. The analysis is created using formula 2.4 Interesting to notice in the analysis is difference in performance between the **summer** (red/orange) and the **winter** (blue). Where, even though the winter has far more outliers mainly due to bad weather, the average OTP is better. This implies that there is a difference between the summer and winter causing this change in performance. The only clear difference between the two seasons is the amount of flights handled per day. This implies that a lack of capacity and thereby a lack of flexibility is a possible cause of the problem. This underlying problem is confirmed by all the experts from all the different stakeholders.

The second noticeable point is the performance decrease during the Friday (red square). Friday is both during the winter and summer the worst performing day. Not coincidentally it is traditionally the busiest day of the week. With both business travellers going home for the weekend and leisure passengers flying for a weekend away. Airlines respond to this by scheduling more flights to meet the demand from the passengers. This once again implies that the performance is closely related to the capacity of the airport.

Box plot of the off-blocks On Time Performance per day



Graph 1: Boxplot of the on-time performance per day of the week, divided by summer and winter

<sup>4</sup> Avg off blocks OTP day =  $\frac{\text{Amount of on time AOBT of flights with SOBT on the day}}{\text{Amount of flights with SOBT on the day}} \times 100\%$

Besides the analysis per day the performance is analysed per hour of the day (formula 3).<sup>5</sup> The analysis indicates the percentage of on-time departures that were scheduled within the hour bracket, during the summer and winter of 2018/2019. Every flight that departed before or within 15 min and 59 seconds after scheduled off-blocks time is regarded as on-time.

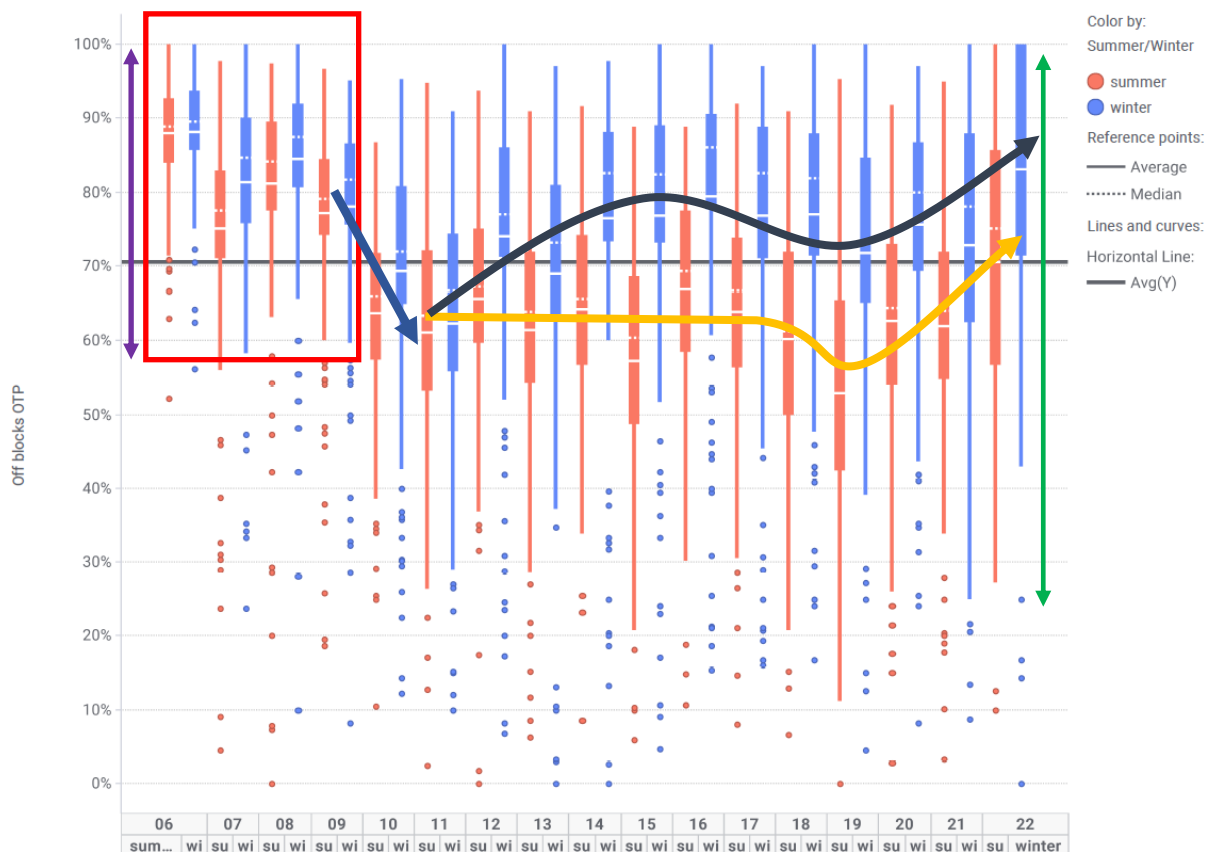
The boxplot resulting from the analysis can be found in graph 2 and the detailed version, including statistical data in appendix IV.

The times are split between summer (red/orange) and winter (blue), the winter has on average a higher percentage of flights leaving on-time during most hours of the day.

Analysing the graph chronologically starting in the morning, the first noticeable point is the relatively high OTP during winter and summer from 6 until 10 (red bracket), indicating a stable operation. The median deviation is low in the morning (purple arrow on the left) this means that the airport can operate stable on a structural basis, day after day. At the end of the day the median deviation is high (indicated by the green arrow), indicating big differences in the off-blocks OTP between the days. At 10 in the morning a drop in OTP occurs (blue arrow) both during summer and winter. Because the winter has more capacity it could mean that the decrease in performance at 10 is not capacity related. During the winter the system able to recuperate and returns above the Schiphol target of 71% (dark blue trend line). Which characterizes a resilient system, being able to recover from the disruptions in the morning.

During the summer, after the decrease in OTP at 10 in the morning, the average returns above 71% late in the evening (yellow trend line). This is an indication of a system that is not resilient enough and cannot recuperate from the morning deviation during the afternoon hours. Sometimes even worsening until 20:00 hours. This is an example of the domino effect, when the problem arises in the morning and the system is not robust and resilient enough then it is unable to return to the original planning causing further deviations and plan instability.

Box plot of the off-blocks OTP per hour [LT]



Graph 2: Boxplot off-blocks OTP per hour of the day

<sup>5</sup>  $Avg\ off\ blocks\ OTP\ hour = \frac{Amount\ of\ on\ time\ AOBT\ of\ flights\ with\ SOBT\ within\ bracket}{Amount\ of\ flights\ with\ SOBT\ within\ bracket} \times 100$

Multiple experts from KLM, LVNL, Schiphol and Eurocontrol recognized this domino effect, explaining and suggesting the possible triggers of the domino effect:

- First rotation effect: Schiphol is a hub airport used by KLM as home base. As a result, almost all of the KLM flights fly depart or arrive from Schiphol. If a flight departs Schiphol in the morning with a delay, it has a high probability of returning with the same delay. So, if multiple flights leave Schiphol in the morning with a delay or are delayed while at an outstation. This will start a domino effect through the day, with the following flights all having reactionary delays. Especially during the busy summer, where all aircraft are tightly scheduled to perform as many flights a day. Flights are unable to recuperate from their delays obtained earlier in the schedule.
- Eurocontrol effects: The airlines rely on Eurocontrol to plan and manage the European airspace. Especially CTOTs are believed to play a big role in outbound delays at the Schiphol. In the experience of the experts, the amount of CTOTs given starts to increase around 10 in the morning. Especially in the summer when free airspace capacity is low.
- Early Arrivals: The aircraft arriving too early can affect the outbound flow by taking capacity away from flights that are delayed or on-time. They create the biggest problems during the peak moments at the airport when little to no additional capacity is available. When little capacity is available the airport still tries to accommodate early arrivals, which can create delays in the flights that arrive with a delay and need a quick turnaround to make up for lost time.
- Outbound bunching: Due to the current procedures used by airlines and the slot coordination the departure plan is unrealistic at the moment of the first schedule. Too many flights are scheduled on the same off-blocks time for the departure system to handle.

## 6 External influences

Within this chapter the influence of early arrivals, ATFM slots from the Eurocontrol network manager and outbound bunching, are analysed.

### 6.1 Eurocontrol Network manager

With the help of a SIPOC model the process of the CTOT allocation is analysed (table 11).

CTOT process Eurocontrol				
Supplier	Input	Process	Output	Customer
Airline: <ul style="list-style-type: none"> <li>Responsible for execution of the flight: aircraft, passengers, crew, etc.</li> <li>Flight Plan</li> </ul> Ground handler: <ul style="list-style-type: none"> <li>Delivers aircraft ready for pushback</li> </ul> Eurocontrol: <ul style="list-style-type: none"> <li>Network operations plan</li> </ul> LVNL: <ul style="list-style-type: none"> <li>Departure capacity</li> </ul>	TTOT (ground handler) Airline (flight plan)	<ul style="list-style-type: none"> <li>Eurocontrol Network Manager compares Network Plan to updated flight plan in ACDM</li> <li>Regulates flights when sector capacity is low</li> <li>Hands out CTOT's randomly to flights through the restricted sectors</li> </ul>	CTOT's	Airline: <ul style="list-style-type: none"> <li>Must delay take-off until within window</li> </ul> Schiphol: <ul style="list-style-type: none"> <li>Flight stays longer at ground than scheduled</li> </ul> Ground handler: <ul style="list-style-type: none"> <li>Pushback ready but not allowed</li> </ul> LVNL: <ul style="list-style-type: none"> <li>Sequencer starts to recalculate sequence</li> </ul> Eurocontrol: <ul style="list-style-type: none"> <li>No under capacity in airspace</li> </ul>

Table 11: SIPOC Process Eurocontrol

Eurocontrol uses CTOTs to delay flights on the ground because of a potential under capacity in the air. CTOTs give Eurocontrol the ability to create a stable input for their network operations plan, preventing expensive and potentially dangerous under capacity in the air. When a deviation from expected capacity occurs, flights are kept on the ground and new (delayed from flight plan) departure times that comply with the newly formed circumstances are allocated. Eurocontrol takes the instability out of their system and moves it to the ground operation of the airport. Where flights, ready for departure, must wait for their CTOT. As a result, the off-blocks times get delayed and more ground capacity is used.

The supplier side of the SIPOC that there is no consideration of information about ground capacity while allocating CTOTs. Without this information ATFM slots are allocated at the airports during moments the airport ground infrastructure is unable to accommodate them. Especially during the ground peak hours, the ATFM slots can heavily affect the ground capacity.

The LVNL is less effected by the instability because the flight sequencer takes the instability of the CTOTs away and automatically adjusts the outbound departure sequence.

To conclude, the Eurocontrol network manager influences the ground operations output stability while managing the network operations plan. Visualized in figure 24. (Voogt, 2019)

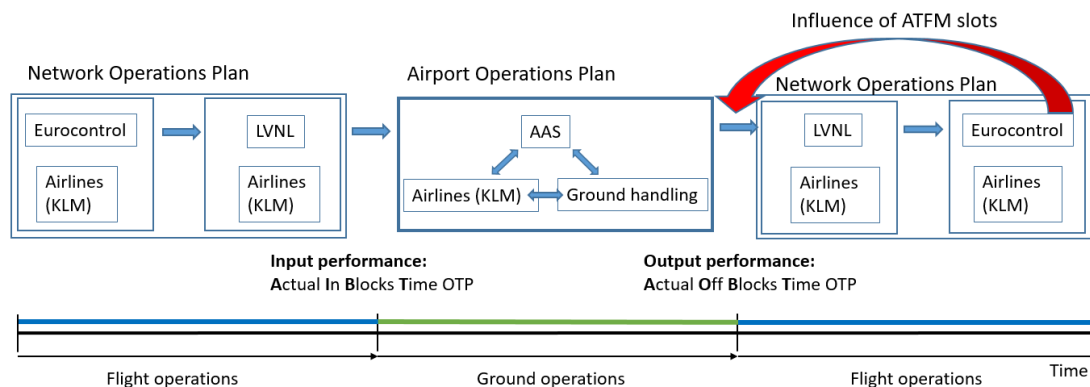
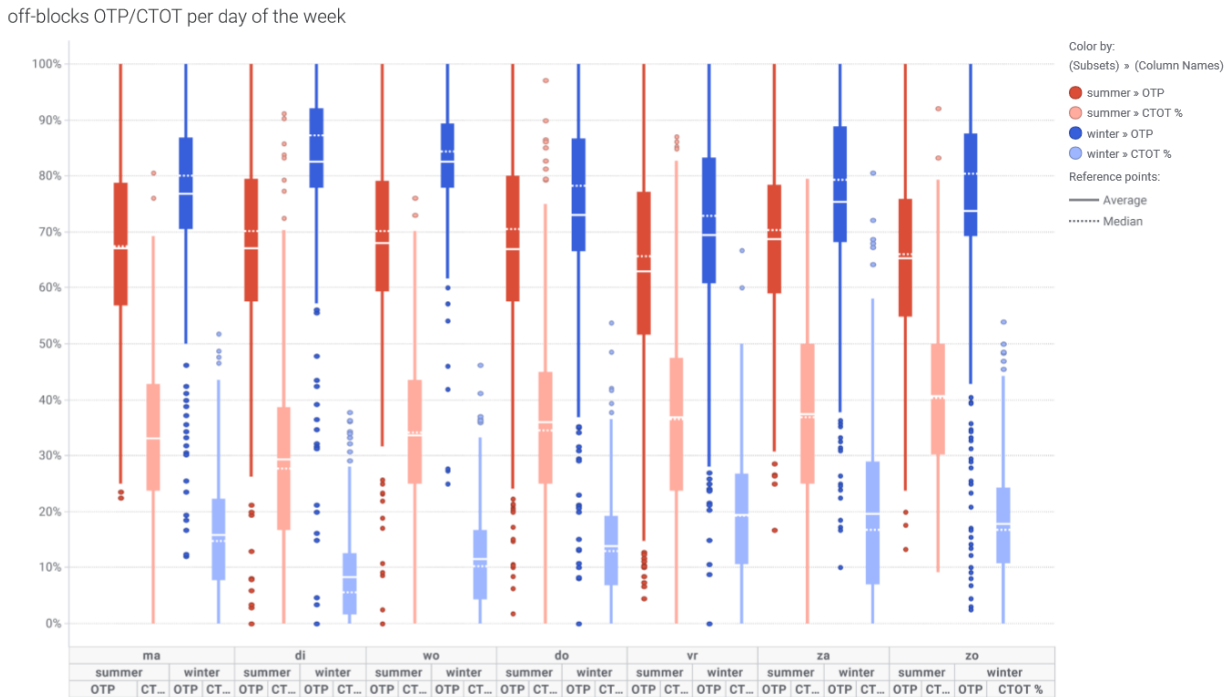


Figure 24: Influence of ATFM slots within airport systems chain

To analyse the influence of CTOTs, the percentage of flights affected by a CTOT is determined per day of the week using formula 4<sup>6</sup> and at every hour bracket, formula 5<sup>7</sup>. The same methods as used with the off-blocks OTP.



Graph 3: Boxplot comparison off-blocks OTP and CTOTs

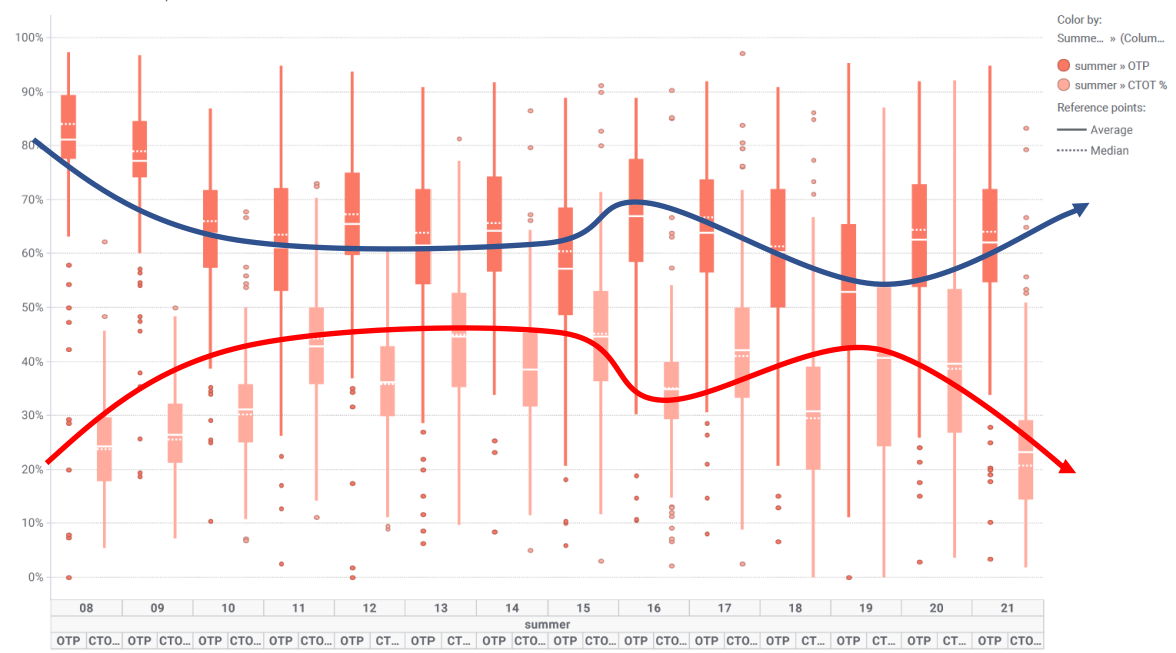
The Boxplot of graph 3 indicates both the off-blocks on-time performance and the percentage of flights affected by a CTOT at that day of the week. During the summer (faded orange) more regulations are given compared to the winter (faded blue). Interestingly the percentage of flights per day of the week with an ATFM restriction appear to be mirrored with the off-blocks on-time performance of the airport. When the percentage of flights affected by a CTOT is high the off-blocks OTP appears to be low.

