IMPLEMENTATION OF AN AIRPORT OPERATIONS CENTER (APOC) AT SCHIPHOL AIRPORT:

Improving capacity management?

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Thesis

Implementation of an airport operations center (APOC) at Schiphol Airport:

Improving capacity management?

Complete version

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Preface

Before you lies the thesis ”Implementing an airport operations center at Schiphol: Improving capacity management?”, an exploratory study aimed at improving capacity management for Amsterdam Airport Schiphol. It has been written as part of the Aviation Operations track at the University of Applied Sciences, accounting for 30 ECTS. I was engaged in researching and writing this thesis from September 2017 to January 2018.

The project was commissioned by the KDC Mainport Schiphol, in collaboration with the Amsterdam University of Applied Sciences - Aviation Academy (HvA). The research was challenging due to diverging visions of stakeholders. I believe I managed to balance their interests without detracting any of them, and came up with insights for the implementation of an airport operations center.

However challenging, I had the support of aviation experts, researchers and friends along the way. I acknowledge the contributions of all people involved, but I must thank some contributors individually:

I would like to thank Evert Westerveld, Alina Zelenevska, Frenchez Pietersz and Ferdinand Dijkstra for their support along the way. Their continuous input and feedback during the research helped shape the end result.

Furthermore, I want to express my appreciation to the CDM-team at LVNL: specifically Eugene Tuinstra, Ruud van Gils and Karin Elbers. Your roles, both mentor and sparring partner on A-CDM at Amsterdam Airport Schiphol, proved very insightful to me in creating a deeper understanding of CDM@AMS.

My basic knowledge on meteorology was no issue to John Brouwer, who has been so kind to invest time in explaining the role and benefits of KNMI (Meteorological Institute of the Netherlands) in airport operations and A-CDM.

Without feedback from the stakeholders, the value of this research drops drastically. Ceriel Janssen & Eugene Leeman, thank you for being my direct connection to KLM & Amsterdam Airport Schiphol.

Thanks are in place to my fellow students Joep, Remsey and Niek, making every day at the office not just an ordinary day, challenging each other, both in research, as in contributions to the end results.

Above all, I thank anyone taking the time and effort to read this thesis, and I truly hope my results will prove to be a blueprint for the airport operations center at Schiphol.

Huib de Jong

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Abstract

Introduction After qualifying as a CDM airport with NMOC, Amsterdam Airport Schiphol considers the implementation of an airport operations center to further improve capacity management. By exposing inefficiencies in (the current version of) A-CDM, the choice to implement an airport operations center to improve capacity management is bolstered.

Method To expose the inefficiencies in A-CDM, and the added value of an airport operations center, data analysis was performed on CDM data: 2 weeks of raw CDM outbound data ($n \approx 10.950 flights$). The focus was on Estimated Off Block Times (EOBT), Target Off Block Times (TOBT) and Target Startup Approval Times (TSAT). These variables were linked to behavior of ground handling agents, airlines and influences of weather to prove the magnitude of external influences.

Expert validations were used to verify the findings of the data research. These findings were translated to recommendations for implementing an airport operations center at Amsterdam Airport Schiphol.

Findings The research proved TSAT to be an unstable predictor for airport operations, since it is highly influenced by actors' behavior. To improve capacity management, stakeholders should share data more intensely. However, they are reserved towards sharing data, as they are afraid of misuse or misinterpretation of shared data.

Conclusions A successful implementation of an airport operations center would improve accuracy and predictability of the airport system, but requires major contributions to the program by all stakeholders like data sharing.

Keywords:
Actors' influence on airport system; Airport operations center (APOC); Capacity management; Collaborative Decision Making (CDM); Data sharing; EOBT management; Schiphol airport; SESAR2020; TOBT management; Total Airport Management (TAM); TSAT instability

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List of abbreviations

A - P	
A-CDM	Airport-CDM *(see CDM)*
AAS	Amsterdam Airport Schiphol
ACC	Area Control Center
AIBT	Actual In Blocks Time
AMAN	Arrival Management/Manager
ANSP	Air Navigation Service Provider
APOC	Airport operations centre
ATC	Air Traffic Control
ATFCM	Air Traffic Flow & Capacity Management
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATOT	Actual TakeOff Time
AUAS	Amsterdam University of Applied Sciences, *NL: Hogeschool van Amsterdam*
CDM	Collaborative Decision Making
CPDSP	Collaborative Pre-Departure Sequence Planner
CTA	Control Area
CTOT	Calculated TakeOff Time
CTR	Controlled Traffic Region
DMAN	Departure Management/Manager
DLR	German Aerospace Center, *DE: Deutsches Zentrum für Luft- und Raumfahrt*
EHAM	Amsterdam Schiphol Airport
EIBT	Estimated In Blocks Time
ELDT	Estimated Landing Time
EOBT	Estimated Off Blocks Time
EXIT	Estimated Taxi In Time
EXOT	Estimated Taxi Out Time
ICAO	International Civil Aviation Organization
KDC	Knowledge & Development Center Mainport Schiphol
KLM	KLM Royal Dutch Airlines
KNMI	Dutch Meteorological Institute, *NL: Koninklijk Nederlands Meteorologisch Instituut*
KPI	Key Performance Indicator
LVNL	Air Traffic Control the Netherlands, *NL: Luchtverkeersleiding Nederland*
MTT	Minimum Turnaround Time
NM	Network Manager
NMOC	Network Manager Operations Center
PaxMAN	Passenger Management/Manager

R - Z

RPAS	Remotely Piloted Aircraft System
SESAR	Single European Sky ATM Research
SMAN	Surface Management/Manager
SOBT	Scheduled Off Blocks Time
SWIM	System-Wide Information Management
TMA	Terminal Manoeuvring Area
TMAN	Turnaround Management/Manager
TOBT	Target Off Blocks Time
TSAT	Target Startup Approval Time
TTOT	Target TakeOff Time
TWR	(Air traffic control) Tower

Glossary

Airport Actors
The term 'airport actor' is used (in this report) to describe key players/ organizations in the airport operations. E.g. airlines, ground handling agents, air traffic control, the meteorological institute, and the airport operator.

Airport Collaborative Decision Making *A-CDM*
A-CDM is a collaboration between stakeholders aiming to improve the operational efficiency of all airport operators by reducing delays, increasing predictability of events during the progress of a flight and optimizing allocation of resources.

Arrival Manager *AMAN*
The arrival manager tool combines flight plan information, radar data, aircraft performance, local environment data and weather data into a trajectory prediction. This prediction, together with the input constraints (runway spacing and availability) will advise on arrival sequences and assigned arrival times.

Airport Operations Center *APOC*
An operational management structure that permits relevant airport stakeholders to have a common operational view and to communicate, coordinate and collaboratively decide on the progress of present and near term airport operations.

Airport Operations Plan *AOP*
The Airport Operations Plan is a single, common and collaboratively agreed rolling plan that will form the single source of airport operations information shared bi-directionally with all airport stakeholders including the Network Manager.

Capacity Forecasts *Cap. For.*
The collaborative forecast on capacity shared four times daily, including weather forecast, planned runway configurations, and expected disturbances. *(Definition applies to Amsterdam Airport Schiphol only.)*

Departure Manager *DMAN*
DMAN is a planning system to improve departure flows at airports by calculating the Target Take Off Time (TTOT) and Target Start-up Approval Time (TSAT) for each flight, taking multiple constraints and preferences into account.

Estimated Off-Block Time *EOBT*
The estimated time for the aircraft to be taken off-blocks, meaning the aircraft is ready for start-up and pushback.

Network Operations Plan *NOP*
The Network Operations Plan describes operational actions to be taken by the Network Manager and its stakeholders - actions needed to meet set performance targets. It is a short to medium-term outlook of how the ATM network will operate.

Network Manager Operations Center *NMOC*
Formerly known as CFMU, NMOC is the organization appointed to regulate and control the fair use of available airspace capacity.

Passenger Management *PaxMAN*

The main tool to synchronize and harmonize airside and landside operations in TAM, monitoring and assessing passenger processes.

Single European Sky ATM Research *SESAR*

The SESAR project is the European programme to modernise air traffic control infrastructure. SESAR develops the new generation air traffic management system capable of ensuring the safety and fluidity of air transport worldwide over the next 30 years.

Surface Manager *SMAN*

SMAN integrates surveillance and lighting infrastructure at an airport to a surface movement management system, providing situational awareness for airport actors.

Total Airport Management *TAM*

The basic principle of TAM is to create an environment enabling airport partners to maintain a joint plan – the airport operations plan – thus working towards dynamically agreed goals in order to get the full A-CDM benefits. The scope of TAM is the entire airport, monitoring and guiding airside and landside operations.

Turnaround Management *TMAN*

TMAN is a system to manage the turnaround process. It acts as an integrated link between air traffic control and apron control and calculates all A-CDM and ground handling times. When extended with a delay-cost logic model, it can be used for prioritization of flights.

Target Off-Block Time *TOBT*

The target time for completion of ground handling process.

Target Startup Approval Time *TSAT*

The target time for startup and pushback, to depart from the runway in time.
TSAT window: $\text{TSAT}_{\text{-5 min}}$ – $\text{TSAT}_{\text{+5 min}}$

Target Take-Off Time *TTOT*

The target time for takeoff from the runway.

Executive summary

Amsterdam Airport Schiphol will qualify as an A-CDM airport with NMOC from May 2018, and expects to receive all A-CDM related benefits. An EUROCONTROL analysis proved improved accuracy in takeoff predictability for airports with A-CDM. The next step in capacity management is the integration of the Airport Operations Plan and the Network Operations Plan (AOP-NOP integration). In this integration, the airport operations center (APOC) will function as linking pin between NMOC and Schiphol airport.

KDC Mainport intends to find out how an airport operations center would benefit Schiphol airport. The APOC is a SESAR-concept aimed at collaborative management of the airport operations. It combines landside and airside processes through continuous data sharing amongst all partners, working closely together in a physical (or virtual) center to optimize capacity usage.

The research aims to answer the main research question:

How does the implementation of an airport operations center (APOC) improve capacity management at Amsterdam Airport Schiphol?

To answer this question, the research focused on three themes: understanding the SESAR concept of APOC, analyzing the inefficiencies in (the Schiphol version of) A-CDM, and applying gained knowledge to recommend necessary requirements for the implementation of an APOC.

APOC vision applied to Schiphol

To create an understanding of the APOC vision[1], desk research was performed. In this SESAR concept the APOC functions as the local control center for the management of the total airport, both landside processes and airside processes. The concept itself is still under development, meaning there are no airport operations centers currently active anywhere in the world[2]. The vision is applied to the case of Schiphol airport: identifying stakeholders and data flows.

In order for an APOC to succeed at Schiphol airport, the APOC's function and mandate must be agreed upon by all stakeholders at the airport. The SESAR-concept envisions the APOC as the central node in the holistic approach of the airport, combining information to manage all airport processes both on the apron and in the terminal. Once this vision is accepted, it is necessary to get the main actors on board: Amsterdam Airport Schiphol (AAS), Air Traffic Control the Netherlands (LVNL), (representatives from) main airline operators (KLM Royal Dutch Airlines, Transavia, easyJet), (representatives from) main ground handling agents (Menzies, Swissport, KLM Ground services), and the Royal Netherlands Meteorological Institute (KNMI).

At the future Amsterdam Airport Schiphol an APOC will function as the main support tool for total airport management. It bridges gaps between main airport actors by collaboratively deciding on capacity measures. These decisions will be supported by simulation and planning tools. The uniformity of the decisions will improve capacity management.

[1] The SESAR-concept as explained by EUROCONTROL & DLR (DE: *Deutsches Zentrum für Luft- und Raumfahrt*)

[2] There are certain airports who claim to have an APOC, but those airports only have a select number of functionalities from the SESAR concept as described by EUROCONTROL and DLR.

Analyzing inefficiency of the current system

To analyze the inefficiency of the current system, two full weeks of CDM outbound movements have been analyzed ($n \approx 10.950 flights$). The stability and predictability of the airport system are determined by the accuracy of the A-CDM process. The focus was on Target Off Block Times (TOBT), Estimated Off Block Times (EOBT) and Target Startup Approval Times (TSAT). By improving the stability and predictability of the A-CDM process, capacity management improves.

The TSAT at Schiphol airport is considered unstable, resulting in fluctuations of the TSAT and undesired extra workload for ground handling agents, air traffic controllers, apron controllers and airline crews/pilots. The instability is caused by multiple factors, the main reason is the frequent updates from TOBT autogenerated by the changing estimated landing times (ELDT). Changing runway configurations, the influence of weather and the influence of actors' behavior also impact the stability of TSAT.

This behavior can be identified in the data. For example, the size of TOBT updates when an aircraft is in blocks, is frequently smaller than 5 minutes. In other words, the manual updates of TOBT (< 5 minutes of $TOBT_{n-1}$) are within the TSAT-window, therefore unnecessarily triggering the outbound sequencing algorithm, causing fluctuations in the TSAT.

To a lesser extent undesired behavior was observed in the manual updates of EOBT. These updates are generally after the initial EOBT, and can therefore no longer be used to accurately calculate air space capacity within Europe. This results in an inefficiency of air traffic flow management (ATFM) measures.

An APOC would provide insight in aforementioned behavioral inefficiencies and would ease steps to improvement. Beneficial to reducing TSAT fluctuations, this indirectly leads to better capacity management at Schiphol airport.