A boxplot visualizing the percentage of flights effected by CTOTs compared to the off-blocks OTP, per hour of the day is created (graph 4 and 5, detailed version in Appendix IV and V). Due to the great amount of data would contain an overload of information causing it to be very confusing. To prevent this from happening two separate boxplots are made for the summer and winter season.

<sup>6</sup> Percentage of flights with CTOT day =  $\frac{\text{Amount of CTOT effected flights with SOBT within the day}}{\text{Amount of flights with SOBT within the day}}$

<sup>7</sup> Percentage of flights with CTOT hour =  $\frac{\text{Amount of CTOT effected flights with SOBT within the hour}}{\text{Amount of flights with SOBT within the hour}}$

off-blocks OTP/CTOT per hour summer

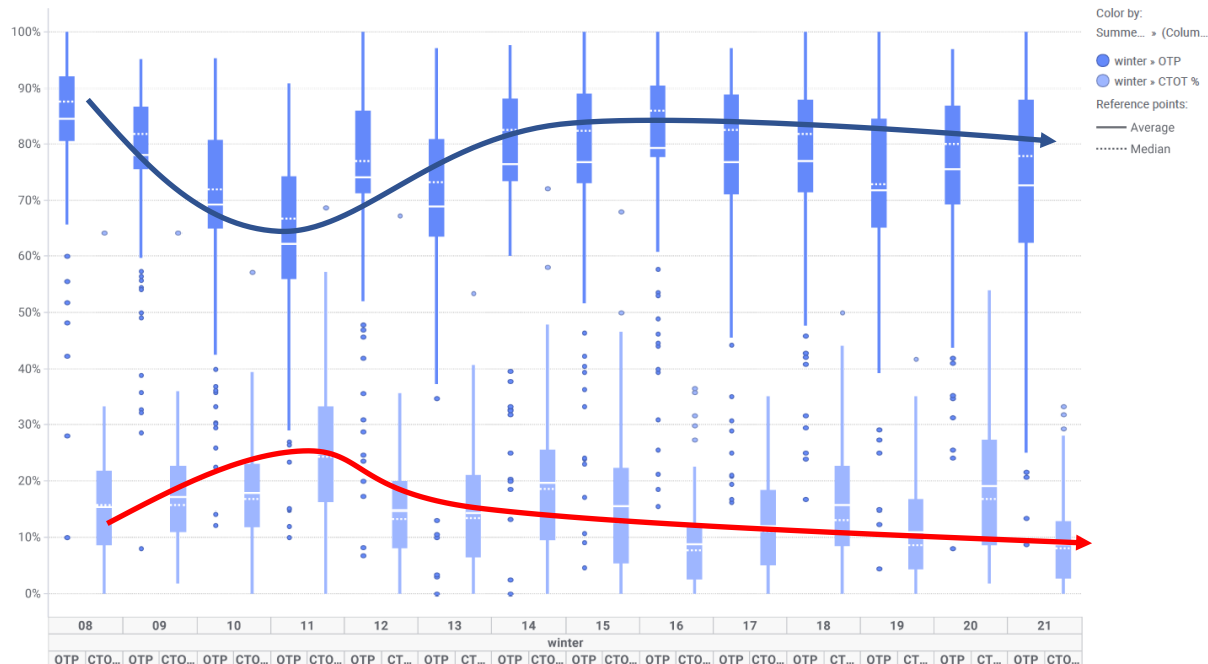


Graph 4: Comparison off-blocks OTP and CTOT percentage per hour during summer

The boxplot per hour has the same characteristics as the day of the week boxplot. The trend line of the CTOTs is indicated in red and the trend line of the off-blocks OTP in blue. The trend lines almost mirrored, with a high percentage of CTOTs the OTP decreases and vice versa. Special focus is on the moment the on-time performance decreases around 10:00 in the morning. The OTP decreases whilst the percentage of CTOTs rises. The first real peak in the average amount of CTOTs is at the bracket of 11:00. From then on never decreasing below 30% of the flights until the bracket of 21:00 hours while the off-blocks OTP never increases above 70%.

(The flights before 08:00 and after 22:00 hours are excluded from the graph, due to night restrictions the amount of ATFM slots is exceptionally high during these hours and of no added value to this research)

off-blocks OTP/CTOT per hour winter



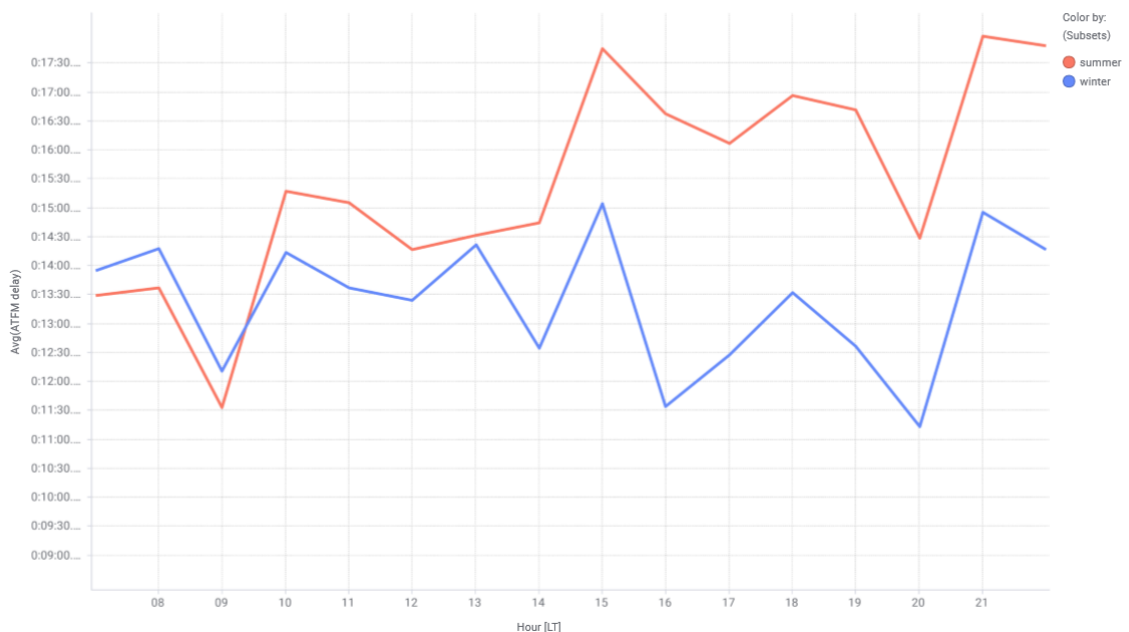
Graph 5: Comparison off-blocks OTP and CTOT percentage per hour during winter

The boxplot with the winter data (figure 29, detailed Appendix V) has a difference compared to the summer boxplot. Similar to the summer, the percentage of CTOTs is at its highest at 11:00 in the morning. However, afterwards at the 12:00 hour bracket, the average percentage of CTOTs and has decreased.

### 6.1.1 CTOT effects

The CTOTs create instability within the airport ground process by delaying flights at their parking positions. The CTOTs can be given until just before the target off-blocks time. For this reason, they are sometimes very unpredictable and cause unexpected last minute deviations in the system. The delays obtained by CTOTs are analysed.

Average ATFM delay minutes per hour of day [LT]



Graph 6: Average ATFM delay per hour of the day, summer and winter

The graph resulting from the analysis of the average amount of ATFM delay obtained by a flight within a certain hour bracket of the day is represented at graph 6. The graph illustrates that during the summer the percentage of flights receiving an ATFM slot is higher and the average amount of minutes an aircraft needs to wait is higher. To understand the impact, table 12 indicates the percentage of flights that had an ATFM delay of more than 10, 15, 20 and 30 minutes.

ATFM delay	10-15 min	15-20 min	20-30 min	30+ min
percentage of flights	18.187%	10.434%	13.611%	11.596%
amount of flights	7936	4553	5939	5060

Table 12: ATFM delays grouped per delay minutes

By multiplying the amount of flights with the minimum delay this gives a total minimum delay of 418,235 minutes, equal to about 290.5 days. If all CTOT delays above 10 minutes would be solved, this would deliver a free gate space at the airport for at least 290.5 days.

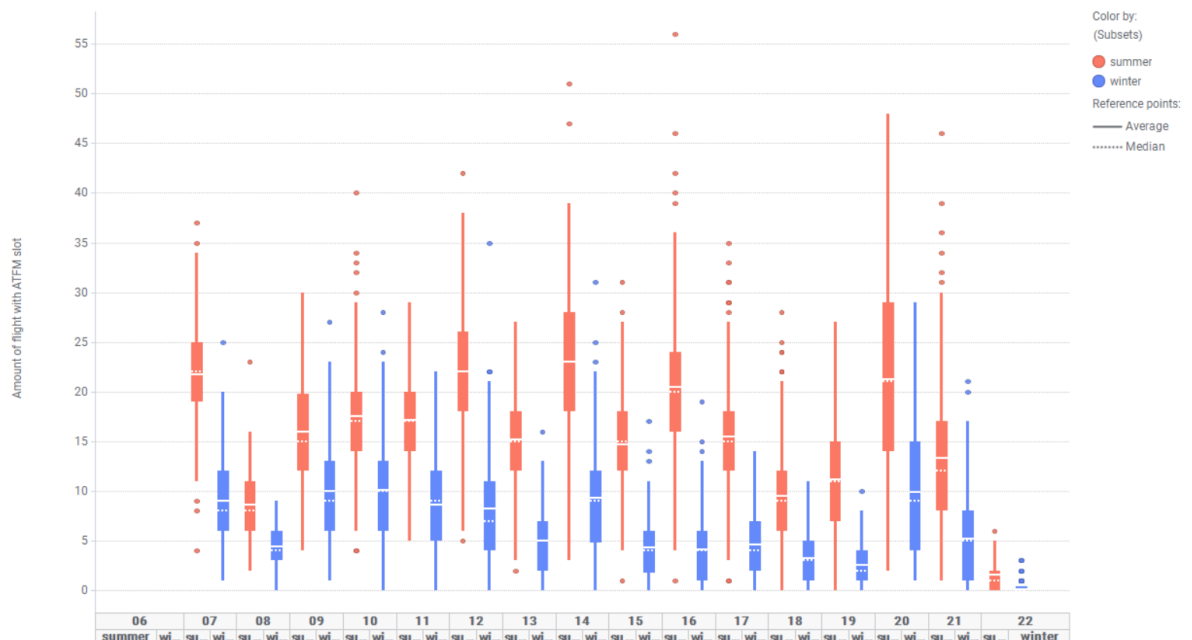
### 6.1.2 CTOT ground procedures

During the observations the following is found on the procedures that should prevent the CTOTs from effecting the ground operations:

- The procedures apply to flights with a delay of at least  $\pm 20$  minutes, with this requirement the procedures only cover a minority of the flights with an ATFM delay.
- Currently the infrastructure to execute the procedures is lacking. There are not enough holding positions where an aircraft can wait until their CTOT window starts. The positions that are available, are also used for other procedures causing an under capacity of waiting positions.
- The positions that are available, are not in tactical positions on the airport causing extra ground movement to get there.
- The use of the procedures is a disadvantage for the flight. When a flight taxis to a buffer position to await the CTOT-window, the flight gives up the right for an improved CTOT. Causing pilots to prefer to stay at their parking position hoping for an earlier ATFM slot.

The analysis resulted in the following findings. The current average ATFM delay is about 14.5 minutes. The procedures only cover flights of  $\pm 20$  minutes and above, the biggest amount of ATFM delays is not accommodated for. But even when the procedures are adjusted to cover more ATFM delays the infrastructure is not able to accommodate it. The Papa platforms are currently used to buffer in and outbound flights and tow movements. All the Papa buffers offer taxi-in-taxi-out capability where the pilots can independently taxi in and out of the position. One of the remote buffers is located near the centre of the airport offering capacity, when fully filled, in the following configurations: 2/1, 1/3, 0/5 (wide-body/narrow-body). (Appendix VI) The other remote buffer is located near runway 18L-36R (Polderbaan). Offering capacity, when fully filled, in the following configurations: 2/0, 1/2, 0/4 (wide-body/narrow-body) (Appendix VII). Due to the location of this buffer it is only logical to use it when runway 18L-36R is in use and only by the flights departing or arriving at this runway. Subsequently to answer if this is enough capacity. The questions is raised how many flights need to wait until their ATFM slot during their departure process.

Box plot amount of flights with ATFM slot



Graph 7: Boxplot of the amount of flights affected by ATFM delays per hour bracket

The graph 7 boxplot indicates the amount of flights affected by an ATFM slot per hour of the day and split into summer and winter. During summer it is on average usual to have more than 15 flights per hour waiting for their ATFM slot. With an average delay time of 14.5 minutes and evenly distributed over the hour this requires a continuous capacity of 4 stands. During the highest average peak of 23 flights waiting for ATFM slots this becomes 6 stands. This strongly implies the current infrastructure does not offer enough buffer positions. Especially because it is highly unlikely that the flights are perfectly distributed over the hour and 23 flights is the average peak, not the actual. Within the research no distinction is made between wide- and narrow-body capacity the 6 flights requiring an outbound buffer stand could all be wide-body aircraft.

The current buffers come with another problem besides the under capacity. The illustration figure 25 indicates the two locations of the remote buffer holding positions within the Schiphol airside infrastructure. The green dotted line indicates the direct taxi route from the B-pier towards take-off runway 36C. The blue dotted line indicates the route when an aircraft needs to be led to a remote buffer holding position before it can continue towards the take-off runway. The blue line is about double as long compared to the green line. Increasing the load for the taxiway system and the time required from the air traffic controller to guide the aircraft through the airport. Thereby are the taxiways around the centre remote buffer area very busy due to the close location to runways and parking positions. An air traffic controller wants to prevent adding extra complexity by guiding an aircraft through this busy piece of the airfield when it is not necessarily needed.

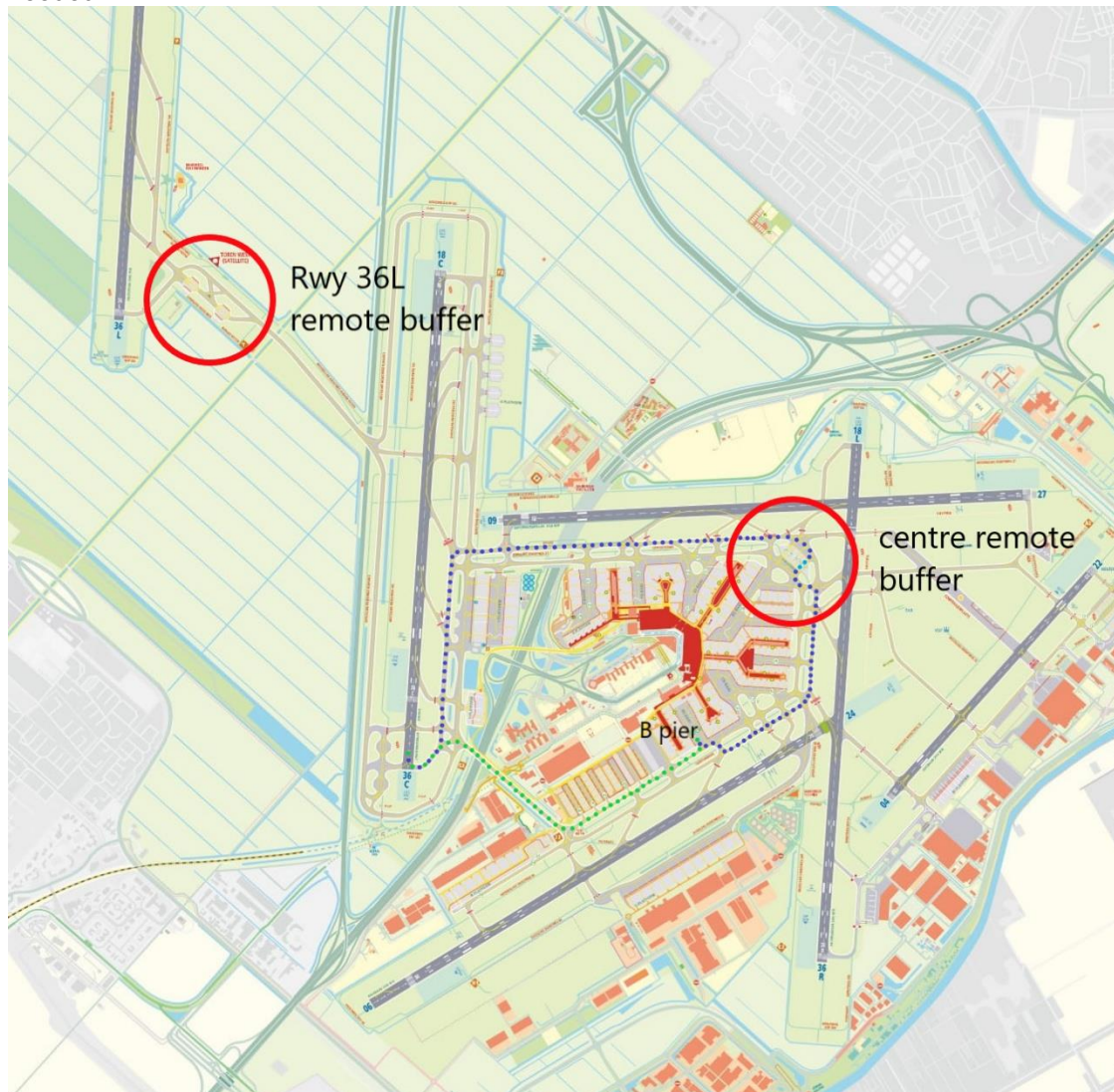


Figure 25: Ground map Schiphol indicating buffer positions and taxi routes

#### 6.1.2.1.1 Eurocontrol CTOT updates

Currently the Eurocontrol network manager uses a system in which a flight can receive a new CTOT (an update) until the Actual Off-blocks Time. This applies to both earlier and later CTOTs. When an aircraft leaves the parking position for a remote holding position, the flight loses the ability to receive an earlier ATFM-slot. This causes pilots to stay at the parking position if possible and hope for an earlier ATFM-slot.

### 6.1.3 CTOT and OTP correlation

The analysis of the relation between the percentage of flights affected by an ATFM slot and the off-blocks on-time performance (actual compared to scheduled) resulted in the following linear correlation. The OTP is measured according to the AAS definition: Until 15:59 minutes after scheduled off-blocks time is registered as on-time. This can cause flights to be delayed by a CTOT while not being noted as an off-blocks delay. The analysis is performed to confirm the system has a low off-blocks OTP at the moments Eurocontrol influences the system.



Graph 8: Linear correlation off-blocks OTP / Percentage of flights affected by CTOT

Y	X	p-value	FStat	RSq	R	Df	n
OTP	percentage flights with ATFM slot	<.001	1552,96	0.25	-0.5	4593	4595

Table 13: Results from linear correlation analysis OTP/CTOT

With a calculated (formula 8)<sup>8</sup> rho (R) of about -0.5 and a probability of far below the required 0.05 the result of the analysis is that the percentage of flights with an ATFM slot and the off-blocks OTP of the airport indicates a moderate correlation.

This means that it appears that, even with the off-blocks OTP margin of 15:59 minutes, Eurocontrol is influencing the off-blocks on-time performance of Schiphol. In figure 8 the green arrows indicate the line of points at which the percentage of flights with an ATFM delay exactly matches the percentage of flights that has an off-blocks delay. This confirms the relation between the two as well.

This analysis does not prove causality. With this data it is impossible to statistically prove that the off-blocks on-time performance is a direct result of the ATFM slots. The main cause for this, is the amount of different influences on the off-blocks on-time performance.

<sup>8</sup>  $r = \frac{\sum(X-\bar{X})(Y-\bar{Y})}{\sqrt{\sum(X-\bar{X})^2}\sqrt{\sum(Y-\bar{Y})^2}}$

## 6.2 Early arrivals analysis

A SIPOC model of the early arrival process is created (table 14) to determine the influence on the input stability of the system. Interesting difference with the outbound flow is the absence of Eurocontrol at this phase.

Airport early arrival process				
Supplier	Input	Process	Output	Customer
<p>AAS, responsible for:</p> <ul style="list-style-type: none"> <li>Sufficient ground infrastructure: Taxiways, Runways, ground holdings</li> <li>Parking position planning (according to flight plans of airlines)</li> </ul> <p>LVNL, responsible for:</p> <ul style="list-style-type: none"> <li>Aircraft guidance from fir entry to runway to parking stand. Following (first come first serve principal)</li> </ul> <p>Airline:</p> <ul style="list-style-type: none"> <li>Responsible for execution of the flight : aircraft, passengers, crew, etc. (according to filed flight plan)</li> </ul> <p>Ground handler:</p> <ul style="list-style-type: none"> <li>Prepares parking position for arrival</li> </ul>	<p>Flight arrives early at airport</p>	<ul style="list-style-type: none"> <li>Schiphol assigns stand to aircraft if available</li> <li>Ground handler prepares stand for aircraft</li> <li>LVNL guides aircraft towards stand when available</li> <li>If no stand available/ready flight has to wait at remote holding or taxiway until a stand becomes available/ready</li> </ul>	<p>flight goes in blocks</p>	<p>Airline:</p> <ul style="list-style-type: none"> <li>Ability to perform their flight earlier than planned</li> </ul> <p>LVNL:</p> <ul style="list-style-type: none"> <li>Flight leaves their control , no difference to their system</li> </ul> <p>AAS:</p> <ul style="list-style-type: none"> <li>Start of use of gate capacity (longer use of ground capacity than scheduled)</li> </ul> <p>Ground handler:</p> <ul style="list-style-type: none"> <li>Starts turnaround (earlier than scheduled)</li> </ul>

Table 14: SIPOC Early Arrival Process

As indicated by the operational experts early arrivals can cause instability in the input of the ground operations. When the aircraft arrives on the ground, the effects are dependent of the moment of arrival. If the aircraft arrives during a peak moment when free system capacity is low, this could cause deviations because the airport will still try to accommodate the early arrival by offering a parking position. When this is not possible the flight is guided to a remote holding position until a parking position becomes available. Holding an inbound flight on a buffer creates a negative experience for the passenger, who needs to wait while so close to the destination. On the other hand, if a flight arrives too early when enough system capacity is available, the effects are positive. Increasing passenger experience and increasing the stability of the output with a higher chance of an on-time departure due to a longer turnaround time.

The current procedures around early arrivals are analysed using the observations at the KLM Operations Control Centre, KLM Hub Control Centre and the Schiphol gate planning. Currently there are no structures to communicate by the airport about the possible consequences of an early arrival to the airlines.

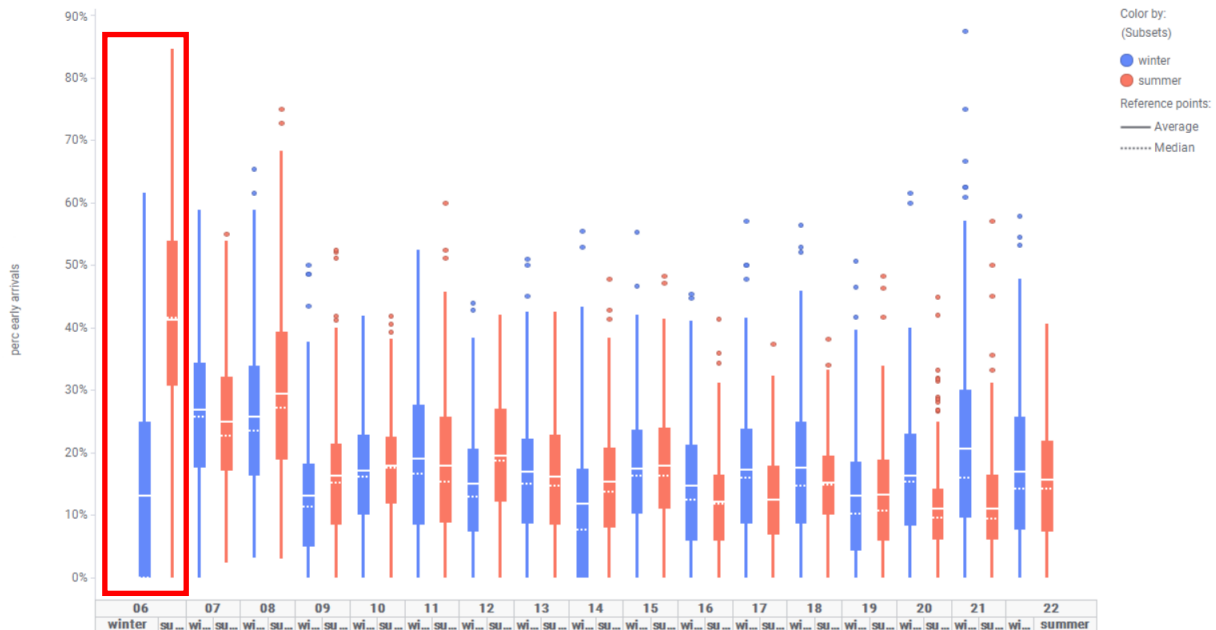
The airlines have flights departing ahead of schedule towards Schiphol and as consequence, arriving earlier at Schiphol. Another preventable cause of early arrivals are high speed flights. These flights departed with a delay, speed up in the air to compensate to eventually overcompensate and arrive too early.

Explained by the airline: If the flight is ahead of schedule and the airport can offer a stand this increases the passenger experience and decreases the chances of delays during this and the following flight of the aircraft. In some cases, it is a conscious choice to take the risk of arriving too early and having no gate capacity available. The effects of conscious choices are easier to prevent than an unwanted effect.

When managing the deviations in arrival times the KLM Operations Control Centre only considers the available landing capacity of LVNL. However, no structural procedures are in place to consider the capacity of the ground operation at Schiphol airport.

To analyse the effects of the early arrivals, the moment the early arrivals happen is analysed. The boxplot of the percentage of early arrivals is made using formula 7<sup>9</sup>.

Box plot percentage of flights arriving too early per hour



Graph 9: Boxplot percentage of flights arriving too early, per hour of day

The first boxplot (graph) indicates that the highest percentages of flights arriving too early occur until 7 in the morning (red box). This is very logical, because at this moment the system is perfectly capable of handling the flights. By arriving earlier, the airlines increase their chances that their connecting passengers make their connection and that the following flight in the schedule has an increased chance of an on-time departure.

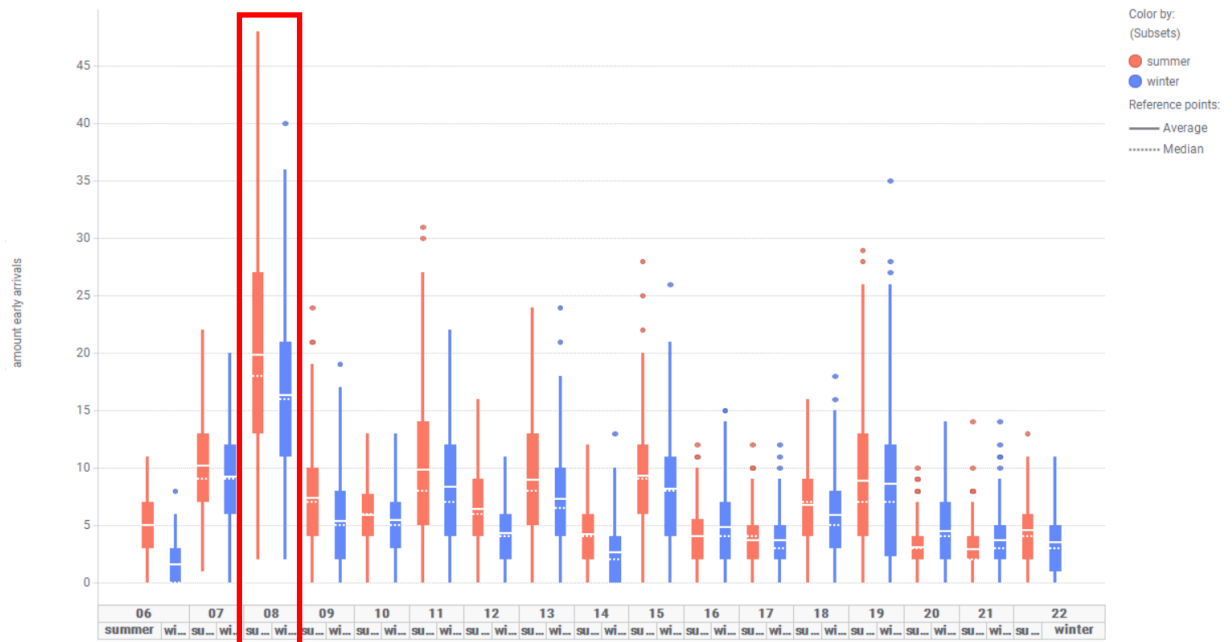
Schiphol experiences the biggest problems with early arrivals during the second inbound wave. Starting at the bracket of 8 o'clock. At this moment the airport is at maximum capacity and early flights cannot easily be accommodated for. However, the boxplot indicating the percentage of flights (graph 9) does not clearly indicate the problem. The percentage is relative to the amount of flights, so 40% can be 2 or 10 flights depending on the total. The boxplot in graph 10 indicates the amount of flights and not the percentage of the total.

The problem becomes visible. The peak in early arrivals is at 8 o'clock (red box) creating unwanted capacity loss to flights that are too early and create input instability and eventually output instability. According to the experts, the biggest problems are caused by wide-body aircraft which cannot be accommodated for due to a lack of wide-body stand capacity. The flights that arrive too early and cannot go to a gate have to wait in the field on a remote holding position until a stand becomes available.

<sup>9</sup>  $Avg\ early\ arrivals = \frac{Amount\ of\ early\ arrivals\ of\ flights\ with\ SIBT\ within\ the\ hour}{Amount\ of\ flights\ with\ SIBT\ within\ the\ hour} \times 100\%$

The amount of flights arriving too early during the summer appears to be higher, even though there are more ATFM delays. This could be explained due to the fact that the airlines calculate extra buffer margin for delays in their block times. When it turned out they do not need the buffer the flight arrives earlier at the airport. The airlines have overcompensated to be on the safe side of delay compensations. However it forces the airport to adjust their planning to accommodate the early arrival.

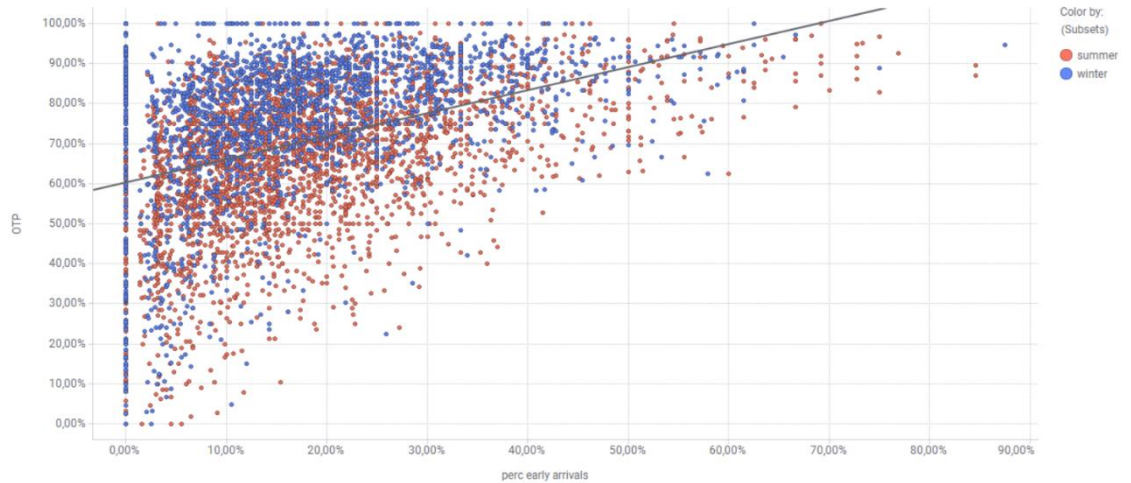
Box plot amount of flight arriving to early per hour



Graph 10: Boxplot absolute amount early arrivals

To determine if there is a relation between the early arrivals and the system output stability a linear correlation analysis is performed. With a calculated (formula 7)<sup>10</sup> rho of about 0.4, a weak positive correlation between both is found. Indicating a situation where it is more usual to expect a low percentage of early arrivals combined with a low off-blocks OTP. This indicates a situation that is wanted. When free capacity is low, less early arrivals take place. However, the ideal situation would be no early arrivals during low capacity moments. Again a causality is not determined due to the many influences on both of the variables.

<sup>10</sup>  $r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2}\sqrt{\sum(y-\bar{y})^2}}$



Graph 11: Linear correlation graph off-blocks OTP/percentage early arrivals

Y	X	p-value	FStat	RSq	R	Df	n
OTP	perc early arrivals	<.001	1034,12	0,16	0,40	5271	5273

Table 15: Result linear correlation analysis off-blocks OTP/early arrivals

To summarize, early arrivals influence the stability of the input of the airport operations even though causality cannot be proven.

### 6.3 Outbound bunching

Currently the outbound slots are managed by Airport Coordination Netherlands. Their working method is described in chapter 3.