Requirements for implementation

To recommend necessary requirements for the implementation of an APOC at Schiphol, available literature has been combined with the expert opinions, and conclusions from the data analysis.

All stakeholders benefit from sharing data, when it increases operational airport efficiency. It does however require (heavy) investments from stakeholders to prepare for datasharing. Technical challenges, like standardizing & anonimizing data and providing secure structures to transfer data, lay ahead.

Apart from technical challenges, the reservedness towards data sharing should be overcome. For stakeholders to invest, the simulation and planning tools should have proven trustworthy and valuable before the implementation of an APOC.

To conclude, the implementation of an APOC at Schiphol is expected to improve capacity management. With a unanimously supported role and function of the APOC, the APOC can function as a linking pin between the AOP and NOP. By providing insight in behavior, resulting in improved stability of TSAT, the path to improved capacity management is smoothened.

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1 Introduction

Amsterdam Airport Schiphol is handling air traffic like never before. Great news! Or is it?

There are two sides to every coin: Schiphol's growth creates capacity challenges for the near future. The transition of non-mainport traffic to Lelystad is one of the measures taken, but it might not be enough. Schiphol's stakeholders are operating under high pressure to be the main hub airport in Europe, offering the best connections to customers.

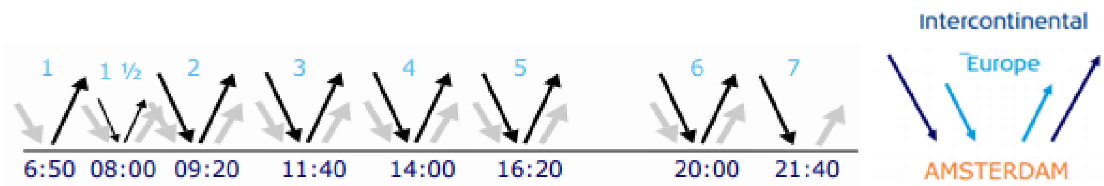

Figure 1: Seven wave hub system KLM at Amsterdam Airport Schiphol

Congestion at Schiphol mainly translates to a shortage of gates in traffic peaks, a high workload for air traffic controllers, and a desire to use the 2+2 runway configuration more frequently. Also more indirect problems related to high traffic numbers add up to the complexity of airport operations, like a buildup of propagational delays, low slot adherence, high erroneous "ready" calls for TSAT, and shortages of staff.

To overcome some of these effects of airport congestion, partly due to the seven-peak system of KLM *(see figure 1)*, three mitigation techniques can be identified: *capacity expansion, operational enhancements and demand management.* (Gillen & Lall, 1997; Jacquillat & Odoni, 2017)

Schiphol and its actors use all three interventions against congestion:

Capacity expansion Schiphol currently invests in gate expansions at pier A and is building a new terminal.

Operational enhancements Through Collaborative Decision Making (CDM) Schiphol aims at involving stakeholders to balance the number of arrivals and departures operated on each runway.

Demand management Airport Coordination Netherlands (ACNL) is responsible for slot control at Schiphol airport, and these slots are distributed under strict guidelines to abide by international rules and regulations of non-discrimination.

(Fictional) Example 1: Inefficiencies resulting from a minor ground delay.

To exemplify the suboptimal situation at the airport, a ground delay and its impact are illustrated below, to underline the importance of intensified collaboration.

Monday morning 08:05LT, gate D18 Schiphol airport.
Flight AA123, an Airline A Boeing 737-800 flight from Amsterdam to Edinburgh is about to call for start-up according to planning. While closing the forward cargo bay, minor damage on the outside of the hull is detected, and it has to be further inspected before takeoff.

In the mean time:
Flight AB456, an Airline B Airbus A320, which landed at 08:02LT on runway 18R while 18C is also in use, is taxiing to that exact same gate D18.Luckily, the damage to the hull is just superficial and has no further implications for the operation of flight AA123, except for the minor ground delay of 15 minutes. The result of not calling up for startup might seem minimal at first.

08:13LT:
The inbound flight is closing in on gate D18 (still occupied) and receives the radio call to relocate to dock at D49 on the other side of the pier.

One can imagine the consequences for flight AA123: it misses its ATFCM slot since the start-up call is >10 minutes after its CTOT. A new slot must be requested at EUROCONTROL, to reserve a flightpath in crowded airspace. When the new slot is approved 20 minutes later, flight AA123 will arrive late at Edinburgh. A consequence might be that airline A starts its day with a delay for flight AA123. All sequential flights with the same aircraft will most likely be delayed, with an additional 4 more legs, this will frustrate both airline and passenger.

The consequences are not only to airline A however.
Schiphol airport, responsible for gate planning, has to reallocate the flights which were to arrive at gate D49, since this has been given to AB456. Passengers for the return flight of Airline B needs to be redirected to gate D49, possibly incurring more required travel time to gate for the passengers (or their luggage). Since flight AA123 did not call for start-up, ATC the Netherlands has to (automatically) reschedule the departures on the runway (the departure sequence), with a possible dip in runway usage as a result.

All measures taken to prevent saturation of the airport. Although... all measures?

Collaboration between airport actors is present, but not yet optimal. Actors are not able to oversee the results of their actions to the operations of others. Intensifying the level of collaboration seems the solution to meet this shortage of insight. The Single European Sky ATM Research (SESAR) focuses on increasing (European) collaboration to optimize the usage of resources with benefit to the air transport system as a whole.

Multiple SESAR initiatives focus on collaboration between system actors. At an airport level, an airport operations center is envisioned to function as a control center to manage and steer capacity of the airport. Through the use of planning and simulation tools decision-making can be improved, minimizing the effects of airport saturation.

Airport operations center at Schiphol
Currently Schiphol has a local form of collaborative decision making in place, sharing airside operations related information. Four times daily, capacity forecasts, based on available capacity and weather are shared.

The implementation of an airport operations center, focused on both airside and landside processes, will drastically intensify collaboration. Information sharing would be continuous, and decision-making is managed from the airport operations center. This fundamental change will enable endless possibilities to improve capacity usage at an airport.

Improvement of operations?
The question arises if the transition from discrete to continuous decision making and the inclusion of additional stakeholder processes will improve current operations, specifically the possibilities for management of capacity at the airport. This research, commissioned by the Knowledge Development Center mainport Schiphol (KDC), aims to answer the following main research question derived:

How does the implementation of an airport operations centre (APOC) improve capacity management at Amsterdam Airport Schiphol?

In order to answer this question, the research focuses on three areas:

1. Understanding the SESAR concept of airport operations center (APOC)[3]
2. Analyzing inefficiencies in (the Schiphol version of) A-CDM
3. Applying gained knowledge to recommend necessary requirements for the implementation of an APOC.

[3]Throughout this report, the SESAR-concept for an airport operations center (APOC), as described by EUROCONTROL & DLR in 2006 (Günther et al., 2006), is discussed as the EUROCONTROL APOC vision.

So expectations are, an APOC will change the airport operations for the better. The question remains... how?

1. To create a vision for the implementation of an APOC at Schiphol, desk research can provide answers. Both internal documents from the KDC members, and public documents from the SESAR project, are combined with scientific publications to create a basis for the APOC-principle at hand.

After qualifying as a full A-CDM airport with NMOC, the next step in capacity management is to integrate the Airport Operations Plan with the Network Operations Plan (AOP-NOP integration). The APOC plays a key role in this process, being the linking pin between airport and NMOC.

2. To analyze the (in)efficiency of (the current Schiphol-version of) A-CDM, data analysis is performed. The CDM outbound movements for two full weeks will be analyzed ($n = 10.950 flights$). The data analysis will focus on Target Off Block Times (TOBT), Estimated Off Block Times (EOBT) and Target Startup Approval Times (TSAT).

The first two, TOBT and EOBT, reflect input values to the CDM-process. The TOBT is the main variable used in local capacity calculations, whereas the EOBT (the scheduled time of departure on the filed flight plan) is used in European air space capacity calculations. The TOBT is the main input to the Collaborative Pre-Departure Sequencing Planner (CPDSP), and determines the outbound sequence at Schiphol airport. Analysis of TOBT updates may provide insight in behavior of the system (auto-generated TOBT updates) and behavior of actors (manual TOBT updates).

Analysis of the EOBT updates may provide insight in airlines' behavior towards EUROCONTROL capacity calculations. The data analysis on EOBT should be placed in perspective: airlines are commercially driven and with the data available, tracing back effects of EOBT updates directly is virtually impossible.

The TSAT at Schiphol airport is presumed unstable, leading to unnecessary workload for air traffic controllers, apron controller, ground handling agents, and airline crews/ pilots. It is the output of the A-CDM process, so both input- and transformation processes can be the cause of this instability. Analysis of this instability may provide insight on the biggest challenges in A-CDM at Schiphol.

By understanding current challenges and the vision described by EUROCONTROL & DLR (Günther et al., 2006), this report tries to explain the improvement of the airport system when an airport operations center is implemented. For this research, there was no data available on the terminal processes, nor was there enough time available to create a full airport model to prove the added value of an airport operations center. Therefore, this research focuses on current challenges and historical (CDM) data; using deductive reasoning to explain the improvements of airport operations, more specifically capacity management, in case of an APOC implementation at the airport.

3. To recommend necessary requirements for the implementation of an APOC, available literature has been combined with expert opinions and conclusions from the data analysis. Since data sharing is one of the key pillars to the implementation of an APOC, requirements for data sharing are explained.

The research focuses on the willingness of stakeholders to share data and the technical challenges for data sharing ahead. To overcome these challenges, this report provides recommendations for implementation.

Structure of report

The research design is justified in chapter 2. Chapter 3 describes current literature on airport congestion, total airport management strategies, an airport operations center, and cooperation within the supply chain. Chapter 4 applies the EUROCONTROL vision of APOC to Schiphol. The predictability of the system is explained in chapter 5, whereas chapter 6 and 7 describe the actors' influence on the airport system and the European network. The requirements for datasharing are considered in chapter 8. Conclusions and discussion of the results take place in chapter 9 and 10. Recommendations to the involved KDC partners are in chapter 11. The appendices further elaborate on the topics, in support of the main document.

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2 Research design

Research approach The goal of the research is to map the impact of an airport operations center (APOC) at Amsterdam Airport Schiphol. The research uses a combination of quantitative and qualitative research to handle three main topics regarding the implementation of an APOC:

1. Applying the APOC vision to Schiphol
2. Mapping the challenges faced in A-CDM at Schiphol, and explain the impact of an APOC
3. Listing the requirements for data sharing

Ultimately, the goal is to find out if and how an airport operations center would benefit capacity management at Amsterdam Airport Schiphol.

Research model The research was performed following the created research model as provided in figure 2. The researched literature topics, the methodology for the analysis of the data, and the validation of results with stakeholders, are explained hereafter.

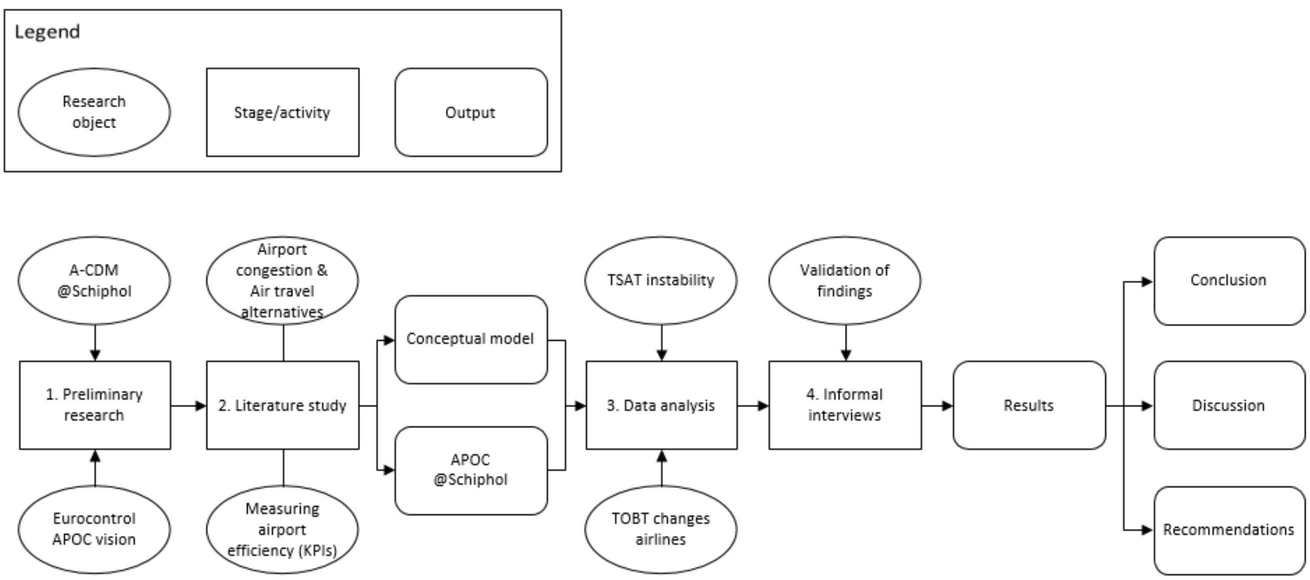

Figure 2: Research model for APOC implementation research

2.1 Preliminary research

The preliminary research was conducted to gain a broad understanding of EUROCONTROL's vision for future air travel, embedded in the SESAR programme. The SESAR 1 programme (predecessor of the SESAR 2020 programme) was an initiative to innovate ATM funded by the European Commission, it provided airports with multiple initiatives to improve airport operations. Although most initiatives never reached the implementation phase due to various reasons, Airport-Collaborative Decision Making has proven successful. SESAR 2020 initiatives enable European airports to evolve from A-CDM to Total Airport Management: airports with an airport operations center, expanding A-CDM with landside activities and transitioning from a discrete to a continuous decision making process.