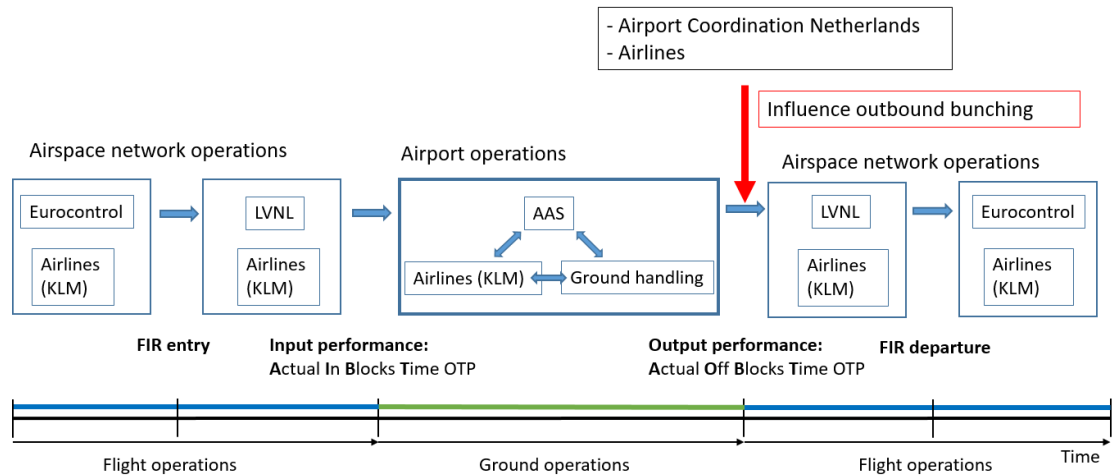


Figure 26: Influence of outbound bunching on airport system chain

The departure slot allocation method is analysed using a SIPOC model (table 16) and compared with the outbound data sample of flight from 2018/2019 the following results were found.

CTOT process Eurocontrol				
Supplier	Input	Process	Output	Customer
Airline: <ul style="list-style-type: none"> <li>Responsible for execution of the flight: aircraft, passengers, crew, etc.</li> <li>Flight Plan</li> </ul> Ground handler: <ul style="list-style-type: none"> <li>Delivers aircraft ready for pushback</li> </ul> Eurocontrol: <ul style="list-style-type: none"> <li>Network operations plan</li> </ul> LVNL: <ul style="list-style-type: none"> <li>Departure capacity</li> </ul>	TTOT (ground handler) Airline (flight plan)	<ul style="list-style-type: none"> <li>Eurocontrol Network Manager compares Network Plan to updated flight plan in ACDM</li> <li>Regulates flights when sector capacity to low</li> <li>Hands out CTOT's randomly to flights through the restricted sectors</li> </ul>	CTOT's	Airline: <ul style="list-style-type: none"> <li>Must delay take-off until within window</li> </ul> Schiphol: <ul style="list-style-type: none"> <li>Flight stays longer at ground than scheduled</li> </ul> Ground handler: <ul style="list-style-type: none"> <li>Pushback ready but not allowed</li> </ul> LVNL: <ul style="list-style-type: none"> <li>Sequencer starts to recalculate sequence</li> </ul> Eurocontrol: <ul style="list-style-type: none"> <li>No under capacity in airspace</li> </ul>

Table 16: SIPOC departure ATFM-slot allocation process

Both the airline and ACNL play a big role in outbound bunching. ACNL has made the procedures in such a way that the airlines have the possibility to create the bunches. On the other hand, the airlines have the possibility to spread the flights more equally over the bracket. However, when spreading the flights will feel like giving up competitors advantage. Which is something airlines are not expected to do.

SDATE	FLTNR	TSAT	SDATETIME	TOBT	AOBT	ATOT	CTOT	TTOT_TARGET	EXOT
1-05-18	KL1223	1-5-2018 07:36	1-5-2018 06:45	1-5-2018 07:40	1-5-2018 07:37	1-5-2018 07:45		1-5-2018 07:50	00:10:00
1-05-18	KL1351	1-5-2018 06:47	1-5-2018 06:50	1-5-2018 06:45	1-5-2018 06:47	1-5-2018 06:55		1-5-2018 06:54	00:09:00
1-05-18	HV6819	1-5-2018 06:53	1-5-2018 06:50	1-5-2018 06:50	1-5-2018 06:54	1-5-2018 07:02	1-5-2018 07:04	1-5-2018 06:59	00:09:00
1-05-18	KL1585	1-5-2018 06:58	1-5-2018 06:50	1-5-2018 06:50	1-5-2018 06:57	1-5-2018 07:05	1-5-2018 07:04	1-5-2018 06:59	00:09:00
1-05-18	KL1839	1-5-2018 07:02	1-5-2018 06:50	1-5-2018 06:55	1-5-2018 07:03	1-5-2018 07:13		1-5-2018 07:04	00:09:00
1-05-18	KL1105	1-5-2018 06:56	1-5-2018 06:50	1-5-2018 06:58	1-5-2018 06:57	1-5-2018 07:10		1-5-2018 07:09	00:11:00
1-05-18	KL16143	1-5-2018 07:30	1-5-2018 06:50	1-5-2018 07:10	1-5-2018 07:27	1-5-2018 07:36		1-5-2018 07:19	00:09:00
1-05-18	HV6115	1-5-2018 07:01	1-5-2018 06:55	1-5-2018 06:55	1-5-2018 07:04	1-5-2018 07:12		1-5-2018 07:04	00:09:00
1-05-18	KL1165	1-5-2018 06:59	1-5-2018 07:00	1-5-2018 06:55	1-5-2018 06:59	1-5-2018 07:06		1-5-2018 07:04	00:09:00
1-05-18	KL1925	1-5-2018 07:03	1-5-2018 07:00	1-5-2018 06:57	1-5-2018 07:06	1-5-2018 07:14		1-5-2018 07:06	00:09:00
1-05-18	KL1699	1-5-2018 07:14	1-5-2018 07:00	1-5-2018 07:00	1-5-2018 07:13	1-5-2018 07:22		1-5-2018 07:10	00:10:00
1-05-18	CND291	1-5-2018 07:18	1-5-2018 07:00	1-5-2018 07:00	1-5-2018 07:16	1-5-2018 07:23		1-5-2018 07:09	00:09:00
1-05-18	ZY7925	1-5-2018 07:12	1-5-2018 07:00	1-5-2018 07:00	1-5-2018 07:14	1-5-2018 07:24	1-5-2018 07:27	1-5-2018 07:13	00:13:00
1-05-18	PP669	1-5-2018 07:18	1-5-2018 07:00	1-5-2018 07:00	1-5-2018 07:18	1-5-2018 07:27	1-5-2018 07:21	1-5-2018 07:10	00:10:00
1-05-18	KL1821	1-5-2018 07:21	1-5-2018 07:00	1-5-2018 07:00	1-5-2018 07:22	1-5-2018 07:30		1-5-2018 07:10	00:10:00
1-05-18	KL1141	1-5-2018 07:04	1-5-2018 07:00	1-5-2018 07:00	1-5-2018 07:07	1-5-2018 07:16		1-5-2018 07:09	00:09:00
1-05-18	MS550	1-5-2018 07:07	1-5-2018 07:00	1-5-2018 07:00	1-5-2018 07:06	1-5-2018 07:18		1-5-2018 07:09	00:09:00
1-05-18	OS378	1-5-2018 07:23	1-5-2018 07:00	1-5-2018 07:00	1-5-2018 07:27	1-5-2018 07:37		1-5-2018 07:10	00:10:00
1-05-18	LX737	1-5-2018 07:43	1-5-2018 07:00	1-5-2018 07:17	1-5-2018 07:43	1-5-2018 07:53		1-5-2018 07:26	00:09:00
1-05-18	Y6291	1-5-2018 07:58	1-5-2018 07:00	1-5-2018 07:20	1-5-2018 07:54	1-5-2018 08:04		1-5-2018 07:29	00:09:00
1-05-18	W8404	1-5-2018 07:53	1-5-2018 07:00	1-5-2018 07:25	1-5-2018 07:50	1-5-2018 08:07		1-5-2018 07:35	00:10:00
1-05-18	KL0981	1-5-2018 07:22	1-5-2018 07:05	1-5-2018 07:05	1-5-2018 07:23	1-5-2018 07:31		1-5-2018 07:15	00:10:00
1-05-18	W1953	1-5-2018 07:25	1-5-2018 07:05	1-5-2018 07:05	1-5-2018 07:25	1-5-2018 07:32		1-5-2018 07:15	00:10:00
1-05-18	Q270	1-5-2018 07:11	1-5-2018 07:05	1-5-2018 07:05	1-5-2018 07:10	1-5-2018 07:20		1-5-2018 07:14	00:09:00
1-05-18	ZY8868	1-5-2018 07:10	1-5-2018 07:05	1-5-2018 07:05	1-5-2018 07:11	1-5-2018 07:21	1-5-2018 07:19	1-5-2018 07:17	00:12:00
1-05-18	HV5355	1-5-2018 07:27	1-5-2018 07:05	1-5-2018 07:15	1-5-2018 07:29	1-5-2018 07:38		1-5-2018 07:24	00:09:00
1-05-18	HV071	1-5-2018 07:05	1-5-2018 07:10	1-5-2018 06:55	1-5-2018 07:05	1-5-2018 07:17		1-5-2018 07:05	00:10:00

Figure 27: Example of outbound bunching

In this sample of the outbound data (figure 27) the bunching effect is clearly visible. The green line on the left indicates the first bracket in which the total amount of flights is not allowed to exceed a certain maximum. The blue line indicates the second bracket. The red line indicates all flight that should leave at 06:50, 06:55, 07:00 and 07:05. Within this window of 15-minutes a total of 25 flights has been planned to depart. This is allowed because part of the peak is at the end of the green bracket and part at the beginning of the blue bracket. It is unrealistic that this amount of flights can depart within this 15-minute window. The execution of this example bracket visualizes the results of the unrealistic planning. Almost all of the 25 flights have a TOBT before or on the scheduled time. This indicates that the ground handling was done on-time and the flights were ready for departure according to schedule. Especially the flights in the end of the bunch appear to be affected by the outbound bunching. The blue dots indicate a flight that has been delayed on TSAT without TOBT or CTOT delay. The green dots indicate flights that are delayed on TOBT and obtained extra delay on TSAT. However, the TOBT was not within the bunch anymore. Decreasing the amount of flights ready to depart within the bunch and attenuating the bunching consequences within this bunch. The delays obtained by the flights at the end of the bunch indicate that the departure capacity was not high enough to handle the amount of flights scheduled within this small amount of time. The flights with a TOBT delay in the end of the bracket result from the built up of outbound traffic. To conclude, the outbound plan is unrealistic due to procedures determined in the strategical planning phase. In the pre-tactical phase the procedures are used to determine the plan of the tactical phase. During the tactical the phase the plan is executed and turns out as unrealistic, the plan is unstable and needs adjustment right away, even though the plan is followed. This exact situation occurs in the inbound flow of aircraft as well. (Moll, 2019) (Riebeek, 2019)

### 6.3.1 Outbound bunching impact

The effect of outbound bunching on the biggest stakeholders (KLM, LVNL and AAS) differs.

- KLM experiences off-blocks delays. The off-blocks delays cause instability in the input of their flight operation. Because they plan their flight with some margin and could perform the flight quicker, they are most of the time able to compensate for the delay by the time of arrival. However, the delays causes inefficiency in their operation and as consequence bring extra cost.
- The impact on AAS is found within the ground infrastructure. With the flights awaiting their TSAT at their parking stand, the planned gate time is insufficient. The outbound bunching causes the flights to stay at their parking stand while the turnaround has been completed. This creates the same effect as the CTOT delays.
- LVNL does not experience the bunching effect as much as the other stakeholders. The sequencer makes sure there is a steady flow of aircraft. However, LVNL prefers to give as little TSAT delays as possible to minimize the work pressure on their system. This could be better when the flow of aircraft is more spread out.

## 7 Research Findings

During the analysis of the definition of plan stability, it turned out that the amount of research within the aviation sector on the subject was minimal. Other sectors (Information Technology) offer the required terminology to analyse and describe plan stability. A stable plan is defined as a plan that is executed as it was intended to. However, in a complex and changing environment as the aviation sector, plans need to be robust and resilient, making it less influenceable by changes and enabling the plan to quickly return to normal when affected by a deviation.

### 7.1 System analysis

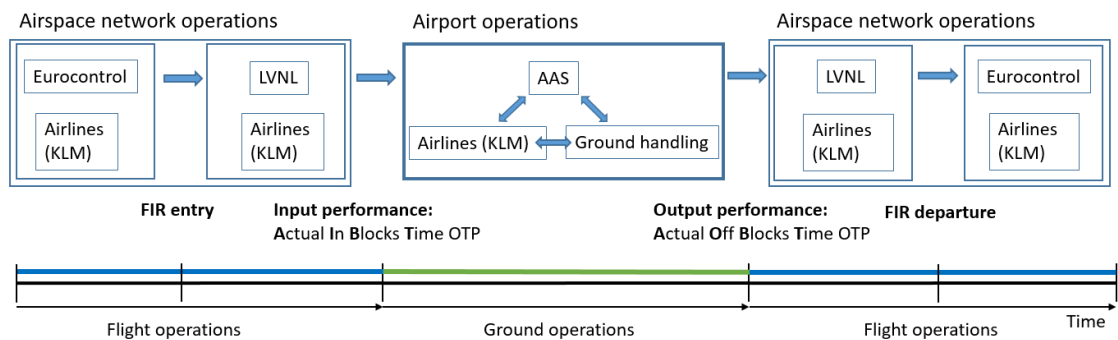


Figure 28: Airport system chain

Currently the aviation airside system consists of separate systems, connected in a chain (figure 28), processing flights. Every stakeholder holds the responsibility over the planning and execution of their part of the system and has designed their operational and management structures accordingly. All the different systems are connected or even overlapping and optimize the communication between all stakeholders to improve the collaboration, using ACDM.

Because it is a chain all the stakeholders need stability and thus predictability to use the system as efficient as possible. The plan stability is measured by all the stakeholders separately and mainly focused on their own part of the chain. Hereby focussing on their own management KPIs and company incentives.

This creates a challenge because none of the stakeholders is responsible for the complete chain and there are no KPIs available to indicate the performance of the complete chain. The same applies for plan stability, all stakeholders have the responsibility over the stability of their own system, managing their own system stability KPIs, without overarching supervision over the effects on the whole chain stability.

A system currently in development at Schiphol is the airport operations centre. In the centre the stakeholders collaborate in the planning, monitoring and managing of the airport operations. In collaboration with the Eurocontrol Network Manager it is possible to overarch both the ground and airspace operation.

The current KPI used by Amsterdam Airport Schiphol to measure plan stability is the off-blocks on-time performance. The off-blocks on-time performance does not fulfil the function as KPI for measuring ground operation stability. The off-blocks OTP is influenced by too many external factors of the ground operations. The Actual Ready Time OTP would be a better option. However, this is not measured within the ACDM of Schiphol and ARDT lacks the ability to indicate the output stability, because currently the ground operation does not end at the ARDT.

The analysing of the output stability (off-blocks OTP) resulted in an overview of the performance during the day. A difference is found between winter and summer performance. The data indicates that the winter performs according to plan while the summer has a lower average off-blocks OTP and thus plan stability. During the winter the plan has a higher resilience as well. When effected by a disruption of the planning the system appears to be able to coop and recuperate to a normal state. During the summer it appears that the system is not robust and resilient. When the first disruptions occur at the end of the morning peak, the system is unable to return to normal causing a domino effect into further instability.

## 7.2 External influences on plan stability

To realise a stable plan, it is important to make sure the system has a stable in and output. If one of them becomes unstable it delivers in both cases the same results: a different reality compared to the scheduled capacity plan. This leads to a decrease in ground operational efficiency. The input stability is influenced by too early arrivals. The output stability is influenced by the input of the airspace network. Eurocontrol has had the exact same problems as Schiphol has today. At moments there is insufficient airspace capacity to handle all the flights. To manage this safely, Eurocontrol has created ATFM slots. Using those, Eurocontrol delays flights on the ground to save fuel and emissions, the most efficient option for all stakeholders. The CTOTs create a stable input for their system but move the instability of their network to the ground operation of the airports. Where fully ready flights wait at their parking stands, to keep the airspace operating stable. The third external influence is outbound bunching. The flexibility in the outbound planning left to the airlines by Airport Coordination Netherlands, influences the stability of the outbound plan. If the plan is unrealistic during the moment it is planned, then it is impossible to be executed stably. Merging the three external influences together in figure 29.