During the preliminary research the current status of Schiphol regarding A-CDM was analyzed.

2.2 Literature research

To create a theoretical framework, literature has been reviewed to develop insight on the APOC-concept and parallels in academic literature. A review has been executed on the following topics:

- Air traffic demand
- Air traffic congestion
- Impact of congestion
- Mitigation strategies for congested airports
- High-speed rail & air connectivity
- Total Airport Management
- Airport operations center
- KPAs for airport systems
- KPIs on landside & airside processes
- Performance indicators of transportation management
- (Logistics) industry collaboration
- Risks of collaboration

Literature inclusion criteria The papers considered were either conference proceedings or journal publications, and were not considered if older than 15 years, or if outdated by newer research. The papers on airport modelling, for simulation purposes, have been used to define the performance indicators for KPAs.

Output:

- Conceptual model
- Vision for APOC at Amsterdam Airport Schiphol.

2.3 Data analysis

TSAT is considered unstable at Schiphol airport; gaining insight in this instability and its causes, and the possible impact of an APOC on this instability, indirectly proves the added value of an APOC. Therefore, the data analysis in this research has been performed on the following two topics: instability of the TSAT, and actors' influence on TSAT instability through TOBT and EOBT updates. Figure 3 shows the relationship between the different system variables, and their link to the airport system's predictability.

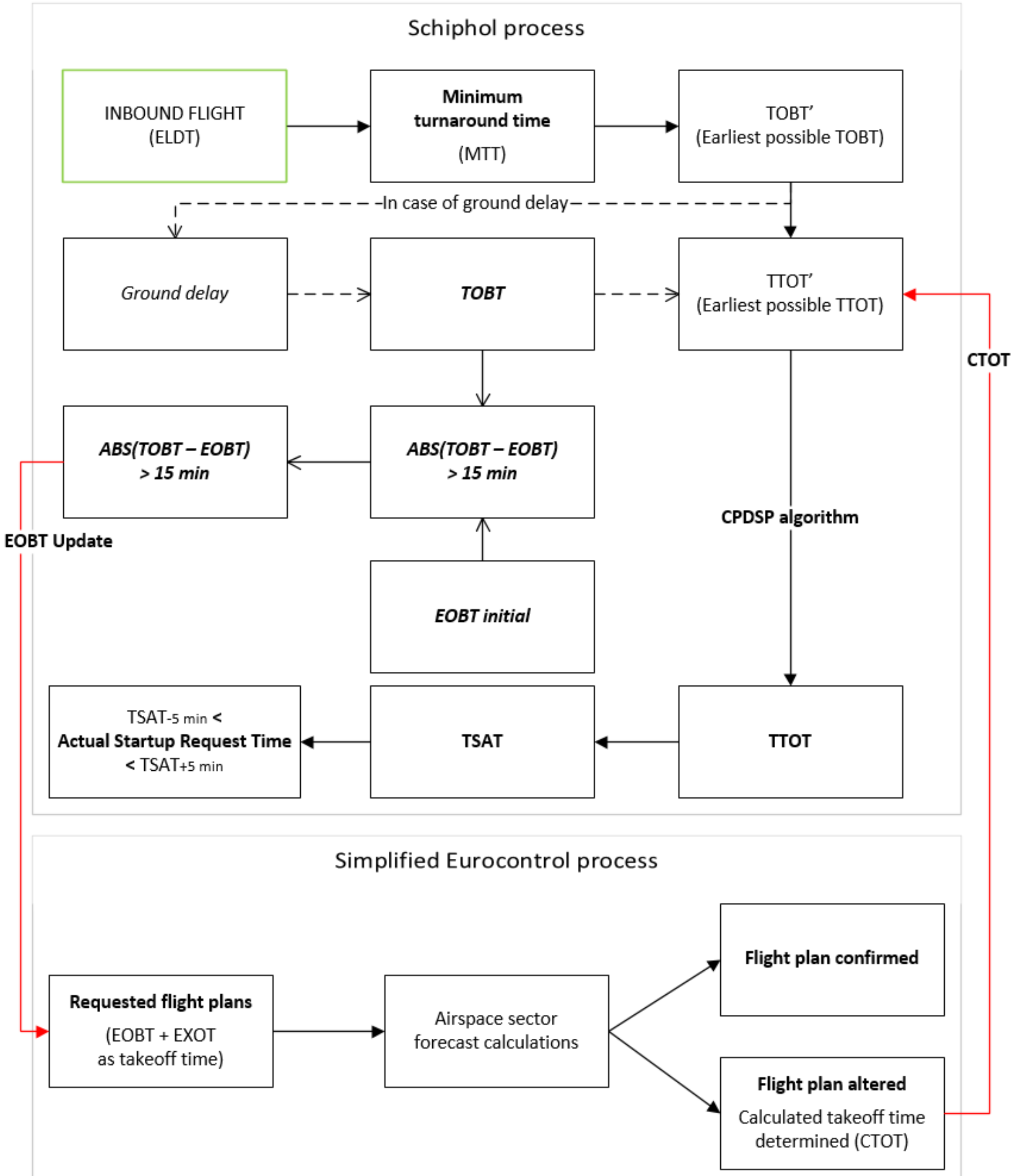

Figure 3: Conceptual model airport system: TSAT and EOBT link to system and EUROCONTROL process. Interpretation based on Schiphol CDM Manual (Duivenvoorde et al., 2013).

2.3.1 Data collection: Selecting the time periods to analyze

Numerous systems log data related to the aviation sector at Schiphol, each system working with different formats, and different outputs[4]. To create an overview of the current datasharing intensity, current dataflows have been analyzed first. The only shared data currently available to all stakeholders, is the flight data shared within the CDM-programme *(CDM@AMS)*, and the capacity forecasts shared four times daily. These datasets were used as a starting point for the dataset to be analyzed, but due to the sheer size of the CDM-log files, it was necessary to determine a time frame to be analyzed.

A monthly extract was taken from the internal ATC-system, VEMMIS, showing the average start-up delays over the course of the day. To increase the usability of the results, this research used the most recent data available at the start of data collection.

Data inclusion criteria To enhance the validity of the analysis, the analysis has been performed on two datasets, each consisting of a week (7 days). For the week to be selected, it had to meet the following requirements:

- As recent as possible (Availibility data[5]: until September 2017), but not more than 1 year old.
- Based on VEMMIS extract: the week should contain 2 irregular ('disturbed') days of operation, and 5 'regular' days.
- One week during the holiday season, the other outside the holiday season[6] ('regular' week)

Based on the these requirements, the following two weeks have been selected:

1. August 14-20, 2017
2. September 4-10, 2017

2.3.2 Data collection: Datasets to analyze

Subsequently the selection of time frames has been determined, the following step in the data collection is collecting the actual data from the different data systems. The following four datasets were collected and used:

CDM The raw data logs for the two periods were imported.

EUROCONTROL EUROCONTROL DDR data explaining the capacity reductions (active regulations) and the NM daily statistics reports (Network Manager) for the researched time frames.

KLM FIRDA KLM FIRDA data containing KLM's flight data logs delays, including linked ICAO delay codes.

KNMI Both the actual registrations of weather conditions at the head of the runways and the Schiphol Probability Forecasts.

[4] See the SESAR SWIM concept in Appendix C for the solution to this challenge.
[5] The starting moment of collection of data was the end of October 2017.
[6] The holiday season for 2017 in the Netherlands was from July 8 until September 3.

2.3.3 TSAT instability

For the instability of the TSAT, all TSATs of each flight in the CDM log files have been plotted against the $EOBT_i$ from $EOBT_{i\ -\ 180\ min.}$ until $EOBT_i$. Furthermore, the average number of TSATs per flight were specified per day, as was their average range.

2.3.4 TOBT & EOBT management

The relationship between TSAT instability and TOBT & EOBT management was made clear, based on the conceptual model on the previous page. The moment and size of TOBT changes (managed by ground handling agents) were plotted on a scale of -180 minutes and +180 minutes to $EOBT_i$.

Since EOBT changes require a deviation of at least 15 minutes to be changed, these were crosslinked with the logged IATA-delay codes for the KLM flights. The average moment in time (with regard to the $EOBT_i$) of the EOBT change was linked with the delay codes, to find patterns in behavior.

2.4 Expert validation

Informal interviews with sector experts were used to validate findings. When the personal agendas would allow it, an appointment was made (outside the biweekly meetings) to discuss the results of this research.

Output:

- Results
- Conclusion
- Discussion
- Recommendations

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3 Literature review

This literature review will look for parallels in research on airport congestion, congestion mitigation techniques, total airport management strategies like an airport operations center, KPIs for steering capacity, and requirements for supply chain cooperation. This should lead to a broader understanding as to the value of the main research goal: improving capacity management at airport Schiphol.

Global air traffic demand is growing and will continue to grow annually by 2.9%-4.8% until 2036 (Airbus, 2017; Boeing, 2016). Graham & Metz (2017) partly oppose the continuous growth as predicted by both airline manufacturers, due to limited growth of the share of infrequent flyers. Airbus (2017) and Boeing (2016) are presenting the trend on the aviation market; last year European carriers grew by 4.8% (Revenue Seat Kilometer), whilst their capacity grew by 5.0% (Available Seat Kilometer). Airports, considered the bottleneck for the air traffic system already (European Commission, 2011; Helm et al., 2013) are to cope with this projected growth and must find solutions to optimize their capacity. Pels et al. (2003) notice inefficient policies with European airports, but concluded for Amsterdam Airport Schiphol the physical capacity exceeds the environmental capacity. Regardless of infrastructure investments[7], Amsterdam Airport Schiphol is reaching environmental limitations agreed upon with local community[8]. (Royal Schiphol Group, 2016).

Besides environmental limitations, Schiphol's runway and taxiway layout is barely capable to cope with peak demand. If traffic reaches levels close to the maximum throughput of the runway system, then the airport cannot accommodate future growth anymore. Schiphol's peak demand is the result of two causes: (1) the concentration in time of traffic due to activity patterns of passengers and (2) the concentration of routes due to Schiphol's hub function for KLM resulting in trunk and feeder routes. (Gelhausen et al., 2013)

Congestion, if present, impacts multiple sides of airport operation: (1) airports cannot accommodate any growth and IATA Level of Service are likely to deteriorate, (2) delays will occur more frequent, and (3) workload for air traffic control and ground handlers will increase. Cook et al. (2009) distinguish two cost types to delays: hard costs and soft costs. Hard costs resulting from passenger delays, such as passenger rebooking, compensation and care. Soft costs are related to the passenger's perspective of the airline and airport performance.

Gelhausen et al. (2013) describe multiple measures to overcome congestion: (1) by changing air traffic control regulations as a result of technological progress to increase movement rate on runways. (2) Airlines can alter flight schedules to shift demand to off-peak, or to neighboring airports with capacity reserves. (3) Additionally, airlines can operate aircraft with more seats without increasing frequency. Finally, (4) infrastructure investments can be made to increase capacity.

Jacquillat & Odoni (2017) offer solutions to balance over-capacity scheduling by airlines through

[7]Amsterdam Airport Schiphol added a 6^{th} runway to enlarge capacity at the time of publication of Pels et al. (2003)

[8]Maximum 500.000 air traffic movements till 2020: environmental limitation, part of the Alders-agreement. In 2016 Amsterdam Airport Schiphol had 479.000 air traffic movements.

schedule coordination, congestion pricing and slot auctions. However, each demand management scheme is a trade-off between mitigating congestion and maximizing capacity utilization. Jacquillat & Odoni state "demand management mechanisms can be supported by advanced models that flexibly optimize the scheduling interventions, based on underlying objectives, rules and procedures."

A broad perspective towards travel, like Flightpath 2050's vision of seamless door-to-door travel, proposes intermodal connectivity on both physical and management level. In other words, the modalities should be connected physically, like a road or train connection at the airport, but should also include collaboration between the different stakeholders of the modalities. Milbredt et al. (2017) and Krain et al. (2017) suggest involving the rail network provider from a passenger centric approach. Xia & Zhang (2017) and Albalate et al. (2015) suggest air-rail cooperation may be encouraged at severely capacity constraint hub airports, e.g. for feeder services. EUROCONTROL's air travel perspective, through SESAR2020 (a joint initiative started in 2006 with SESARJU) focuses on a holistic airport[9]. Total Airport Management (TAM) considers the airport as one node of the overall air transport network. By improving predictability (Spies et al., 2008), available resources might be used in an optimized way and overcapacities can be reduced or prevented. (Günther et al., 2006)

Papenfuss et al. (2017) evaluate the concept for cooperation in an Airport Operations Center (APOC), a SESAR2020 initiative to support TAM. DLR[10] revealed, through job shadowing, a lack of information exists regarding coordination between stakeholders. Moreover, consequences of one's own actions are unclear. The APOC satisfies the need for cooperation through (1) a shared and valued goal, (2) a coordination of resources, tasks and decisions, especially regarding their timing, and through (3) participation and contribution to a shared task fostering cooperation.

Schulze Kissing & Bruder (2016) indicate in their research that roles and scenarios within an APOC should be pre-defined, and improvising should be brought to a minimum to ensure consistency. Moreover, Schulze Kissing & Bruder define the necessity of a shared goal for APOC to be a success. (Newton, 2017, p. 518) surpasses this necessity by stating "It is hard to overstate the importance of shared intentions to human behavior. Recent work in development psychology has shown that from early childhood, human subjects display the ability and desire to engage in collaborative activities."

In the current logistics industry different drivers for collaboration are to be recognized. It primarily occurs as a result of competitive dynamics, encouraging organizations to utilize resources and competences of other organizations to create customer value together. To collaborate is informed by long-term returns on investments such as potential cost savings, improved customer service, better decision making and innovation.

"Drivers, enablers and inhibitors are factors that may affect the collaborative processes during formation, implementation, ongoing management and cessation." Trust, reciprocity, experience and routines are all influencing the outcome of collaboration. (Pateman et al., 2016, pp. 33-35)

[9]A holistic airport focuses on the airport as a node in the European system of airports. The holistic approach implies both airside and landside processes are managed in one center.

[10]DLR: German Aerospace Center DLR

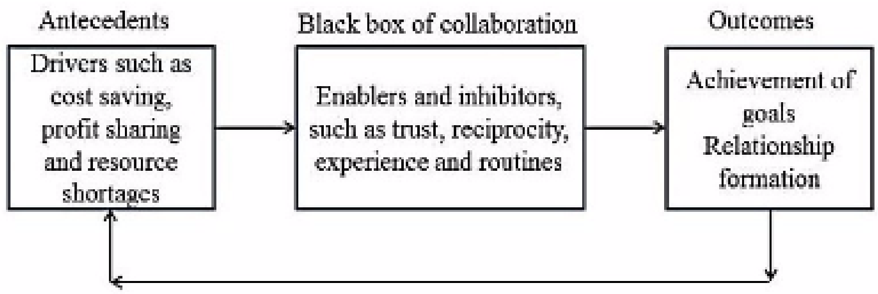


Figure 4: Interactions in a collaborative venture. (Pateman et al., 2016, p.35)

The collaboration in an APOC is ultimately judged by its efficiency to counter capacity constraints at the airport. The concept of total airport management is still to develop to a stage where total airport performance can be measured efficient. Current performance measures are conducted for either landside or airside performance. Gillen & Lall (1997, p. 272) split these processes, although conditionally related, because they have different production technologies and different strategies available to them.

Landside (terminal) efficiency raises, when: (Gillen & Lall, 1997, pp. 270-271)

1. gate capacity is expanded and correctly managed,
2. the airport has a hub airline (or multiple hub airlines),
3. greater proportions of travelers are international passengers, or
4. less baggage belts per gate exist, supposedly through a less complex baggage system.

Airside efficiency raises, when:

1. general aviation is reduced,
2. gate capacity is expanded, and
3. impact of noise regulations is reduced, by: (a) using a preferential flight path, or (b) limiting the hours of operation.

Gillen & Lall (1997) further suggest the use of data envelopment analysis to assess the performance of management of transportation infrastructure. This methodology can be used when the outputs are not easily or clearly defined; for example in determining the efficiency of firms that consume or produce inputs or outputs, which lack natural prices.

Zografos & Madas (2006) explain the importance of data. The content of the data, however, is dependent on the key performance areas to be measured and indexed. The performance areas as mentioned in Helm et al. (2014, p. 64), proposed by EUROCONTROL are:

- traffic volume and demand,
- capacity,
- punctuality,
- efficiency, and
- predictability.

Helm et al. (2013, p. 7) define selection criteria for steering KPIs on the airport landside, which can be applied to both airside and landside KPIs. These selection criteria state the KPI should be of significance, measurable, available and real-time applicable. Examples for landside KPIs are delay, level of service, left behind index (baggage and/or passengers), utilization and economics (e.g. costs of terminal processes). Helm et al. (2013, pp. 8-14)

With aforementioned KPIs Helm et al. (2013) expects not just benefits to the overall system performance as a result of covering all major aspects of terminal processes, but also to all stakeholders involved. When expanding landside KPIs with airside processes within the total airport management, additional advantages can be expected according to Depenbrock et al. (2012).

Merchant (2011) describes one of the eight (perceived) dangers of collaboration to be the threatening idea of a free flow of information. Therefore, it is important to create a flow of information accepted by all the stakeholders. A possible solution is the usage of metadata or, when gains are not balanced, establishing a revenue-sharing construction to motivate each stakeholder to share information efficiently and in a timely manner. Rached et al. (2015, p. 252) An important conclusion by Rached et al. (2015) is that results clearly indicate that cooperation mechanisms and incentives should be made possible, since they benefit both parties and lead to a balanced repartition of resulting gains, thus supporting one of the fundamental pillars of the airport operations center.

To conclude, Europe is challenged by capacity limitations for airports, resulting in congestion both on the airport and in the air. The European Union and EUROCONTROL acknowledge this challenge and have designed solutions to overcome these limitations. The solutions aim to enlarge capacity and improve the current usage of available capacity. With this in mind, the total airport management philosophy was designed.

The airport operations center is the physical translation of a total airport management control center. The main characteristics for an APOC (*ergo* total airport management) are:

- Including all airside and landside processes (terminal and apron)
- Continuous data sharing amongst all partners
- Planning and simulation tools to support decision-making

In order for an APOC to succeed, the following should be unconditional:

- The role and function of an APOC should be agreed upon.
- (Live) Data sharing between all stakeholders
- Planning and simulation tools should have been proven trustworthy.

When Schiphol airport would implement an APOC, its process could drastically change. More accurate predictions and simulations can support the decision-making processes, with benefits to all stakeholders. By minimizing the effects of operational decisions and/or disruptions, costs can be saved and capacity can be managed more efficiently.

4 EUROCONTROL: Total Airport Management

EUROCONTROL envisions an airport operations center to optimize capacity at airports. By providing insight in the European effort through the SESAR-program to overcome air traffic management challenges, the necessity of implementing an APOC becomes evident.

EUROCONTROL focused on optimizing airside processes, coming up with Airport Collaborative Decision Making. The next step after CDM, according to the SESAR 2020 vision, is total airport management. It entails the implementation of all airport processes, both airside and landside, in the future ATM system.

4.1 Airport Collaborative Decision Making

The principle of Airport Collaborative Decision Making (A-CDM) is stooled on improved information sharing and data quality: "the right airport partners getting accurate data at the right time in the right place in order for them to make decisions while working together." (Günther et al., 2006, p. 8) The principles of A-CDM cover the full trajectory of the airplane: a thorough plan to create insight in the *arrival-, turnaround- and departure phase.*

> Initially, flight plan information is shared against airport slot data. Arrival estimates can be improved using the Flight Update Messages provided by the CFMU[11]. These messages combined with local radar sources and tools such as the arrival manager (AMAN) provide assigned arrival times.
>
> The turnaround phase, defined as the time between on-blocks and off-blocks, is known for its tendency to result in delays . By showing partners updates on the progress towards the Target Off-Block Time (TOBT), stand allocation and pre-departure sequencing can be optimized.
>
> The departure phase can be semi-automated with the use of departure manager (DMAN) and surface manager (SMAN). These tools, combined with the AMAN and available information on runway configurations and weather, can provide accurate Target Take-Off Times (TTOTs). Ultimately used for predicting accurate flight profiles and reducing the time a controller spends on planning.

The philosophy of airport collaborative decision making has had a significant impact over the past decade on reducing and/or stabilizing delays due to ATC. However, since air traffic demand is growing and expected to do so *(see literature review p. 16)*, new concepts for airport operations are developed.

[11] The Collaborative Flow Management Unit (CFMU) was replaced in 2011 by the Network Manager Operations Center (NMOC).

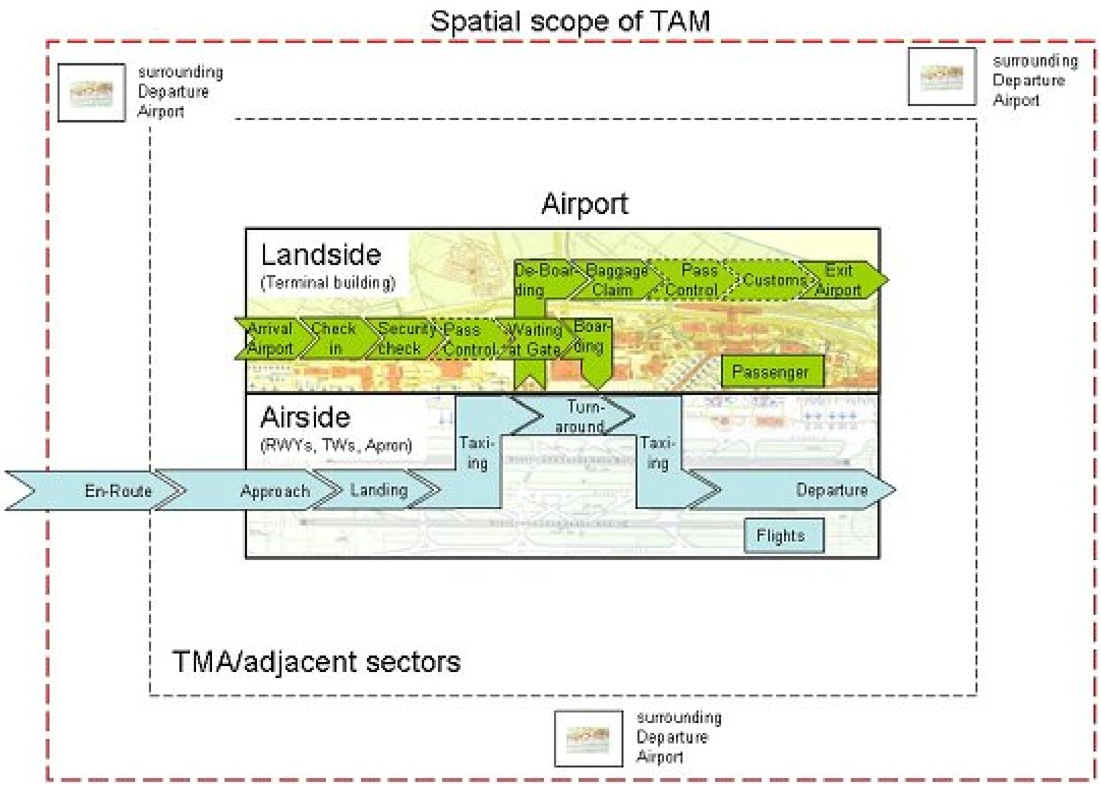


Figure 5: Spatial scope of Total Airport Management, (Günther et al., 2006)

4.2 Total Airport Management

Figure 5 shows the spatial scope of total airport management (TAM). It includes all airside processes from 'enroute-to-enroute', and all landside processes from 'curb-to-gate' and vice-versa.

> *"TAM considers the airport holistically as a node of the overall air transport network. In order to ensure an overall Quality of Service (QoS) of an airport to the customers and to the air transport network, TAM concentrates on the initial strategic and pre-tactical planning phases using the most accurate information, followed by the monitoring (and when required, reactive planning) of the tactical working process."*
>
> (Günther et al., 2006, p. 12)

The customer-centric approach of TAM to the air transport network is used to enable seamless travel for the customer. Seamless travel is related to fewer air- and ground delays, a high predictability, and a stable and robust air transport network. TAM is tasked with breaking down Quality of Service contracts from the network to individual activities of all the airport actors. TAM gives the opportunity to realize a new way of communication. Through the extension of A-CDM to TAM challenges of other actors become visible. The airport operations center is the physical (or virtual) realization of this collaboration. The following SESAR initiatives supporting TAM are explained in Appendix B, because of their strong link with the APOC initiative:

- system wide information management (SWIM),
- extended horizon functionality of AMAN,
- performance based navigation in high density TMAs,
- automated assistance to controller for surface movement planning and routing,
- flexible use of airspace, and
- time-based separation for final approach.

4.3 Airport Operations Center

In 2006, EUROCONTROL & DLR first envisioned an airport operations center (APOC) to manage all airport processes both on the apron and in the terminal. This center should combine information from airport actors to increase predictability and improve decision making. The temporal focus of APOC would be mainly strategical and pre-tactical. On the day of operations, decision making is left to the individual control centers. The defined roles and responsibilities for the APOC in 2006 can be used as a guideline for the 2018 Amsterdam Airport Schiphol APOC.

Strategic	$t_{+4d} \rightarrow t_{+6m}$
Pre-tactical	$t_{+4h} \rightarrow t_{+7d}$
Tactical	$t_0 \rightarrow t_{+4h}$

Time horizons of an APOC

4.3.1 Airport operations center Amsterdam Airport Schiphol

The ***spatial scope of the airport operations center*** as described figure 5 does not change, it focuses on:

- Terminal processes from curbside-to-gate and vice versa, including observations of intermodal hub functionality, like train delays or traffic jams.
- Airside processes from the moment aircraft enter area control center airspace (ACC) till the moment they leave ACC airspace. This includes gate control, full turnaround processes, and special operations like de-icing.

The ***temporal scope of the airport operations center*** predominantly includes the tactical phase, and partly covers the pre-tactical phase. The strategic phase of operations is not part of the day-to-day airport operations center.

Options to extend the time horizon of the APOC in the future must be kept open. Once collaboration intensifies, more in-depth operational choices may be based on collaborative strategies and long-term goals.

4.3.2 Challenges to the implementation of an APOC at Schiphol

Literature review explains difficulties for the implementation of an APOC. First off, the success of an operations center for the airport is determined by the collective willingness of airport actors to strive for a common goal (or goals). A high uniformity is desired in the approach of different airport scenarios. This uniformity can be reached through prescribed strategies, guidelines, and a clear role distinction.