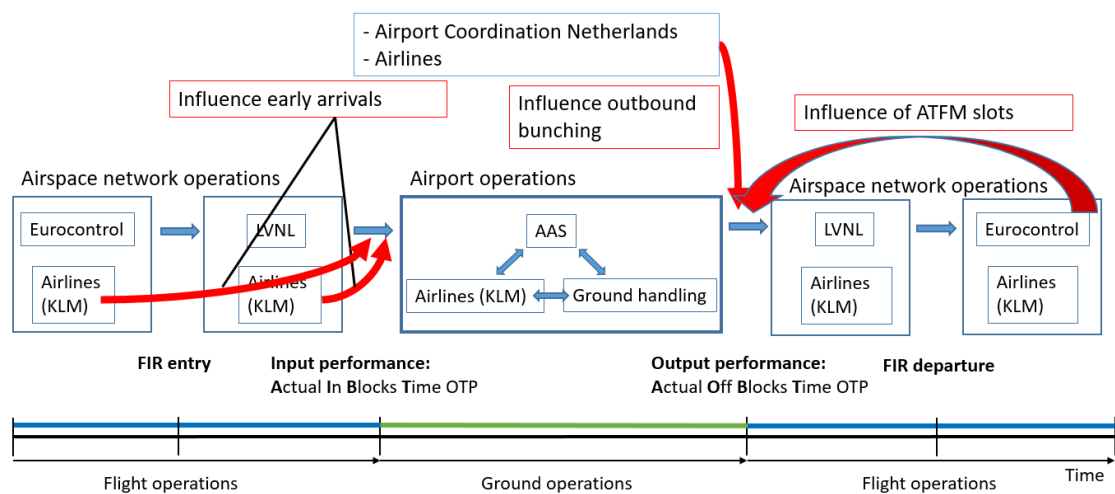


Figure 29: Stability influences visualized in chain

Currently the airport operations has not enough effective structures and procedures to deal with the external influences. The line of expectation is that the impact of the external influences will further increase. With Eurocontrol unable to handle the increasing amount of flights, increasing the amount of ATFM delays. The airlines will add buffers to their flight block times to compensate for the delays and with the lack of stability during the tactical phase a realistic plan in the pre-tactical becomes more important.

Of all the external influences two are created external of the airport ground operations; ATFM slots and early arrivals. Both are examples of management of stability on a sub-systems level. The outbound bunching is an example of an external influence because the decision to follow the allocation procedure had been taken far before the day of operation. The influences could be reduced or prevented if all of the system stakeholders were more aware of the influence they have on the other sub-systems.

## 8 Discussion

During the research multiple decisions and assumptions had to be made to overcome limitations. Within this chapter the decisions and sometimes problems accompanying the decisions are explained. This is done following the same build up as the research, with discussion points per research question.

During the research into research sub question 1; “**What defines a stable planning?**” The following points of discussion occurred:

- Definitions:** The first problem arose with the definitions used around plan stability in the current aviation sector. All the stakeholders use their own definitions based on their own part of the process and priorities within. It is impossible to have matching definitions with all the stakeholders. Because the research is within the KDC seen as initiated by Amsterdam Airport Schiphol, the definitions used by Schiphol are leading. However, this might cause communicational problems for the other stakeholders while interpreting the results.

Looking back at the decision to work with the Schiphol definitions it was at that time still unclear that the differences on plan stability between the stakeholders were that big that this would greatly influence the research. If this would have been known, the research might have been more focussed on the other KDC stakeholder definitions.
- Scoping:** After understanding the definitions around plan stability the broadness of the research became known. The KDC did not really gave a scope to do the research on. The scope was very wide, including all the processes in and influences on the airside ground operations. It was unrealistic to analyse all of them so during the analysis phase experts were used to determine which had the most potential. Due to the facts it was based upon experts’ opinions there is a chance that the causes analysed within this research are not the biggest causes for instability. However, when the causes would be solved, or the effects minimized the plan stability will most probably increase.

When analysing the stakeholders to answer sub question 2; “**What are the responsibilities and options of the KDC stakeholders in maintaining a stable airport operation?**” The following choices had to be made to pursue the goals of the research:

- Complexity:** The system analysis turned out to be much more complicated than expected. Most of the processes within the systems of the stakeholders themselves are that complex, a whole study can be held on them alone. Because this was not the goal of the research, some of the figures are depicted in an extremely simplified version of the processes or structures to keep the figures understandable. However, it might mean some processes are depicted as simple while they are extremely complicated. Further elaboration is done when the complexity was relevant for the rest of the research. An example is figure 18, airport operations system chain. In this figure the process within the ground operations is extremely simplified, then in later chapters each part of the chain is further elaborated on.

The only option to prevent the need to simplify the processes, is by having a smaller scope. In this way it would be possible to go into more detail. However, this research was meant to have a wide scope. It was unpreventable that sometimes not every detail could be included.

To analyse the current stability and hereby answer sub question 3; **“How stable is the current planning at Amsterdam Schiphol airport?”**, some assumptions and decisions had to be made to be able to answer the question. This led to the following points of discussion:

- **Long-term development:** Only the plan stability of the summer 2018 and winter 2018/19 are analysed. This year was the worst year in OTP and plan stability of the last 10 years. It was expected that when an analysis was done on this year the opportunities could be found.

For the scope of this research, the current data scope was sufficient and delivered the expected and requested results. However, it might be that the long-term development of plan stability over the last years delivers more insight into the development of the instability. This was out of scope for this research, with the already extremely broad scope. There was not enough possibility to include it within this research, but the result of the multiple year analysis could be of added value to the overall plan stability overview of the stakeholders.

- **Off-blocks OTP:** The analysis of the current stability is done with the Off-blocks On-Time Performance. This is Amsterdam Airport Schiphol’s main KPI to measure the air side ground operational stability. However, this KPI is not a direct cause of the ground operations. It does indicate the ground operations output stability which is an indication of the total ground operations stability. All the flights influencing the OTP have gone through the system and experienced the stability. However, looking back at the decision to work with the off-blocks OTP it does not completely represent the system stability. The research indicated the influence of the Eurocontrol Network Manager. Looking back an interesting comparison was the one between the off-blocks OTP and the Target Off-Blocks Time. It might turn out that the TOBT is a better KPI to measure the system stability, even though the TOBT does not cover the complete ground operations. Even better would be a KPI indicating the whole system instead of one single point in the process. When the next step is taken by creating new system overarching KPI’s it could be very interesting to compare them to off-blocks KPI to find the actual value of using it as complete system KPI. This does not mean this research is useless, it just means it is less focussed on complete system stability and more on output stability than expected. The output stability is still an extremely important KPI in system stability.
- **Missing data:** To analyse the current stability of the system the ACDM data of the summer 2018 and part of the winter 2018/2019 has been used. There are about three weeks missing within the winter data due to the fact this research was started during the winter and the data was acquired before the end of the season. With 19 of 154 days missing the data sample remaining is still representable for the period. When the days are included a negligible difference can be expected.

During the analysis of the data, it turned out that not all the days/hours had the same n factor. This should be impossible because the n indicates the number of measured hours. The expectation is that during the analysis small parts of the data are lost in the process. However the amount is so small that the statistical underlayment is not influenced, and the overall outcome is not influenced. A 95% confidence interval of the mean is added to be sure there is enough statistical substantiation for the results.  
(All of the n factors are indicated as count underneath the graphs in the Appendixes)

- **Night Operations:** The decision was made to filter all the data from flights happening during the night. The motivation to do this was the difference of the night operation compared to the day operation. The structural problems with plan stability are only present during the day operations. Night flights operate according to a different business model and are less punctual and during the night the airport has an extreme overcapacity.

With this reasons the night operation, flights planned between 23:00 and 06:00 local time, are filtered out of the data. This could result in a slight difference between KPIs in the reports produced by the airport stakeholders and this research.

The last sub question that is answered is; **“Are there and if so, what are the influences of external effects on the on-time performance of Amsterdam Schiphol?”** When analysing the influences the following discussion points occurred:

- **Night restrictions:** Within the analysis of the external influence of CTOTs by Eurocontrol. The decision was made to filter out the flights from 23:00 until 07:00 local time due the high amount of CTOT’s given to the early morning flights because of the night restrictions. These hours are not representative for the normal operations during the other hours of the day and might even influence the results in a negative way.
- **Causality:** Another challenge was the correlation between the off-blocks OTP and the CTOTs or early arrivals. A correlation can always be established. However, a causal relation has much higher requirements. One of them is that in all the cases you must prove that there could not have been any other variable influencing the two variables of which a causality is tried to be proven. In both the cases within this research causality is impossible to prove due to the variation of reasons causing the CTOT, OTP and early arrival performance. The added value of the correlation is that it can indicate a possible causality. However, to prove causality further research is required.  
It was never within the scope of this research to really prove the exact influence of the effects resulting from other systems, on the airport ground operations. The correlations are added to the theoretical framework, which already indicate there must be an influence, to deliver an indication on how strong the relation the relation and influence might be.

## 9 Conclusions

In this chapter the main research question will be answered by bringing all the information and conclusions from the sub questions together. The main research question is: **“What are the opportunities for Amsterdam Airport Schiphol and the other KDC stakeholders to improve the airside ground operational stability of the airport?”**

The first sub question answered is: **What defines a stable planning?** To answer this question all the stakeholder’s perspectives on plan stability are collected and analysed. Concluding that all of the stakeholders had the same definition: Executing a plan according to the way it was meant to be. However, it also found that there were no real definitions that could be used to describe the current plan stability. To solve this problem the definitions used by other sectors are introduced: Robustness and Resilience. A robust system does not have to deviate from the plan due to a minor disruption and a resilient plan easily returns to normal after a disruption has affected the system.

The fact there currently are no overarching definitions is a result of the lack of overarching research involving all the stakeholders. Which introduces the second situation in which insight is needed to answer the research sub question: **What are the responsibilities and options of the KDC stakeholders in maintaining a stable airport operation?** To answer this question experts were consulted, and relevant literature was analysed. It resulted in the finding that a major cause for the differences in definitions was the responsibility of the stakeholder. Every stakeholder has the responsibility over a smaller system within the bigger aviation system chain. To manage the smaller system, the stakeholders have made KPIs and definitions for their own system. However, none of the stakeholders has the responsibility over the whole system chain so consequence no overarching management, KPIs and definitions are created.

To analyse this, it was important to understand the possible impact on the stability of a system when linked to another system in a chain process. What resulted was the importance of in and output stability between all the linked-up systems.

To find opportunities, the research was focused on possible points of improvement. To answer the sub question: **How stable is the current planning at Amsterdam Schiphol airport?** An analysis of the plan stability performance of the airport airside ground operations in the summer of 2018 and winter of 2018/19 is performed. A difference between the summer and winter off-blocks OTP is found. During the winter the performance is stable and on average most of the times above the current target of 71%. During the summer the target is on average only reached in the early morning hours. After 10 in the morning the off-blocks OTP decreases and is not able to recuperate. Indicating a plan that is not resilient and robust enough. An influence on the robustness of the plan is the flexibility. During the summer less free capacity is available due to the higher traffic amount. With less free capacity the airport is less flexible and unable to handle deviations from the original planning. To answer the sub question, the current planning of Amsterdam Schiphol Airport is stable during the winter and in the summer only early in the morning.

During the start of the research it was already mentioned that external influences could have an impact on the plan stability. After the current situation analysis, three influences were found to answer sub question 4: **Are there and if so, what are the influences of external effects on the on-time performance of Amsterdam Schiphol?** Yes, there are, and the most important external influences found are ATFM slots, early arrivals and outbound bunching. All are external effects caused before the actual moment of operation or from outside the ground operations system and effect the in or outbound flow. The ATFM slots are a tool of Eurocontrol to stabilize their network operation by delaying flights on the ground. The impact of this method has risen over the last years due to the limited capacity Eurocontrol is able to offer. With at the peak moment  $\pm 40\%$  of the flights at Schiphol effected with an average outbound delay of 14.5 minutes. Due to the current procedures and infrastructure the biggest part of the ATFM delayed aircraft must wait at the gate. The gates are needed for arriving aircraft to start their turnaround. By delaying the turnaround of the arrival aircraft, a domino effect has started.

The second influence is the too early arrival of aircraft. Due to the current planning and working methods of airlines it commonly happens for flight to arrive more than 16 minutes to early at their parking stand. This causes problems in the scheduling at the peak capacity moments of the day.

The biggest problems are faced between 8 and 9 in the morning, where on average 15 flights arrive too early. The airport will still try to accommodate and offer them a gate even though this causes deviations in their planning. Some of the early arrivals are preventable. There is no procedure for the airport to indicate to the airline that an early arrival causes deviations in the system due to a lack of flexibility at the moment of arrival.

The last influence is that of outbound bunching. As the name implies, the effect causes instability in the outbound flow of aircraft. Due to the way the outbound traffic is planned, peaks are created in which an under capacity in outbound flow occurs. The under capacity creates instability because flights are unable to depart according to schedule.

A major change with positive potential, that is bound to happen within the airport system, is the introduction of the AirPort Operations Control (APOC). The centre will manage the airport from an overarching position. Potentially delivering new opportunities that might help to overcome the challenges in plan stability definitions and management. The APOC will include all airport stakeholders and eventually have a connection to the Eurocontrol Network manager as well. Especially the connection with the Network Manager will deliver the possibility to create an overarching management of the whole system chain. When the management of both ground and air is combined into one adaptive system, it might mean that the unwanted effects of external influences can be more easily managed.

Concluding and answering the main research question, by combining all the findings, many of the reasons for the airside ground operations ground operations are caused from outside of the ground operations systems. To overcome the challenges they represent, the KDC stakeholders should, by working closely together decrease the amount of external instability inserted into the ground system. However, not all the instability is: caused by the stakeholders, possible to prevent or prevention is unwanted because the instability serves another purpose in the operation. In those cases, the airport ground operations stability could be made more robust and resilient to the external influences causing instability. It is important to be aware of the relation of the problems to the system capacity. The problems only arise when the free system capacity is low, and the system is unable to deal with the deviations. Because of the circumstantial requirements, the solutions are not permanently needed and must act as a kind of overflow system when not enough capacity is available. When enough system capacity is available the overflow system disables, and the airport system functions as it used to. Increasing efficiency when possible, while offering flexibility when needed.

## 10 Recommendations

During the research, opportunities have been found that could lead to improvement of the current system stability. The first is a result of the system analysis performed to answer sub question 1: **“What defines a stable planning?”** and sub question 2: **“What are the responsibilities and options of the KDC stakeholders in maintaining a stable airport operation?”** The research delivered a better understanding of the different methods and systems used by all the stakeholders to manage their plan stability. The methods of the different stakeholder differ because they are based on the business incentives of the stakeholder. Due to those different methods the stakeholders have a shortage of common ground within the topic of plan stability. To overcome this problem the stakeholders should introduce overarching uniform plan stability definitions, uniform plan stability KPIs and create management goals for the whole aviation system chain. When done, communication about plan stability should be easier and the overarching effects of decisions regarding plan stability should be easier to analyse. Currently there is no party responsible for the complete chain of system and so there is no party to execute this recommendation. With the introduction of APOC this might change. APOC could create the platform to create the recommended definitions and KPIs. In the airport system chain, the APOC is responsible for the ground operation and the Eurocontrol Network Manager for the flight operation. When combined, covering the complete chain. When cooperating this could create the platform to analyse and manage the stability of the whole chain. The situation would become similar to the system of KLM with an OCC (flight operations) and HCC (Schiphol ground operations). It is recommended to the APOC stakeholders to take a close look into the KLM structure because there might be lessons to learn.

The following recommendations result from the analysis done to answer sub question 3: **“How stable is the current planning at Amsterdam Schiphol airport?”** They regard the difference between summer and winter plan stability performance. This difference is most likely caused by the difference in the amount of flights that need to be handled. Only during the summer improvement of the stability is needed. It is recommended to AAS to offer more flexibility by creating more capacity. This increases robustness and resilience of the current system. The extra capacity should be a variable managed within an adaptive system. The variability of the extra capacity should prevent overcapacity during the winter. The adaptive structures and procedures should be used during moments of (predicted) instability. While during stable moments, the system still offers the added values of the flexibility to the airlines. To prevent extra instability the communication about when which structures and procedures are use is very important. The airport operations plan created within the APOC overarching all the airport stakeholders could prove to be the key in this situation. It is recommended to the airport and its stakeholders to act on predicted instability using an adaptive system. Because all the stakeholder differ in objective, the current adaptive structures are formed within the systems of the stakeholder. Without one overarching adaptive system, all the systems will keep hindering each other and reducing the overall system stability. It is advised to all the stakeholders operating in the complete aviation chain to develop one overarching adaptive system to manage all the variables available to maintain plan stability. The Airport Operational Plan should contain the objectives of the different stakeholders, the adaptive system tries to achieve. To prevent a bias in the controlling of the adaptive system, it is recommended to leave the decision making to a computer that can be overruled by human intervention.

An adaptive system needs sensors (KPIs) in the operation to determine the performance. Currently OTP is not used as a KPI during the tactical phase. Without an actual or predicted OTP the system is unable to steer on plan stability. For this reason it is recommended to the stakeholders to use the KPI of OTP not only post-operational but also during the tactical and pre-tactical phase of planning. An example could be to real time monitor the OTP of all of the ACDM milestones and per milestone combine them into a system OTP to indicate the OTP of the following milestone.

The outcomes from the analysis performed to answer sub question 4; **“Are there and if so, what are the influences of external effects on the on-time performance of Amsterdam Schiphol?”** indicate the current challenges within the airside ground operations stability caused by the external influences such as the Eurocontrol ATFM slots, early arrivals and outbound bunching. The current structures to prevent the Eurocontrol ATFM slots from effecting the system, are unable to prevent the effects on the ground operations output stability. With an average ATFM delay of 14.5 minutes and at peaks, on average, 40% of the flights affected. To increase the functionality of the current structures to prevent the ATFM-delay effects, the following is recommended:

- AAS and LVNL should restructure the moment a flight with an ATFM delay qualifies to be brought to an outbound holding position by changing the requirements to:
  - A minimum ATFM delay of 10 minutes.
  - Parking position is needed for following flight.
  