Currently, Dutch politics pursue a mainport strategy which focuses on the hub-function of the airport. A common goal like striving for an optimum usage of runway capacity during peak hours is conceivable for all stakeholders. The implications of such a goal and its related constraints to all stakeholders should be understood and agreed on. Only then, collaboration has the chance to succeed.

The decision-making process in the airport operations center should be autonomous. Decisions must overrule control centers of individual stakeholders, in order to manage capacity orderly. By using planning and simulation tools, the APOC can provide an orderly and constant flow of traffic. This lowers workload for operators and secures the stability of the airport system.

4.3.3 Schiphol actors for the APOC

The following stakeholders should at least be joining the airport operations center at Schiphol from the start in order to make the APOC a success:

Category	**Description**
Airlines	KLM, Transavia & easyJet
Airport	The Schiphol Group
ANSP	ATC the Netherlands (LVNL)
GHA	KLM Ground services, Aviapartner & Swissport
Meteo	KNMI

Table 1: The minimum required stakeholders for the first version of an APOC at Schiphol

To conclude, EUROCONTROL's APOC from 2006 is altered to the new standard in air transport. It is the main support tool for total airport management: bringing together main airport actors to collaboratively decide on capacity measures, supported by simulation and planning tools.

5 Predictability & stability in airport operations

Resource allocation, both manpower and material, is crucial for a fluent operation. Hiccups in planning can cause a large effect on operations due to the 'ripple' effect. To create a stable planning, one which is not easily disrupted, slack should be incorporated in the planning and inescapable disruptions to the systems should be known as early as possible to mitigate its effect.

Each of the three partners of the KDC draft their planning based on a demand on the planning horizon, essentially optimizing backwards in time. This chapter is divided in three sections; (1) planning processes, (2) causes of TSAT instability, and (3) TSAT instability quantified.

5.1 Resource allocation at Schiphol, KLM and LVNL

Air space capacity determined by workload air traffic controllers
The operational planning for LVNL determines the required number of air traffic controllers per sector. The demand is a derivative from the requested flight plans for a certain time frame (obviously linked to airport slots). This demand is translated to a certain workload, and is subsequently translated to a number of air traffic controllers per sector, defining the available capacity.

If however conditions at the airport change for the worse, LVNL reduces their declared capacity, and asks NMOC (Network Management Operations Center) to set restrictions for inbound aircraft, to prevent a logistical deadlock due to a gate and apron shortage and manage workload.

ATFCM (Air Traffic Flow & Capacity Management) delays work both ways, and can also be activated by EUROCONTROL to prevent a certain airspace from overloading, ensuring safe air management at all times. ATFCM measures might result in imposed ground delays for aircraft situated at Schiphol (in which case a new timeslot for the flight will be imposed: CTOT, Calculated Takeoff Time, *see the conceptual model on p. 12*). Through this way, ATFCM measures and weather conditions affect the workload of air traffic controllers, in turn determining the available capacity of the system from the perspective of air traffic control.

Resource allocation determined by TSATs departing airplanes
For the operations departments of both KLM ground services and Schiphol, resource allocation is determined by the number of airplanes on the ground, and their respective target start-up approval time (TSAT).

Plan stability is defined as the ability of the planning to cope with disruptions, and to minimize the magnitude of a 'ripple'. The ultimate goal for all stakeholders is a predictable and stable operation, thus minimizing the fluctuations in TSATs.

Unfortunately, the calculations of TSATs at Schiphol, an output generated by the outbound planner (sequencing algorithm, or 'sequencer') is currently an unstable process due to the complex logistics at Schiphol airport (due to its runway layout with 6 runways and its constantly changing usage due to environmental agreements and weather influences).

5.2 Multiple causes to TSAT instability

The irrefutable importance of a stable TSAT calculation to the airport system seems self-explanatory. But to illustrate the complexity of TSAT instability, this section will elaborate on the causes:

1. Runway configuration alternating,
2. Weather influence,
3. Target off block times (TOBT) changes,
4. ATFCM measures: imposed ground delays.

5.2.1 Calculations based on current runway configuration

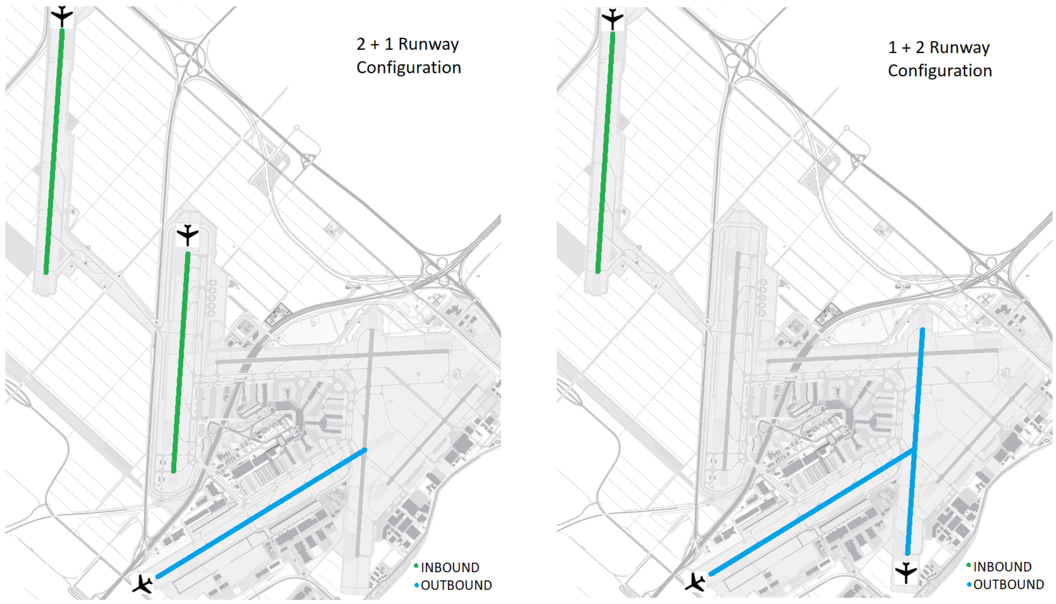
The current outbound sequencing algorithm (CPDSP) calculates TSAT based on the current runway configuration only. To illustrate the problem; during an inbound peak (figure 6a), the TSATs are also calculated for the subsequent outbound peak (figure 6b). Thus, the available capacity for starting aircraft used in the calculation of TSAT is strongly reduced, resulting in TSATs for departing aircraft further in the future than the actual start-up time to be expected, considering the change in runway configuration.

Adding to the complexity, is the varying use of runway configurations at Schiphol. Schiphol has one of the most challenging and complex run- and taxiway systems in the world, and agreements with the adjacent municipalities in the Alders agreement on air traffic movements and on runway usage limit the endless usage of runway combinations. Combined with traffic patterns these limits will result in a varying use of runways, directly impacting Schiphol's operational stability.

LVNL is aware of this problem and the development of a new departure management module (sequencing algorithm) is in progress.

5.2.2 Weather conditions' influence on TSATs

Weather is only predictable to a certain degree, but its effect on airport operations can be grand. Capacity of runways is partially determined by the interdependency of runways, and partially by weather conditions on the ground. Both visibility and the wetness of a runway can limit the maximum capacity of the runway. Thus changing the maximum number of traffic movements to be planned, and in turn changing the TSATs for outbound flights.



(a) 2 + 1 Runway configuration (b) 1 + 2 Runway configuration

Figure 6: Example runway configurations at Schiphol airport

5.2.3 Target off block time changes

Changes to the target off blocks time (TOBT) are impactful in regard to the airport system and stable TSATs. The next chapter will explain the impact of TOBT management on the airport system.

5.2.4 ATFCM measures: imposed ground delays

ATFCM measures impact the plan stability of Schiphol, since imposed ground delays by NMOC trigger a recalculation of the TSATs. The imposed ground delay ends at the calculated takeoff time (CTOT), thus the new TSAT for the delayed flight equals the CTOT. The vacated takeoff slot will be reassigned to the flight with the lowest target takeoff time (TTOT), after the CTOT slots have been assigned.

5.3 Quantifying TSAT instability

TSAT instability is elucidated in three ways: (1) the distribution of TSATs per flight (2) the correlation with weather conditions, and (3) traffic related instability in peaks.

5.3.1 Distribution of TSAT per flights

Noting the traffic figures for the researched datasets are more or less stable during the week (Monday-Friday), the average number of unique TSATs per flight should stable. Table 2 shows the average number of unique TSATs per flight, specified per day. The desired average should be as close to 1 as possible.

Date	**Number of flights**	**Average number of unique TSATs**
Monday August 14, 2017	808	16
Tuesday August 15, 2017	792	26
Wednesday August 16, 2017	778	31
Thursday August 17, 2017	804	17
Friday August 18, 2017	808	19
Saturday August 19, 2017	718	18
Sunday August 20, 2017	788	16
Monday September 4, 2017	815	18
Tuesday September 5, 2017	787	14
Wednesday September 6, 2017	777	24
Thursday September 7, 2017	797	17
Friday September 8, 2017	808	27
Saturday September 9, 2017	699	18
Sunday September 10, 2017	762	18

Table 2: Average unique TSATs per flight
Datasets: CDM log data, periods August 14-20 (5496 flights) & September 4-10 (5445 flights)

5.3.2 Time domains of TSAT instability

To identify instability of the TSAT calculations, it is only partly insightful to have the average number of unique TSATs, as provided in table 2. The picture is colorized only after the deviations of the TSATs are mapped (figure 7).

Figure 7 is a standard box and whisker plot, whereas the box identifies with 50% of the data points analyzed. The whiskers represent respectively the upper quartile and lower quartile of the data points. Note the spread of TSATs (specifically 2^{nd} and 3^{rd} quartile) on especially August 16 and September 8. A high spread (large box) represents a high uncertainty of the TSAT.

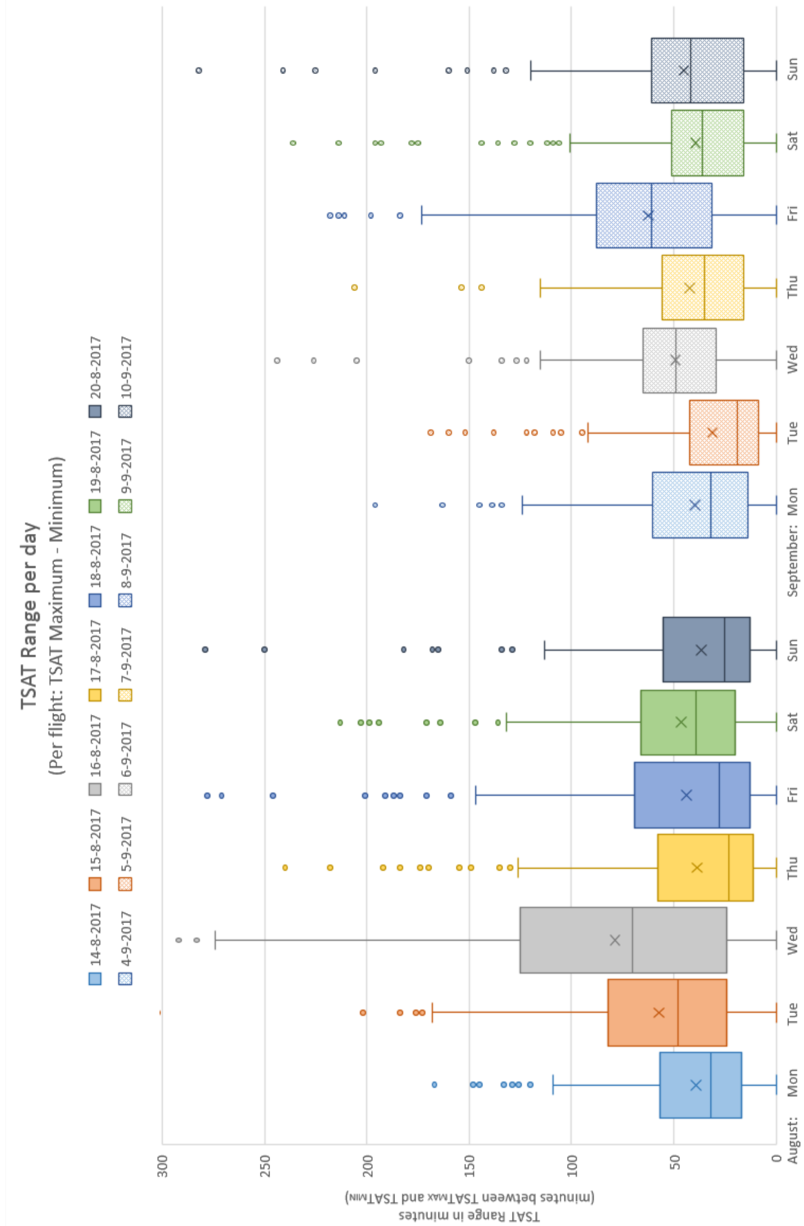


Figure 7: Average TSAT Ranges in minutes per day explaining inaccuracy of the TSAT
Datasets: CDM log data, periods August 14-20 (5496 flights) & September 4-10 (5445 flights)

5.3.3 TSAT instability decreases towards EOBT_i

TSATs become more accurate over time, closing in on theEOBT_i. Even minutes from EOBT_i, TSAT is still deviating from schedule (EOBT_i). Figure 8 shows the inaccuracy of the TSAT at Schiphol over time, from three hours before until EOBT_i. Analyzing the figure, both the domain and the average declaine approaching EOBT_i. However, at the moment of EOBT_i, the TSAT still deviates approximately 11 minutes to EOBT_i.

5.3.4 Clear link between weather conditions and TSAT instability

An explanation for instability can be found in the causes of disruptions. The original datasets were selected based on two disrupted days (by weather), parallels can be identified in the TSAT instability. Even though traffic numbers are roughly similar, four days deviate:

- Tuesday August 15, 2017
- Wednesday August 16, 2017
- Wednesday September 6, 2017
- Friday September 8, 2017

EUROCONTROL DDR data provides us with insight on the delay circumstances for these days. Table 3 *(see p.29)* shows regulations in the Dutch FIR for the days, and the assigned reduced capacity.

Date	**Most penalizing restriction**	**Reduced capacity**	**Regular capacity**
Tuesday August 15, 2017	Airport Capacity *(EHAMA15A)*	21	68
Wednesday August 16, 2017	Weather *(EHAMA16M)*	21	68
Wednesday September 6, 2017	ATC Capacity *(EHARTIP)*	30	*N.A.*
Friday September 8, 2017	Weather *(EHAMA08E)*	33-60	68

Table 3: NEST extract showing the most penalizing regulations for EHAM

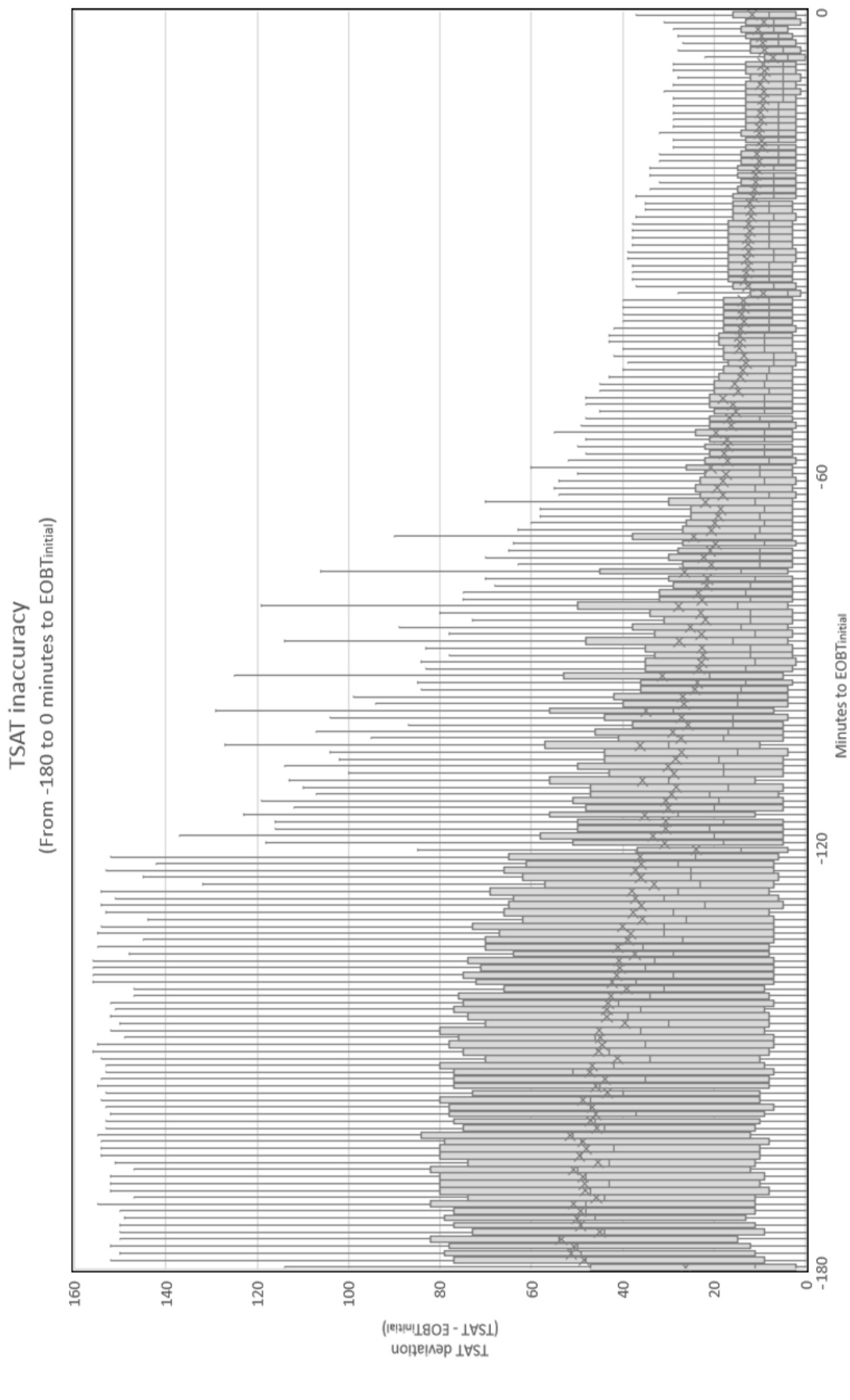


Figure 8: TSAT inaccuracy towards $EOBT_i$ (scale from -180 to 0 minutes to $EOBT_i$)

August 16 & September 8 affected by adverse weather conditions
Both August 16 and September 8 put EHAM in the top-15 most regulated European restrictions due to weather. This is confirmed with KNMI actual weather data, these days the airport experienced limited visibility, constraining operations through limited runway capacity.

Verification with data from the KLM FIRDA-system acknowledges weather related delays for August 16. For September 8, delays are mainly categorized as network function-related delays.

August 15 & September 6 affected by airport and ATC capacity
The network function of KLM too provides the majority of the delays in FIRDA for August 15 and September 6. It does however show a portion of delayed flights due to 'ATFCM restrictions, due to ATC en-route demand/capacity, standard demand/capacity problems'. These delays are less far-reaching than the impactful weather delays.

To conclude, plan stability is the ultimate goal for all stakeholders regarding capacity management. Currently, allocation of resources is based on the TSATs calculated by the CPDSP. The TSAT is not a good predicting variable to the actual operations. It deviates enormously due to multiple factors like runway configuration, weather, TOBT management and ATFCM measures, with an inaccurate TSAT as a result.

6 Actors' influence on airport system

Previous chapter has proven the CDPSP (outbound sequencing) algorithm unstable. Some of the issues can be explained by the structure of the algorithm, and the procedures it follows to calculate target takeoff times, and subsequently target off block times. A more detailed breakdown analysis of CDPSP triggers can be found in Appendix D. This chapter will focus on the influence of system actors on the airport system and its output. Also, it will explain how an APOC would change the situation.

6.1 Actors unknowingly influence the CPDSP system

When the CPDSP algorithm is broken down into unique events triggering recalculations of takeoff times, it is important to remind us of the triggers for recalculation as mentioned in previous chapter.

When the aircraft is in blocks (AIBT = actual in blocks time) the TOBT reflects the ground handling agents perception of the minimum feasible off blocks time. This time should be updated to reflect the actual expectation.

Changes to TOBT by the ground handler can trigger a CPDSP recalculation in two ways (schematic of the changes and type declaration are added in Appendix D):

1. $TOBT_n$ is earlier in time than $TOBT_{n-1}$
2. $TOBT_n$ is later in time than $TOBT_{n-1}$ & $TOBT_n$ exceeds the TSAT

All TOBT changes where [$TOBT_{n-1} < TOBT_n <$ TSAT] applies, no recalculation will be triggered. However, if a new calculation by the CPDSP algorithm is triggered by another token, this calculation will use the newly set TOBT value as input to the sequencing algorithm. The new TOBT values used for calculation might alter the sequence and the assigned TSAT.

The following figure shows CPDSP recalculations where the system was triggered by a type-1 TOBT change. The identification of multiple patterns in this data leads to the acknowledgement of behavior (either from the system itself, or from the users of the system).

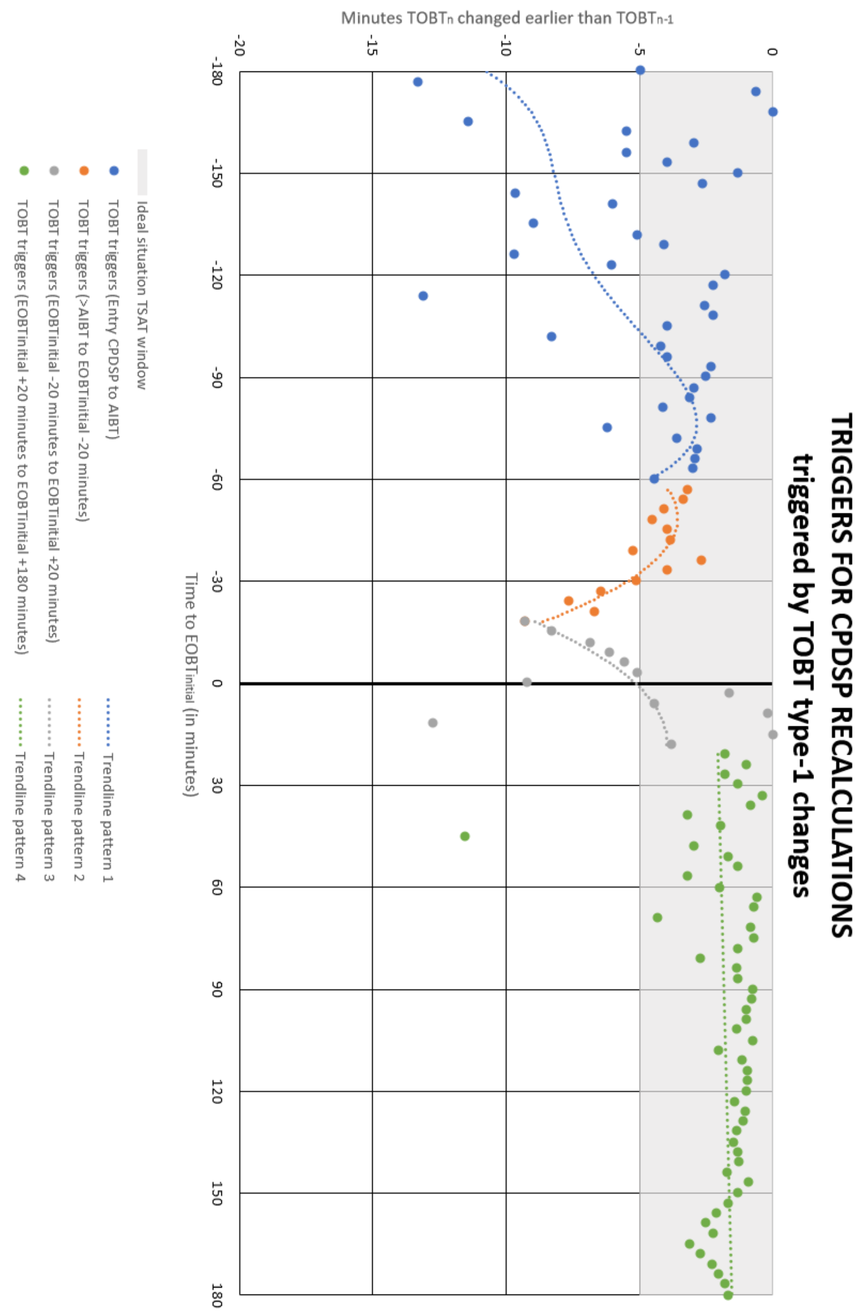


Figure 9: TRIGGERS FOR CPDSP RECALCULATIONS: TOBT Type-1 updates to the system

The figure shows 4 patterns:

1. [BLUE] From entry in CPDSP to Actual In Blocks Time
2. [ORANGE] From Actual in Blocks Time to 20 minutes to $EOBT_i$
3. [GRAY] From 20 minutes to $EOBT_i$ to 20 minutes past $EOBT_i$
4. [GREEN] From 20 minutes past to 3 hours past $EOBT_i$

The blue pattern shows the bottom half of a normal distribution of deviations in the flight plan during operations, since only situations where $\mathrm{TOBT_n} < \mathrm{TOBT_{n\text{-}1}}$ are shown. These deviations in flight times are natural occurrences due to an indefinite amount of variables constantly affecting total flight time. These deviations translate to the TOBT, since in ideal turnaround[12]:

$$TOBT = ELDT + EXIT + MTT \tag{1}$$

These deviations have an undesired effect, grounded in the algorithm's choice to link new entries to the sequence, despite knowing the fluctuation behavior of ELDT.

The orange and gray patterns represent normally distributed alterations to the TOBT by the ground handler, in favor of the airline, possibly granting an earlier takeoff time.

The green pattern, however, shows the undesired outcome of ground handling agents micromanaging the TOBT to be as accurate as possible. Every alteration of the TOBT within TSAT window should be brought to a minimum. The TSAT call-up window provides the required flexibility, by offering an "early ready call", from $\mathrm{TSAT_{\text{-}5}}$ to TSAT.

Explanation of identified behavior is found in training content
In current CDM-training, ground handling agents are isntructed to update the TOBT as frequently as necessary to stay accurate. Unfortunately, ground handling agents are overdoing TOBT management, resulting in undesired micromanagement. Since training brought awareness for management of the TOBT, training should contribute to the awareness of consequences of micromanagement.