- The system in which Eurocontrol freezes the CTOT at the moment of off-blocks should be reconsidered for flights that taxi to an outbound holding position before take-off. When the flight has gone off-blocks it should stay eligible for CTOT improvements until it had left the outbound holding position to taxi towards the runway. This could be achieved by adding a milestone to the ACDM in which outbound flights that go to an outbound holding receive a target end of holding time from the sequencer to help the ATC to estimate when an aircraft can leave the holding and arrive at the runway within the CTOT-window. The actual end of holding time could be used at the moment the CTOT is frozen. When this could be achieved the negative effects of outbound holding for the airlines are reduced, Eurocontrol is able to use their airspace more efficient by controlling CTOTs of aircraft in outbound holdings, Schiphol can use their ground capacity more efficient and LVNL will experience less work pressure from an instable in and outbound flow of aircraft. To achieve all this, Eurocontrol needs to be convinced to adjust the current procedure of the ATFM-slots. It is recommended to cooperate with other European airports and airlines to ask Eurocontrol to adjust the procedures.
  
- AAS is recommended to improve the infrastructure available for the outbound holding procedure. They should create more outbound buffer positions and make sure they are available to the flights effected by ATFM slots. Hereby, make sure the buffers are on tactical locations, minimizing the pressure on the system by reducing extra taxi time and using taxiways which are not the main nodes in the system. During this research a group of high school students performed a research into this which indicated great potential in some already available locations spread over the airport: reducing taxi times and system complexity.
  
- Make the system adaptive: when the amount of ATFM-delays rises above a level that the plan stability is or might become severely compromised and a domino effect starts or might start. Switch the system from only when Schiphol ground control, LVNL and airline agree on an outbound holding, to: The procedures demands outbound holding due to a lack of system capacity. It is recommended to let the control over the adaptivity of the outbound holding system be a part if APOC and the AOP. Where predetermined requirements determine if outbound holding is active or not.

Important to realise in these recommendations is that the KDC stakeholders and Eurocontrol must all comply to make them work. Schiphol must deliver the infrastructure on the airport, LVNL needs to change procedures and instruct air traffic controllers, Airlines need to adjust procedures and train pilots and Eurocontrol must change the ATFM slot procedures.

The second external influence on the airside ground operations safety is the too early arrival of aircraft at moments of low capacity within the ground operation. One of the causes for this problem is the found in the communication between the airport and airlines. The airport changes the structure of handling early arrivals at every moment. The airlines know this and arrive too early hoping the airport facilitates them. Causing too early arrivals hoping to be the one facilitated to improve the performance and passenger experience. It is recommended to the airport to make the gate planners able to communicate to the airlines, during the planning process, if a flight has a chance of facilitation when arriving to early. If a flight is planned during an off-peak moment, the flight will be facilitated in arriving to early. However, when the flight arrives too early during peak hour. The flight has a high chance of not being handled until the system is able to, without

replanning and causing instability. When following this recommendation, the airport can offer the added value of flexibility to the airline if the system allows it. When the system needs to perform on full capacity the flexibility is no longer guaranteed.

The third and last recommendation regarding the external influences is one to all of the KDC stakeholders. They are all part of Airport Coordination Netherlands. The current outbound bunching is mainly caused by the way the current departure slot times are allocated. If the brackets would be decreased from 20 to 10 or even 5 minutes, the plan would beforehand get more realistic and can be more stably executed. This can be an adaptive variable, where the brackets depend on the season or moment of day. During the peak hour, strictness with brackets of 10 minutes and during the off-peak hours, flexibility with brackets of 20 minutes.

All the recommended measures to reduce the impact of the external influences can be included as a variable in the adaptive system, controlled within the APOC. Outbound bunching needs to be prevented in the strategic planning of the system, inbound early arrivals in the pre-tactical and tactical phase, and the impact of ATFM slots can be reduced during both the pre-tactical and tactical phase of the system planning. An even better improvement could be the collaboration of the Eurocontrol Network Manager Operation Centre with the Schiphol APOC. This would create one system of all the smaller system boxes. Changing the external influences to internal influences making it easier to manage them and manage the overall system chain performance. With this reason it is advised to prioritize the continuation of the development of the Schiphol APOC from a local collaboration, overarching the local airport system, into a collaboration centre with the Eurocontrol NMOC, overarching the complete system. It is expected that this can deliver structural improvement of the plan stability for all the stakeholders.

## 11 Further Work

During the research, points of interest were found that require further research to fully understand and develop them. This chapter will discuss them point by point.

- **System KPIs**

When APOC is introduced to the system it is recommended to create KPIs covering the whole system that can clearly indicate the effect of a decision on the whole system. Currently those KPIs are non-existent and research is needed to determine those KPIs. How they can be calculated and what they indicate and do not indicate. This would be the next step in working towards a collaborative system stability management, which could be a part of APOC.

- **Ground Capacity KPIs**

Within the growth Schiphol has seen over the last year, the ground capacity of Schiphol has become the bottleneck of the operation at moments where full landing capacity can be offered, and the ground operations are disrupted. Many of the stakeholder manage on the landing capacity because this has always been the most restricting. They do this, using a tool, in which they can monitor the offered landing capacity and the predicted flights demanding landing capacity.

With the new restriction in the ground operations, the stakeholders should manage on ground capacity when needed. However, currently there is no prediction in ground capacity, such as used in landing capacity, available to the stakeholders. A reason for this is the extreme complexity to determine ground capacity. Further research is advised into the determination of ground capacity and the option to make a simplified dashboard that could be used by the stakeholder to manage on ground capacity.

- **OTP monitoring**

Currently the OTP of all the ACDM milestones is only used as KPI in the post-operational analyses phase. Further research is advised into the possibilities of the use of OTP in the tactical and pre-tactical phase of the plan. For example, OTP prediction or live OTP tracking could make the stakeholders better able to adjust their current operations to the current stability of the operation. A possible application could be within the dashboard used within the APOC manages the tactical operation.

- **Summer/Winter difference**

This research concluded there is a difference in plan stability (off-blocks OTP) between the summer and winter ground operation. The cause for the instability during the summer is believed to be the lack of flexibility in the system due to an under capacity. The exact relation between the under capacity and the lacking system stability is not analysed within this research. It could prove to be valuable information in overcoming the instability. There could be a balance between stability and the amount of over-capacity delivering the required flexibility. When this balance is found it becomes easier to predict and prevent instability.

- **CTOT/off-blocks OTP relation**

The research has been unable to prove the exact relation between CTOTs and off-blocks on-time performance. It could be of interest to know exactly how many flights was delayed with more than 15:59 minutes, because the flight had a CTOT delay. It was out of scope for this research to analyse the performance per flight what the effects of the CTOT has been. However, correlation found between CTOTs and off-blocks OTP implies there might be an even bigger relation when analysed per flight. If this is the case the CTOTs have an even bigger impact than this research can prove.

- **Outbound Bunching**

The analysed effects of outbound bunching are based upon the experience of the operational experts and the current procedures described in the operational manuals. Further data analysis could be valuable in finding the exact effects of outbound bunching on the outbound stability. It might prove that the impact on the system is low and no further action is necessary, or it might be the root cause for the outbound instability.

- **Benchmarking**

During this research all the focus has been on the Schiphol airport system. The instability currently faced by Schiphol airport must occur at other airports as well. Especially the other hubs in Europe face the same outbound stability caused by the ATFM slots. Research into the way they handle the instability could prove to be very valuable in overcoming the challenges at Schiphol.

- **CTOT short-term prediction**

Due to the way CTOTs are allocated, up to 2 hours before the estimated off-blocks time of a flight, there is an opportunity to use the amount of flights affected by a CTOT to predict the off-blocks OTP over the next coming two hours. If a pattern in the way CTOTs are given is established, this pattern could calculate the amount in two hours and relate it to an off-blocks OTP. The off-blocks OTP is equal to the output stability. Enabling the airport system to predict the output stability and act on instability before the system is influenced.

- **System against flight analysis**

All the analysis within this research are focussed on the system performance. A disadvantage of this strategy is the inability to pinpoint root causes for effects. With this reason it is advised to perform further research into the found effects by analysing the causes for instabilities a flight endures. When done for multiple flights it should be easier to determine which of the effect causes the biggest instability.

- **Historic development**

All the effects that have been analysed have not just started in the last year. Within the research the choice was made to scope only on the past year. The data over more years is available and can be used to analyse the historic development of plan stability over the past years. It is strongly advised to analyse the stability over the past years because it could lead to the turning point where the summer became instable. The turning point could lead to the root cause which might be able to overcome when you have found it.

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## Appendix I Reflection

The STARR (Situation, Task, Action, Result and Reflection) method is used to reflect on the research and the KDC learning environment. The method is used to reflect on both my development in primary research skills and the SCRUM and Sprint sessions that worked as a guidance through the research. All the star points are discussed in relation to both the topics.

### Primary research skills

#### Situation

The plan stability of the airport system has been decreasing over the last years. This leads to loss of performance and loss of efficiency at all the stakeholders within the system. Previous researches performed by the KDC have already delivered different insights into the functioning of smaller parts of the system and the stability of those parts. However, the KDC stakeholders requested a research on the total system and causes for the system instability.

#### Task

The research was commenced to find and analyse possible causes for instability in the airside ground operations of the airport system. Requested was to perform an analysis on a higher level than the other KDC researches, avoiding a very detailed analysis of smaller sub-systems and focussing on the bigger picture of the system.

#### Action

The research consisted of both qualitative research and the quantitative research. The qualitative research was done to understand and analyse the current structures, procedures and the human factors within the system. The qualitative research was used to analyse the current performance of the system. When combined the theory could be compared to the reality.

#### Result

The result of all the analysis was a system overview of the current airside ground operations and the influence and responsibilities of all the stakeholders within the system. The overview had led to multiple internal and external causes of instability within the system.

#### Reflection

When I started the research there was no clear scope of the requested end result. The only scoping I had was: something with plan stability. This can still be a very specific and detailed research, while it can also be a broad research covering many processes with less detail. Before scoping I decided to firstly understand the system and the (KDC) stakeholders to determine a scope with a high potential of delivering valuable additional information to the stakeholders. After some weeks of analysing: a lot of reading and listening. I found that the visions on plan stability of the stakeholders within the system differ a lot. As a result this might lead to instability. With this reasoning, the scope was set to create a better understanding of the system plan stability. With the reasoning that a better understanding might find opportunities for a better stability. During the research it happened often that I found it very difficult to stay at a less detailed, broader level overseeing the whole system, while I knew that I could go into more detailed data, which might lead to interesting results. However, understanding all the stakeholders and their operational incentives turned out to be challenging enough. This was one of the biggest lessons for me: keeping my scope, even though I knew that this might mean I could not analyse all of what I found.

Looking back at the overall process I have developed my research skills on multiple points. I was not very experienced in taking interviews and performing observations. I had no experience with working within a multi-stakeholder environment. Both I have been able to develop and improve. I had already more experience with quantitative research, however within this research I works with Tibco Spotfire for the first time. Teaching myself to work with the program was a challenge but proved to be a very valuable lesson. I can now say that I truly understand the program and can fully work with it.

Within the first period of the research I faced some problems with the complexity of all the systems and relations within. Looking back I am thankful for the people around me who understood the system and were willing to have an exchange of thoughts to help me understand the whole system and stakeholders within. Without this help there would have been a very high chance that I would not have been able to understand it as detailed as I do right now. This understanding proved to be very important in determining my scope. With the broadness I needed to exactly understand until which level of detail it might be of added value to my scope.

An important lesson for me was mapping. I forced myself to write everything I did within the research, down in a couple of key words and the place it had in the system. In the end this turned out to be a roadmap for me whenever I had to understand a subsystem I could fall back on the key-notes I had mapped.

Without the complete picture, I would not have been able to connect the instability to the causes and I would not have been able to deliver the results the research has right now.

Another major lesson for me has been the multi-stakeholder management. During the research I visited all the stakeholders multiple times for observations during the operation and interviews with experts. Important for me was to never have a biased mind-set. Sometimes being at one of the stakeholders and hearing them complain about another stakeholder which I would visit the following day. Especially during those moments I had to stay focused on truth finding.

Another challenge of the multi-stakeholder management was to make sure that I understood what was said by who and why. With the different organisations, using different definitions and working with different incentives, I had to make sure that what I was meaning was clear to the person I was talking to. Thereby also determining that what I understood was the thing that was meant. An example of this is that when an airline employee talks about OTP he means in-blocks OTP. While an airport employee means off-blocks OTP.

## **SCRUM and Sprint sessions**

### **Situation**

Throughout the period the students executed their graduation research at the KDC, the students are supported through SCRUM stand-up and sprint sessions. The Stand-ups were organized once a week and the sprint sessions once every two weeks.

### **Task**

During the stand-ups the progress that all the students had made over the last week and the planning for the coming week were discussed. During the sprints the progress of the last two weeks was presented to the available managers and experts from the KDC stakeholders and the Amsterdam University of Applied Sciences. They had the option to deliver feedback that the students could use in their research.

### **Action**

I tried to be prepared for all of the stand-up sessions, especially because of the limited time it was important to know what to say and ask. However, due to the sometimes busy schedules the preparedness was not always as high as I had hoped it to be. The same applied for the Sprint reviews.

### **Result**

The stand-ups gave me the opportunity to keep myself aware of what the other students were doing and if I might be able to help or use some of their progress within my own research. The preparedness I strived for appeared to work. When I was able to prepare the level of the stand-up appeared to be higher.

The Sprints were very effective, a lot of feedback that I used within my research came from the sprint reviews. This was exactly what they were meant to do.

### **Reflection**

Looking back at the stand up, I doubt that the stand-ups are used to its full potential. By having the stand-up in a group, the focus quickly has to change between the different researches of the students. It has happened multiple times that due to a focus change questions got unanswered. Thereby, due to the time pressure, sometimes vagueness was created by not being able to completely elaborate on your work. The vagueness created problems in the work that, looking back, were unnecessary. However, the stand-ups had some valuable lessons for me. Due to the complexity of the research it was very helpful for me to have a moment in the week to determine

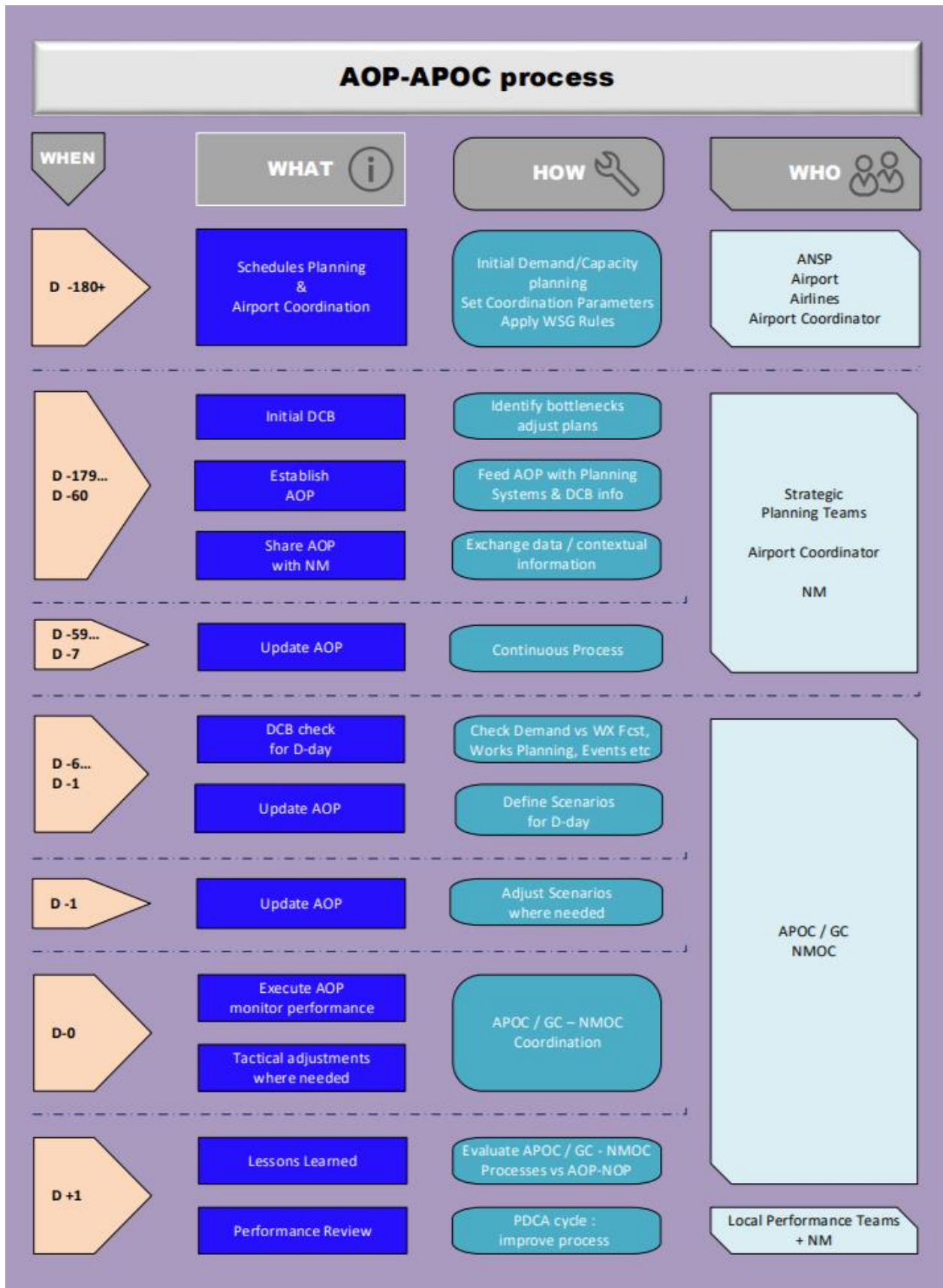
what I wanted to achieve that week. This is something I have copied into my life now. On Monday determining my goals for Friday. Having kind of my own private mini stand-up.