6.2 Actors deliberately influence the CPDSP system

Previous paragraph discussed the unconscious influence of actors on the CPDSP sequencing algorithm. It would be witless to think there would not be deliberate misuse of the system. Anecdotal evidence suggests airlines deliberately misuse the system to their advantage.

Certain airlines[13] found the design weaknesses in the sequencing algorithm and use them to their advantage.

They manually change their TOBT to an impossibly early TOBT, knowing they will not meet the set target. This ensures the TSAT to be linked to their TOBT. When they eventually change the TOBT to a realistic target (using multiple TOBT updates), the assigned TSAT is much lower than in the normal process.

[12] Estimated Landing Time + Estimated Taxi In Time + Minimum Turnaround Time

[13] Since it has not been possible for the researcher to prove the cases mentioned in anecdotes due to time constraints, the airlines are not mentioned by name.

Currently there are no rules (from the airport) which prevent this behavior, and the deliberate misuse of the system goes unpunished. When a new sequencing algorithm comes in place, a new set of rules can be designed. For example, lowering the sequencing priority for airlines low on accuracy, therefore rewarding the airlines who present desired behavior.

6.3 Improvement of behavior with APOC

This chapter has indicated influences of airport actors, deliberately or undeliberately influencing the system resulting in unpredictability and instability of the airport system. The question arises whether implementation of an APOC would overcome this instability. Undeliberate influences of airport actors result from unawareness of the consequences of their actions. Whereas deliberate influences are driven by policy or individual beliefs, approving of behavior, placing their needs and gains above the efficiency of the system as a whole and above all of her users.

Unawareness of consequences overcome in APOC
The consequences of actions, justified by true intentions to act optimally to both the own organization and the system as a whole, become clear to all stakeholders in an APOC. Since the relationships are intensified due to the collaborative setup of an APOC, organizations are less restrained in communicating their concerns. The post-operation analysis performed in the APOC would bring up causes to undesired effects on the operation, like the micromanagent example above.

Deliberate misuse of system less likely in APOC
The deliberate misuse of the system, like the airline example above, is a risk of collaboration (on any level) which will not necessarily be overcome when an APOC is implemented. Egocentricity is always a risk when collaborating, but there are means to overcome the outcome of the influence: trust and formal contract. (Jiang et al., 2015)

By means of trust, parties believe in the shared intentions of all stakeholders, to use the airport system to the intended purpose, without intentional impairing anothers' operation. Since in an APOC actors are more dependent on each others' information sharing, egocentricity is less likely, and trust is built. The peer pressure related to collaboration, has the tendency to increase productivity, as long as the compensation is team based. (Sotiris Georganas et al., 2015)

Formal contract, or formal rules of conduct, is a means to enforce desired behavior of airlines. In the case of the intentional misuse of the design flaw in the CPDSP algorithm, changing the sequencing algorithm might suffice to enforce good behavior in future.

To conclude, currently airport predictability, and therefore airport capacity management, is influenced by the actors' behavior towards the system. The transition to an APOC would reduce the degree of unawareness, improving capacity management at Schiphol airport. Intentional misuse of the system would still be possible in future. But when good behavior is rewarded (and the reward is high enough), the outcome is likely to be desired behavior.

7 Airline' influence on airport system

No airline in the airport system wants delays, but delays are inevitable. They should be minimized, as should their impact to the system it uses. This section explains the EOBT updates, and their impact on the European network.

An EOBT change is a manual input from the airline updating the estimated off blocks time of the aircraft at the gate. In essence, it is a correction by the airline to the $EOBT_i$ for incurred delay in the ground handling process, or for an insurmountable inbound delay[14]. The result of each EOBT change is an update from the input data to the EUROCONTROL process *(see conceptual model on p.12)*. Therefore, each EOBT change must be updated as early as possible, to minimize the erroneous inposing of CTOTs.

7.1 Timing and frequency of EOBT changes to the system

The timing of EOBT changes in respect to $EOBT_i$ has an effect on the stability and predictability of the system. The effects of late EOBT changes to the system are likely to be weightier than early adaptions of the EOBT.

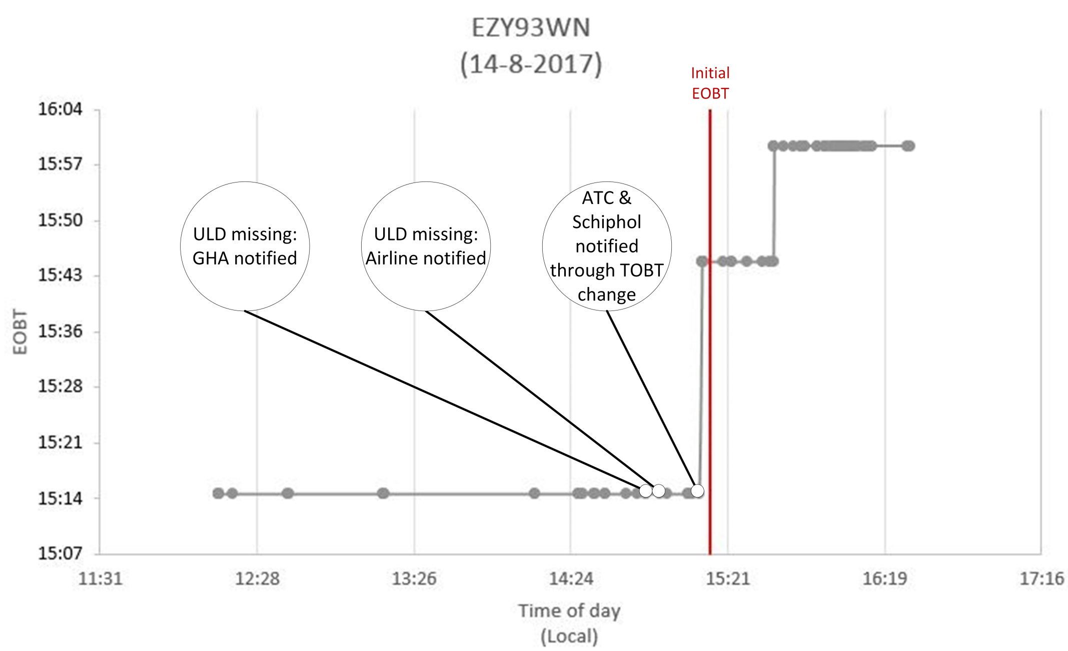


Figure 10: Airline behavior for flight EZY93WN, August 14, 2017

[14]Incurred inbound delay, also referred to as backpropagation delay, is a delay for the outbound flight as a result of delayed inbound flight. Since the processes at turnaround are optimized in terms of time, minimal slack is available to recover an incurred inbound delay. Especially low-cost carriers maximizing the number of legs per day risk this type of delay.

To further illustrate this behavior with a specific flight, figure 10 shows flight EZY93WN from easyJet[15] on August 14, 2017. easyJet altered their EOBT 3 minutes before $EOBT_i$with an estimated delay of 30 minutes. A second EOBT update 25 minutes after $EOBT_i$(5 minutes to new EOBT) was another delay of 15 minutes. Thus changing the input to EUROCONTROL twice, possibly imposing CTOTs.

EOBT changes per airline

It is arbitrary which airline changes their estimated off blocks time, that does not mean however each airline changes it as often. Figure 11 shows the average number of EOBT changes per flight for the top 10 contributing airlines at Schiphol (based on air traffic movements). The bars in figure 11 represent the number of flights, labelled on the leftsided vertical axis. The dots represent the average number of EOBT changes per flight for each airline, the red line represents the weighted average for all contributors.

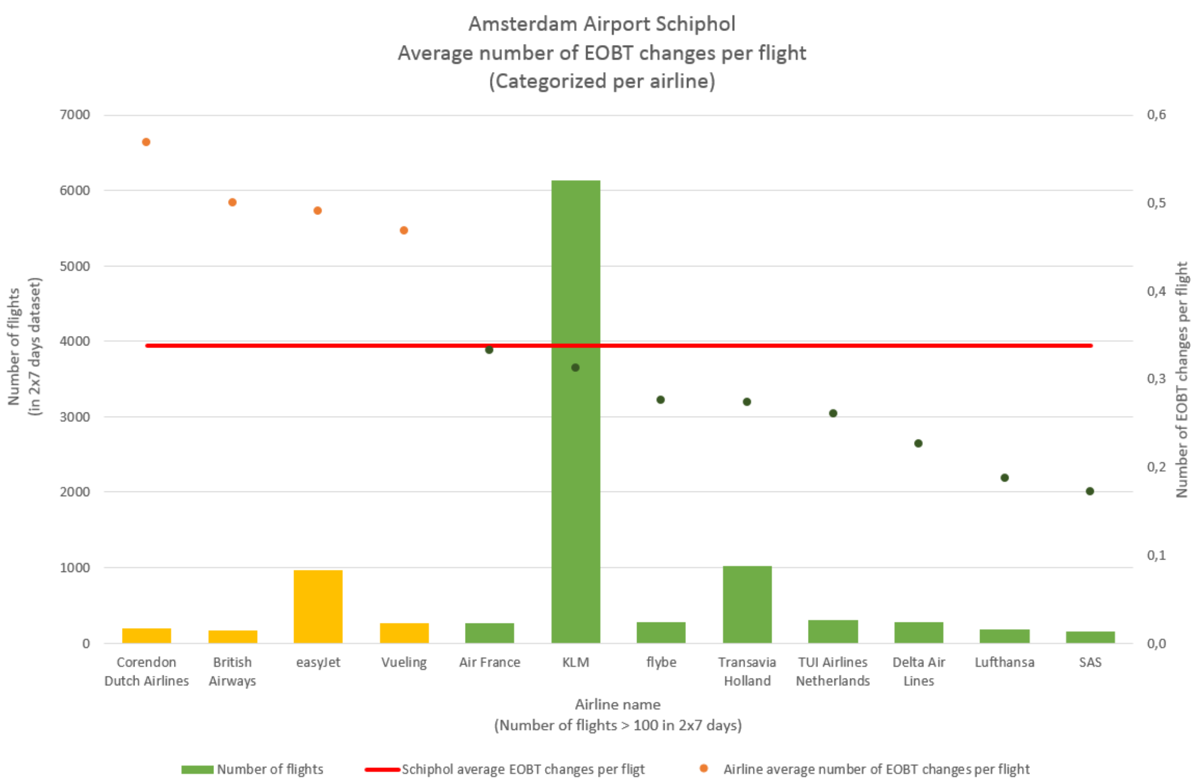


Figure 11: Average number of EOBT changes per flight (categorized per airline), for Amsterdam Airport Schiphol

[15]Note that easyJet flight EZY93WN could be easily interchanged with any other flight from any airline.

7.2 Airline behavior identifiable in the data

To underline the fact that the behavior of late changing EOBTs is not incidental, all EOBT changes are mapped. Figure 12 shows the probability an EOBT will be altered by any of the airlines, in respect to their $EOBT_i$. The light blue dots represent the specific data points per minute. The dotted dark blue line is the floating average for the chance.

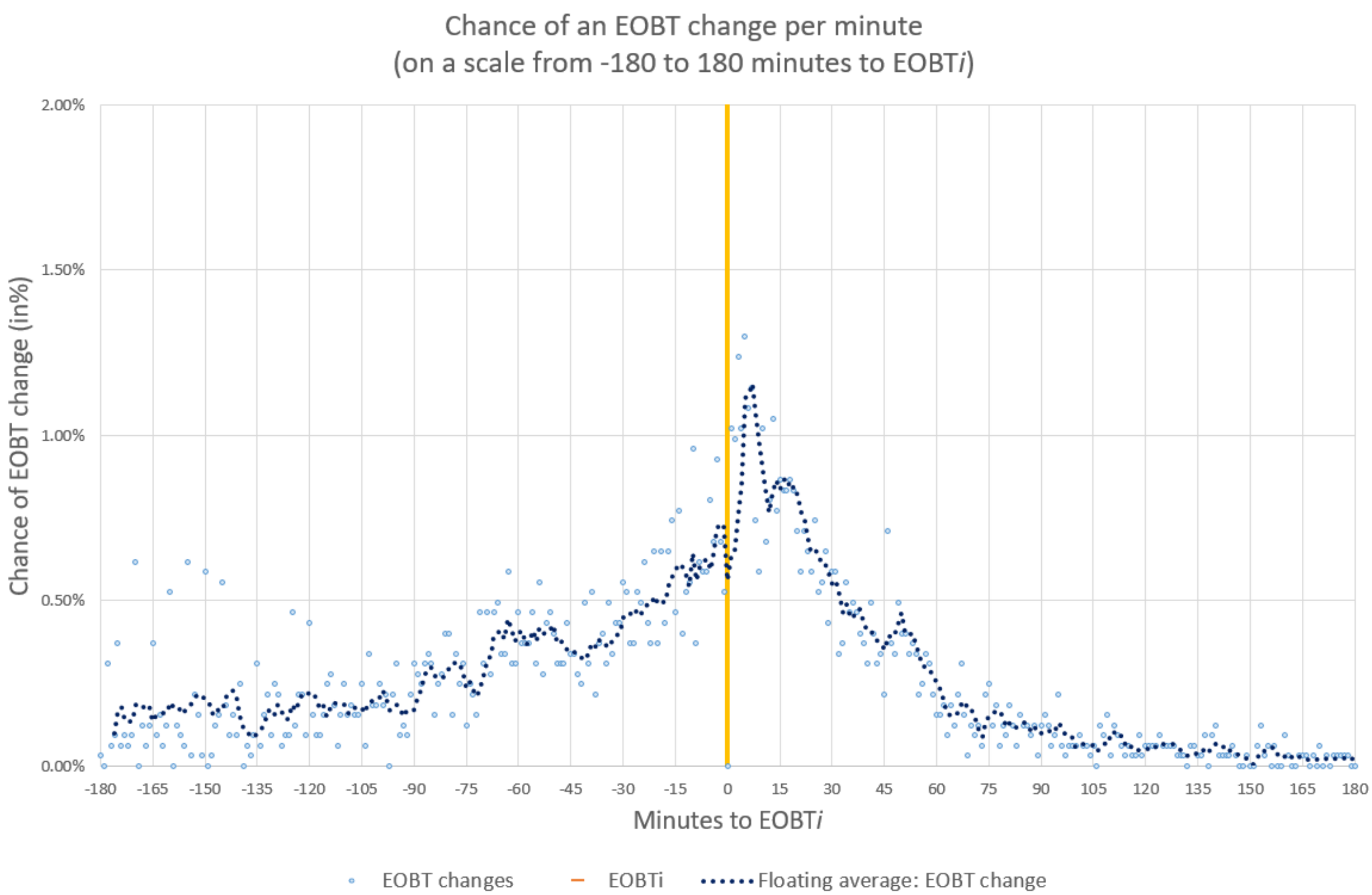


Figure 12: Chance of an EOBT change, in respect to the $EOBT_i$ *(time frame = $EOBT_{i\text{-}180min.}$ – $EOBT_{i+180min.}$)*

Figure 12 suggest EOBT changes are likely to happen close to $EOBT_i$ It must be said that the majority of possible delays are unlikely to result in an EOBT change.