The Sprint reviews delivered some other interesting points of reflection. Personally I found it very interesting to present my research within this multi-stakeholder setting. There has not been one Sprint review that did not end in a discussion between the stakeholders around the table, having to be cut short due to a lack of time. Managing these discussions and trying to say the right things with so many different interests on the table was one of the biggest lessons of this research for me. However, it was also one of the most challenging, having to deal with so many different opinions, it proved difficult to satisfy all of the people around the table. This meant choosing, what I thought was the right way to go. However, choosing the right way is not very easy with such a broad research scope. An example is a discussion about the desired level of detail in my research. This has been changed multiple times over the course of the research. Eventually requiring me to make the decision to focus on the broader system, decreasing the level of detail. This still delivers discussion until this very last week of my research.

A problem I faced within the Sprints was the limited time. Sometimes the analysis results I wanted to present were too complex for the 5 minutes we each got to present. In my eyes this decreased the effectiveness of the feedback I received because I was only able to present a small part of my results. Another problem was the constant changing composition of attendants. When someone attends who has not seen any of my previous sprints, it is not surprising that it is difficult to understand.

Overall the Sprints have been one the biggest lessons to me of my whole graduation research at the KDC. Requiring me to present complex information in a small amount of time with multiple contradicting opinions around the table listening to you. Looking back, I really have to thank all of the attendants to my Sprint sessions because I have learnt so much from them.

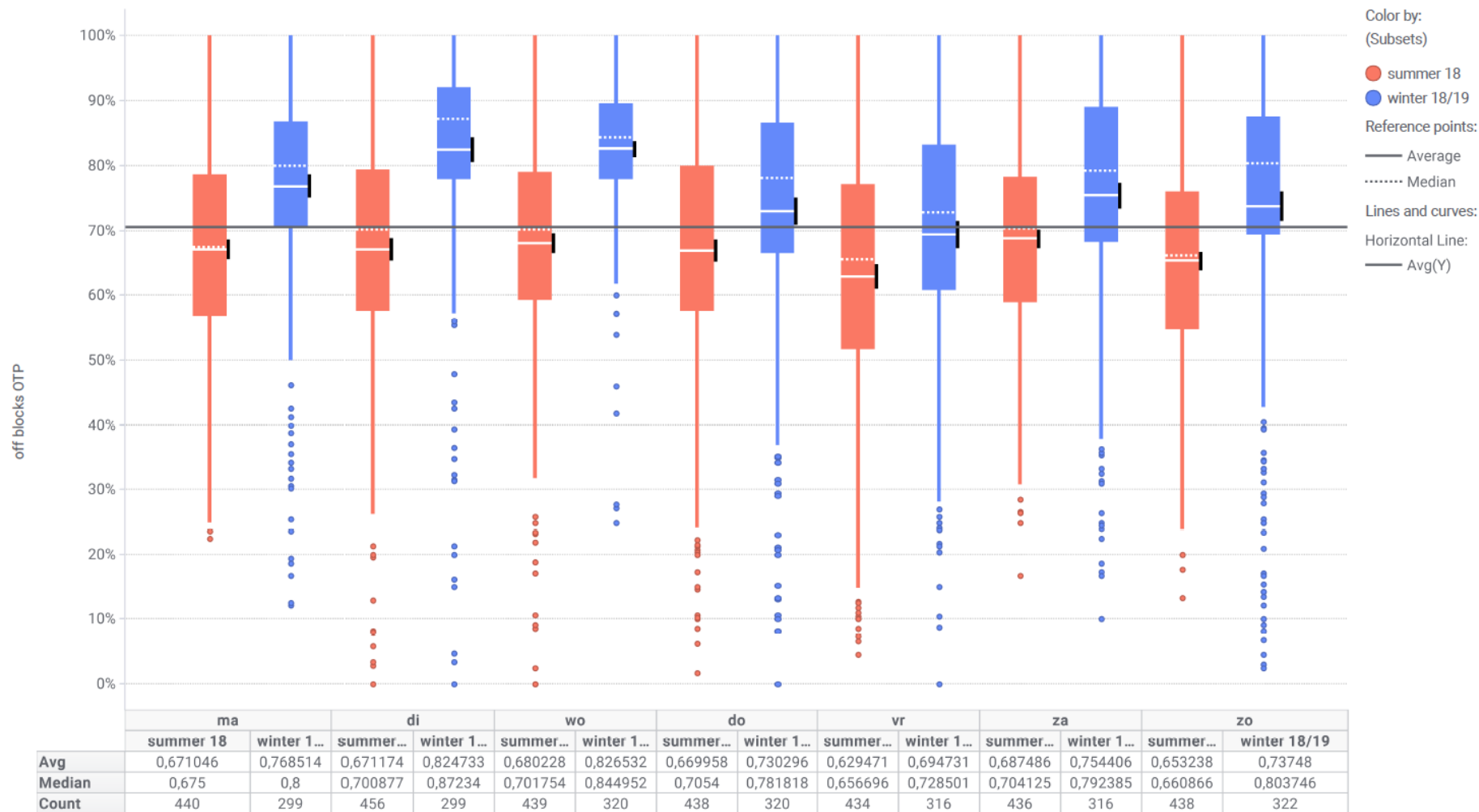
## Appendix II Eurocontrol AOP-APOC process



(Eurocontrol, 2018)

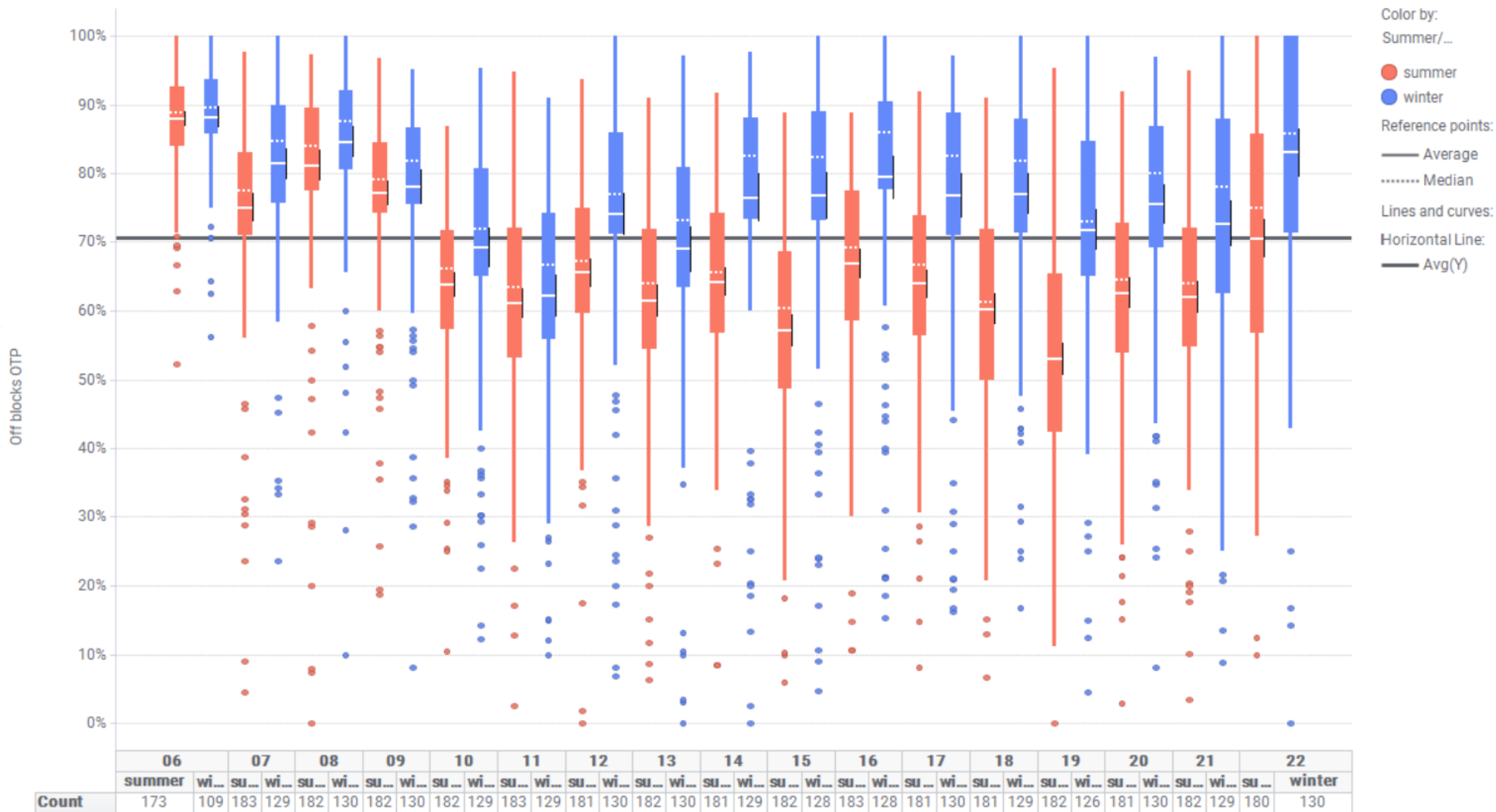
### Appendix III Boxplot of the on-time performance per day of the week, divided by summer and winter

Box plot of the off-blocks On Time Performance per day



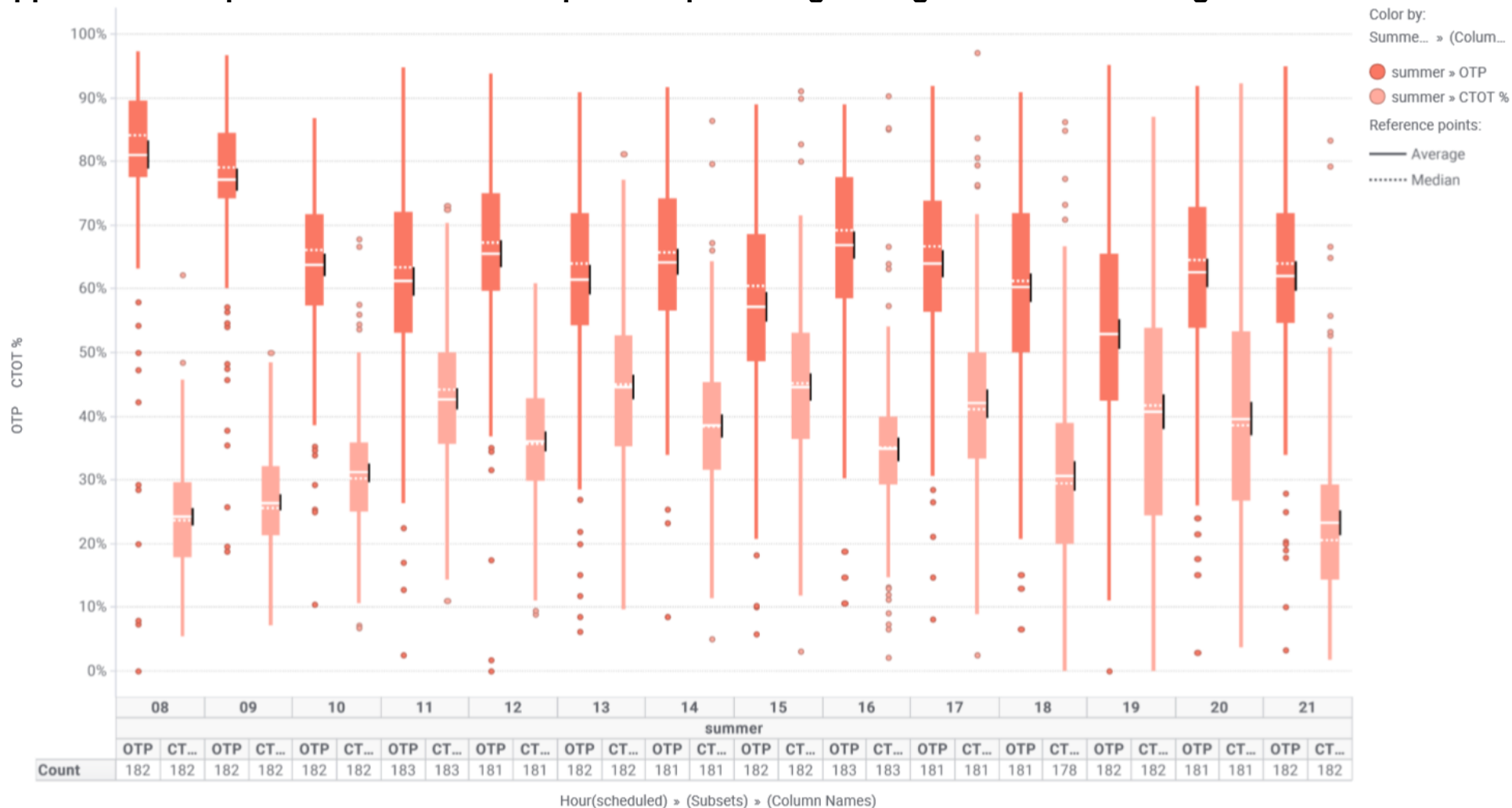
\*Black lines next to the boxes indicate the 95% confidence interval of the mean.

### Appendix IV Boxplot of the on-time performance per day of the week, divided by summer and winter



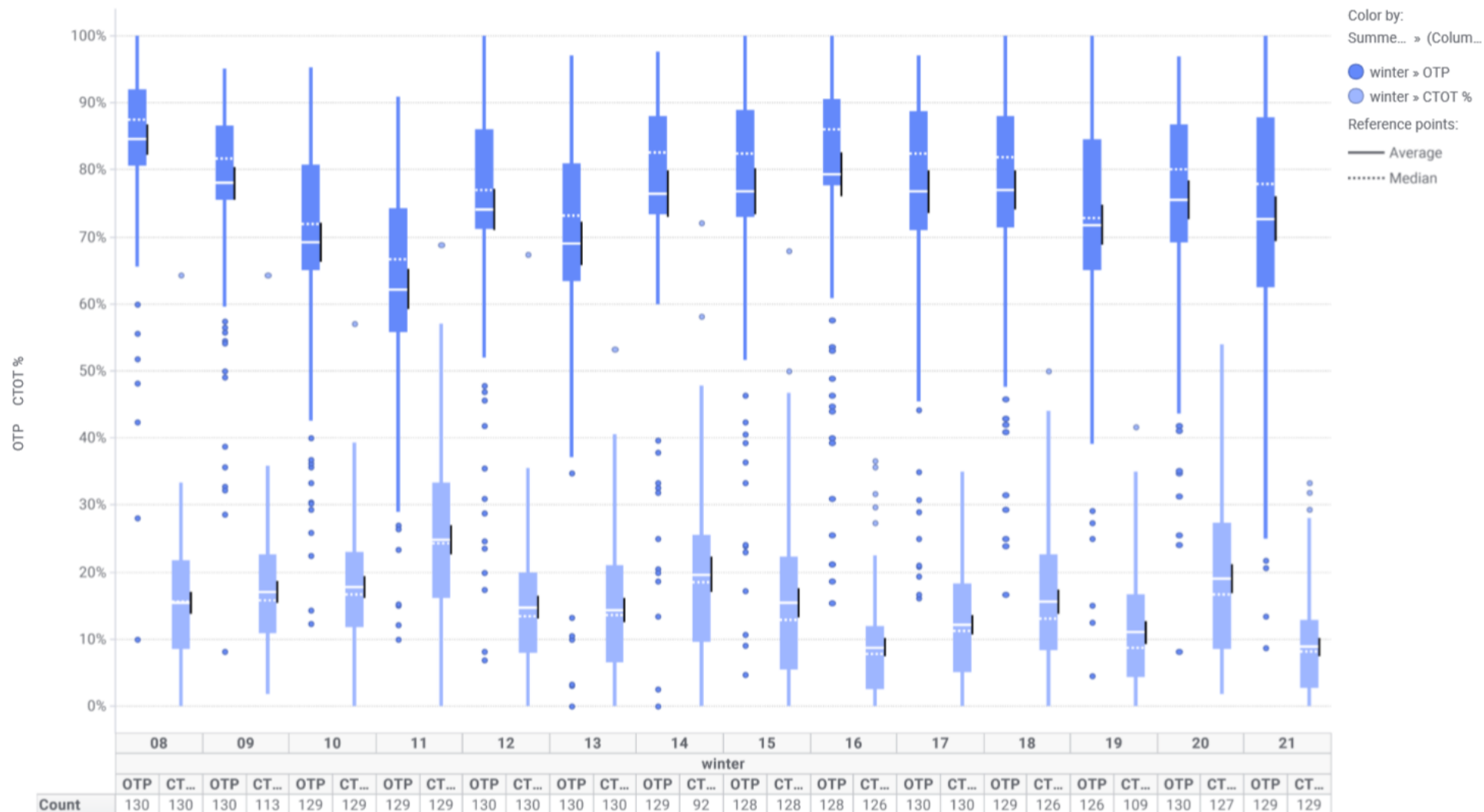
\*Black lines next to the boxes indicate the 95% confidence interval of the mean.

### Appendix IV Boxplot off-blocks OTP compared to percentage of flight with CTOT during summer 2018



\*Black lines next to the boxes indicate the 95% confidence interval of the mean.

### Appendix V Boxplot off-blocks OTP compared to percentage of flight with CTOT during winter 2018/19



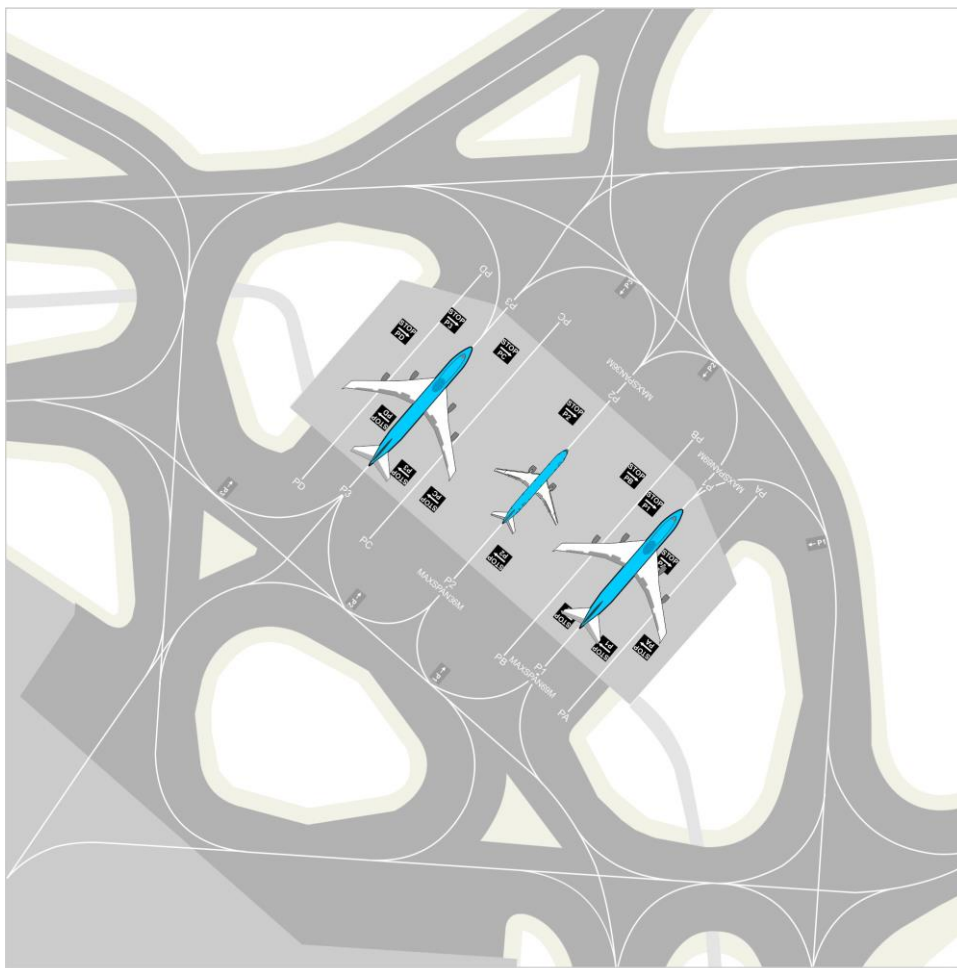
\*Black lines next to the boxes indicate the 95% confidence interval of the mean.

## Appendix VI Remote holding platform

**i** Info: Spanwijdterestricties

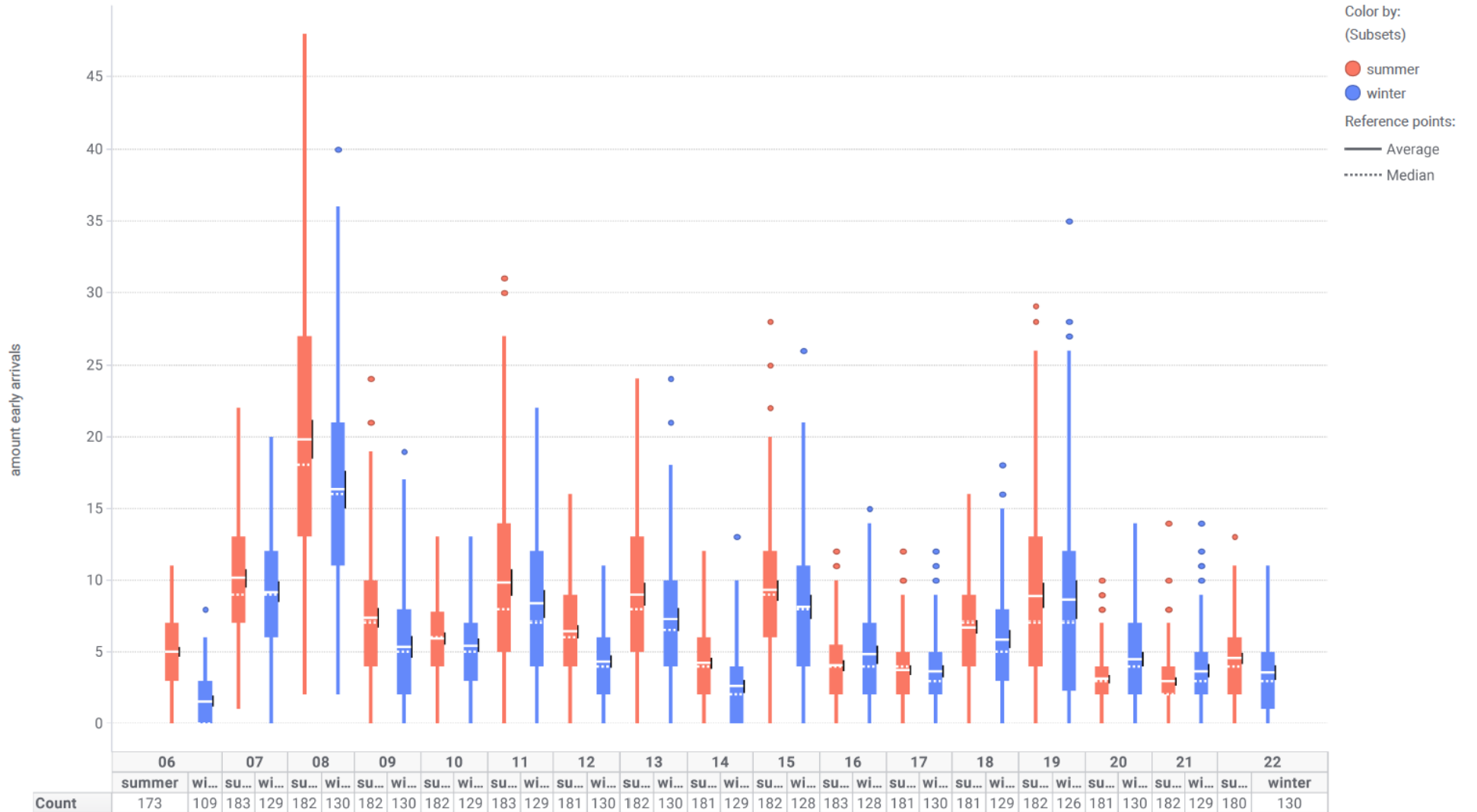
Positie	Maximaal toegestane spanwijdte
P-holding:	
P1	69 m
P2	36 m
P3	80 m
PA, PB, PC, PD (secundaire opstelposities)	36 m
P6, P7	Geen beperking
P6A, P6B, P7A, P7B (secundaire opstelposities)	36 m
P20, P21 (secundaire opstelposities)	36 m

**i** Info: P-holding





### Appendix VII Boxplot of amount of flights per hour of the day



\*Black lines next to the boxes indicate the 95% confidence interval of the mean.

## **Appendix VIII Interview Suzan van Zutphen, APOC process owner Amsterdam Airport Schiphol, 30-04-2019**

### **In which way do you think that the APOC of Schiphol is able to improve and stabilize the airport operational plan?**

Firstly, what is nice about APOC, is that we are able to look further ahead. With a scope of more than 24 hours the APOC tries to deliver a better way of anticipating. Which will give us the ability to manage an operational deviation before they have even happened. Currently we do this only when we are anticipating a big disruption such as snow. However, it is not standard procedure to look at the predictions of the systems to keep adjusting the predictions. One of the main key performance indicators that will be looked at is the predicted on-time performance. Which will give you the possibility to change the planning of resources or procedures. That doesn't take the cause of the deviation away but it will give you the possibility to lower the effects.

Secondly, in the APOC the whole aviation sector is represented and, if it goes to plan, we will all have the same targets. At this moment all stakeholders have their own targets, which is logical, but it creates difficulty when we really need to work together. Being all represented in the APOC creates close connections to each other and makes it easier to collaborate on the goals.

One of the other features of the APOC are the future scenarios. Multiple scenarios are created at D-3 and the best one is chosen as a standard option. When deviations from the standard scenario occur we could change to another scenario at D-1 which better fits the new circumstances. In these scenarios the interests of all stakeholders are taken into account. This should automatically create a better cooperation.

### **Is the influence from the network around Schiphol also taken into account at the APOC?**

Yes, however, the connection to the European Network Manager is not planned for the introduction in 2019. We are planning and working on the implementation of the connection in a later stadium because we do think it is something which could be really beneficial. For example London Heathrow already uses European ACDM data to predict their performance, which shows very promising results.

### **In what way will the airport operational plan be changed at D-1 compared to D-3?**

At D-3 you start to make the first predictions, which gives you more time to start managing compared to D-1. Then at D-1 you determine the definitive airport operating plan, based on the latest more detailed information. But even after D-1, the plan will keep updating itself when unexpected changes occur. Then it will also be a task of the APOC to make sure those changes are accommodated in the system. With as a big improvement that we have made a D-3 scenario together combining all of our tasks, targets and goals.

### **In what way will the APOC manage the deviations from AOP at D-0?**

Initially APOC will mainly steer on alerts regarding certain incidents if they will effect capacity or punctuality of the system. So if an incident does not affect the complete operation and can be handled by one stakeholder on its own then the APOC will not take any action. However, one of the things which is still missing now, is a clear indication of when an incident needs to be handled by APOC and what the response should be.

### **In what way could APOC create an improvement for the problems arising with the amount of CTOTs given by Eurocontrol and the resulting ATFM delays?**

By implementing APOC we will enhance our predictability. This could give us the option to communicate with Eurocontrol about our (predicted) operation. This might decrease the amount of CTOTs given by Eurocontrol although this is heavily dependent on the way Eurocontrol uses this information.

I do think it is important to realize the reason that CTOTs are given: under capacity. So eventually we should be able to reduce the amount of CTOTs in the European system if we would stop making a planning of which we know, it is unrealistic: think about bunching. This is something that APOC could play a role in. Important then is that we get the right policy measures. Then, having all stakeholders at APOC, we could actually create a plan which is realistic, limiting the amount of CTOTs given.

### **Do you see any potential in a system in which certain airport slots have a restrictions that an early arrival means that the flight will end up on an inbound buffer/remote handling position and what role could APOC play around this problem?**

I definitely think this is something that will benefit the operation. The role APOC could play in this is firstly, showing all the parties involved what problems they cause when they arrive too early. The problem still is that we currently do not have the right policies in place to reinforce such procedures. So that is something that should change first.

Though this is part of a solution to another problem we are facing. The stakeholders do not understand each other's operation enough. Which means that they cannot understand what the consequences of their actions within their operation are on the operation of the other stakeholders.

**Remarks:**

Until now the solution to lack of ground capacity has been to build more infrastructure. I no longer believe in this solution mainly because we have reached the moment that we can no longer justify it to our surroundings. To build more infrastructure we need money, especially because the airport is government owned we should always consider the way we spend our money and try to look if it is really necessary. Secondly to build more infrastructure we need land. Which is something we cannot constantly justify to our surroundings and that is something we should always be able to do, being a utility to these surroundings. This means we need to start looking for other possibilities in the area of new procedures and policies like APOC and AOP, creating more possibilities to act proactive on changes. To do this the airport needs to change of some of the current infrastructure. With as main target, improve flexibility and predictability of the operation to make sure the airport is better able to recover from unexpected changes. For example in- and outbound ground buffering or wide body remote handling.

## **Appendix IV Interview Fred Steevens, asset manager gate planning Amsterdam Airport Schiphol, 12-04-2019**

### **According to which restrictions is the gate planning made?**

During the planning flights are subjected to certain restrictions regarding the type of passengers on board, type of aircraft, origin or destination, ground time etc. When planning the flights the planners try to cluster the flights, which means that the planners try to keep in mind that if an aircraft is handled by a certain ground handler, the next aircraft at that stand preferably is handled by the same handler, reducing vehicle movement on the airport and optimizing workhours of the ground handler.

There are regulations in place which tell the planners which restriction is more important. For example the restriction determining which flight will be handled on a remote buffer when there are too little connected stands available is the amount of passengers, the flight with the least passengers is handled remote to have the lowest impact on the passenger flows.

### **When is the planning made?**

The planning is made the day before and changes in the flight plans can be given to the gate planners until 17:00 hours LT the day before. So all changes afterwards are no longer taken into account in the planning. Changes that occur later on are done by the gate control centre of the airport and are based upon the original planning that was made.

### **How far ahead do the gate controllers start changing the planning?**

It really depends on the deviation. In the planning we already have some buffer margins so if the deviation is within the margins we do not change anything.

### **If it is needed and a flight is delayed, when do they start changing the planning?**

The information from the CDM and the ground handlers needs to be updated first. When this is done the system starts updating. So it is dependent on the moment that the information becomes available.

### **Wouldn't it be beneficial to have a system which predicts the flights for the whole day instead of only the current flights that share ACDM data?**

Not necessarily, it would only be if it was very accurate, which is almost impossible because there are so many variables. In that case you really have to watch what you are doing because you do not want to create some kind of apparent reality.

What you also see when things become really uncertain, during bad weather for example, is that airlines keep telling that their departure time is still as planned. They do this to their passenger the flight is not cancelled and to keep their slot times they originally received. Even though we as planners can see that the planning of the flight has become completely unrealistic. Which causes problems in the planning and then we as planners have to ask the ground handlers and airlines to update the data so it becomes realistic again.

### **At which point do you switch the gates to a flight around is this leads to an inbound delay?**

Smaller delays of 5 minutes are not enough because switching it around causes problems as well. The ground handler might already be waiting at the gate, passengers inside the terminal need to change position, etc. All this higher the change of something going wrong on the next flight, for example missing passengers or bags causing further delays. However, when a delay becomes too high, let's say 30 minutes then we will start deviating from the original plan because the effects on the inbound flight are too high.

### **What do you see currently as the biggest challenge to the current operation?**

The lack of management based on the available ground infrastructure. Everyone mostly look at the landing capacity, while this is not always the most restrictive. Sometimes it is the stand capacity. By doing this we create an increase in pressure on the ground infrastructure and because it becomes busier we will see it much more often that there will be waiting traffic in the field awaiting a free stand.

### **Do you think outbound holding would be an option to release some pressure on the gate capacity?**

Yes absolutely, specifically these flights which have an outbound delay of around 15 minutes often happen and cause problems for the following inbound flights. However, not all the airlines like to do it because it means they have to wait in the field. Very recently they started doing it with smaller aircraft, until cat-4 (737). However, we lack the infrastructure (remote holding stands) to do it on a structural basis. When we would be able to use it structurally this would definitely create the planning space we would like to have.

### **Does it happen often that flights arrive too early causing you to change the gate planning?**

Yes, however, it really depends on the moment of the day what the impact is. The first arriving flights of the day mostly do not have another flight on their stand before they arrive. So when they arrive too early, it will not create a problem. This is done by airlines because this creates extra connection time for their passengers, which creates a higher chance that the connection flight leaves on-time. Thereby does it increase passenger satisfaction because they have unexpectedly more time at their destination or during the connection. The problem arises on the flights arriving later than the first arrivals. Here the gates are already occupied demanding the gate planners to change the planning and look for other options to handle the aircraft. In this case we have an aircraft on the ground which we realistically cannot always accommodate.

**Could it be an idea to create special slots that will tell an airline that the airport is not able to accommodate an early arrival on that slot. If they do arrive early they will be handled remote or maybe even be buffered until gate capacity is available?**

Yes, only problem is, once again, you need to have that buffer space. Nevertheless, indeed there should be more communication between the airlines and the airport about the possibilities.