Note the peak is only after the $EOBT_i$, meaning the delay is reported after the flight should have been departed. From the airlines' perspective, it is crystal clear why they would try to avoid reporting a delay early; when the delay would not take place, their slot for departure is lost without a cause, needlessly incurring a startup delay. Although understandable, these EOBT changes should be reported as soon as reasonably possible. Neglecting the importance of timely EOBT changes, is neglecting the system's feedback loop for CTOTs, based on the EOBT input at EUROCONTROL *(see conceptual model, p. 12)*.

7.3 IATA delay code explains moment of EOBT change

As clearly presented in the figures on previous pages, airlines have the tendency to change their EOBT as late as possible, whereas the system requires it to change the EOBT as early as possible.

Table 4 shows the top 15 most frequent delays in the researched dataset, and the moment these delays are passed along through an EOBT change. These delays can be categorized in three types of delays: conditional delays (e.g. weather issues, ATC delays, etc.), (airline) network function related delays (e.g. inbound aircraft delayed), and (airline) network customer related delays (e.g. waiting for passengers).

When analyzing the table, these categories can be identified rather well. Airline network function related delays happen frequent, but are communicated to the system relatively early. Conditional delays are communicated rather late, but are outside the circle of influence of the airline. Airline network customer related delays however are communicated rather late, whilst influential to the system, but are considered more important to the fruitful future of the airline.

To conclude, the EOBT change, the airlines' change to the system in case of a ground delay, is an indicating variable to large disruptions. Through their feedback loop, using the EOBT as input to the EUROCONTROL capacity calculations, they influence the total European air transport system. Since this behavior is expected not only at Schiphol, but at all airports, it is even more important to minimize the late EOBT changes, to minimize the influence of erroneous CTOTs in airport operations.

IATA delay code	Explanation IATA code	#	Minutes to EOBTi
16	COMMERCIAL PUBLICITY/PASSENGER CONVENIENCE, VIP passenger arrangements	7	35
71	WEATHER AT DEPARTURE STATION, below aircraft operating minima	11	32
8	START UP DELAY CAUSED BY ADVERSE WEATHER CONDITIONS	9	22
41	AIRCRAFT DEFECTS, urgent repairs required	19	16
20	BASS DISTURBANCES, break-down or incorrect distribution	10	12
58	OTHER AUTOMATED EQUIPMENT FAILURE	7	10
89	RESTRICTIONS AT AIRPORT OF DEPARTURE WITH OR WITHOUT ATFCM RESTRICTIONS, including startup and pushback delay	14	3
3	MISSING CHECKED IN PASSENGER	29	2
33	LOADING EQUIPMENT, lack of or breakdown, e.g. high loader, conveyer belt	11	0
4	INTERNAL PRIORISATION BETWEEN KLM DEPARTMENTS AT SCHIPHOL	16	0
19	BAGAGGE NOT DIRECTLY CONTROLLABLE	13	0
32	LOADING/UNLOADING CONTROLLABLE, late or wrong load planning / lack of loading staff	56	-14
93	AIRCRAFT ROTATION, late arrival of aircraft from another flight or sector	291	-25
95	CREW ROTATION, awaiting crew from another flight (flightdeck or entire crew)	202	-29
91	LOAD CONNECTION, waiting for passengers, cargo or mail from another flight	75	-48.6

Table 4: KLM delays per category of IATA code
Dataset: KLM FIRDA data, periods August 14-20 (4888 flights, 594 flights) & September 4-10 (4955 flights, 401 delayed)

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8 Data sharing

The footing of APOC is its principle of collaborative insight through data sharing. Whereas A-CDM translates the airside processes into a predictable operation (compared to non-CDM), total airport management extends its spatial scope to the landside processes. Depenbrock et al. (2012) expect the expansion of landside KPIs with airside processes to yield additional advantages. This section identifies the requirements for data sharing amongst partners, and the challenges on the road ahead.

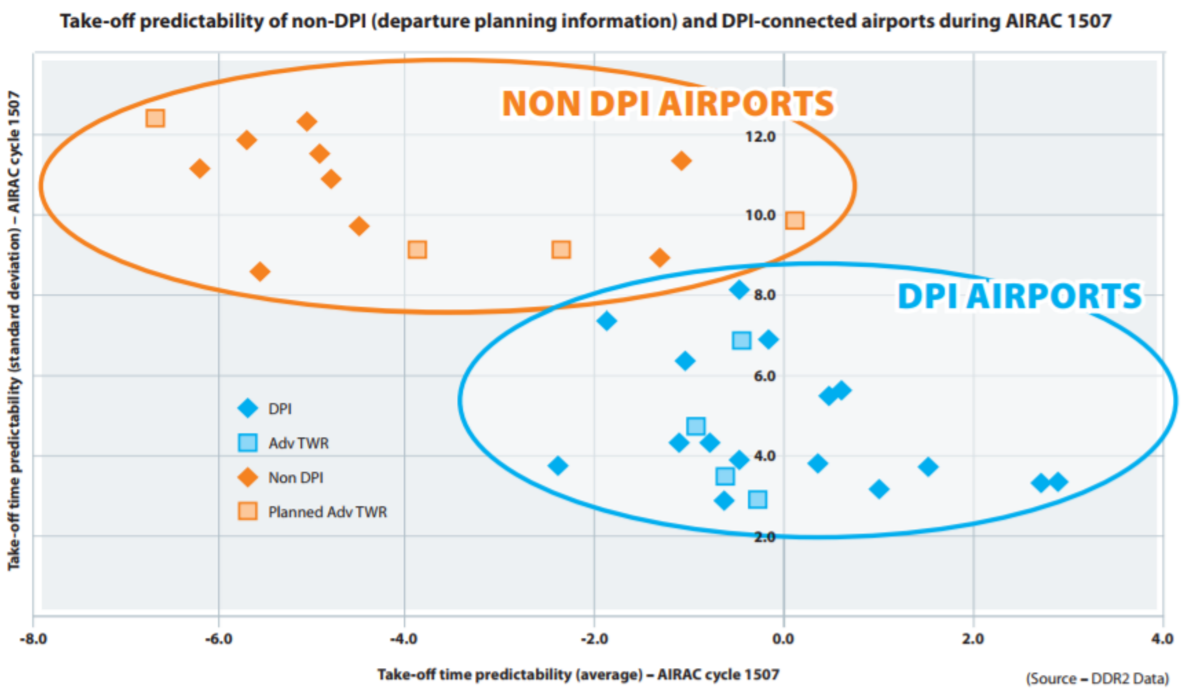

Figure 13: The takeoff predictability of CDM-implemented airports (sending DPI) messages, is more accurate than non-DPI airports. (Huet et al., 2016, p. 2)

8.1 Current stakeholder stance to data sharing

Chapter 4 listed five mandatory partners for an APOC to function at Schiphol airport:

1. ATC the Netherlands,
2. Ground handling companies,
3. KLM,
4. KNMI, and
5. Schiphol Group.

Most of these stakeholders are currently united in the 'CDM@AMS'-program at Schiphol, a local CDM program aiming to increase takeoff predictability. To identify patterns of behavior in this data is difficult, as tracing back triggers to the system is a labor-intensive process. Thus, CDM-data is currently used for monitoring the status of the flight based on the CDM-milestones and the ground process in the "live"-operation (D_0) only. During post-operations analysis, the stability of variables like TSAT and TOBT are analyzed. Predictions are, after the update from local CDM to full A-CDM, predictability and accuracy of takeoff will improve even further.

Although data sharing proved its value greatly in A-CDM, stakeholders are reserved in joining the philosophy of total airport management. Stakeholders are open to the ideas of total airport management and an APOC, but uncertainty about investments costs and forecasted benefits are holding them back.

8.1.1 Provision of (historical) data for this research

When assembling the data for this research, the following reservation was perceived by the researcher, ranked to their cooperability towards sharing data for the research.

To clarify figure 14, it is important to understand the circumstances leading to the rating of each of the valued stakeholders. It seems none of the stakeholders are deemed unwilling in supporting this research, or research in general. The requested contribution of the stakeholders focused on the operational log files from internal data systems, for the periods spanning August & September 2017 (or a fraction thereof).

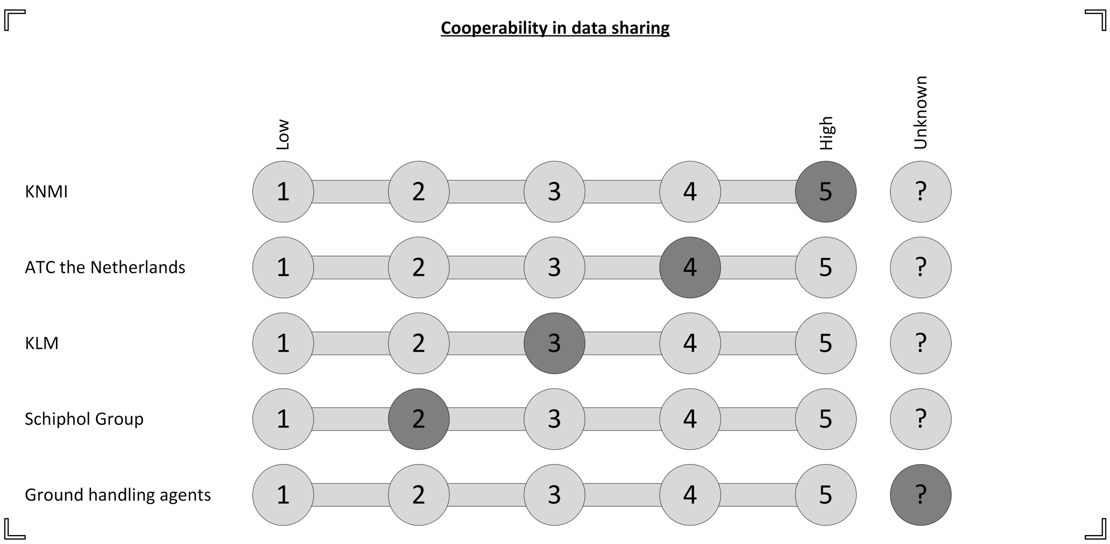

Figure 14: Cooperability of stakeholders towards the provision of data, as perceived by the researcher during the execution of this research.

Some explanation for the stakeholders' stance in providing researchable data can be found in the cost structures of each of the organization. The two organizations most cooperative in data sharing are (independent) agencies of the government, thus focused on contributing to the public

Stakeholder:	**Situation @Schiphol airport**	**Data sharing in CDM**	**Data sharing in Total Airport Management (used in APOC)**
Airport operator	Schiphol Group	Availability infrastructure, gates, pushback trucks	*CDM* + Passenger related processes: Check-in availability, security capacity, border control
Airlines	KLM, Transavia, easyJet	Status of flights (CDM milestones) Flight planning	*CDM* + status ground handling process, status passenger processes (check-in, transfer, PRM)
ANSP	ATC the Netherlands	Availability capacity runway & airspace	*CDM*
Ground handling agents	KLM Ground services, Aviapartner, Menzies	CDM milestones	*CDM* + actual status of each of the individual processes
Meteorological institute	KNMI	Weather forecasts	*CDM*

Table 5: Data sharing in an APOC compared to CDM

domain.

The two organizations least cooperative in data sharing are either stock listed-, or public limited liability companies. Driven by profit, they are less eager to invest scarce time in research, due to the adjoined costs.

The main obstacle to receive data from Schiphol Group turned out to be company structure for data ownership. Each dataset is linked to a person within the organization responsible for this data, and its usage. To receive the requested data has proven a time-consuming and slow process, eventually resulting in the absence of passenger and terminal related data for this research.

Table 5 above mentions the minimum required data to be shared in the current situation of local CDM, and the future state of full CDM, compared to the possible state of Total Airport Management, using an APOC.

Level of trust should increase to enable intense data sharing
Data sharing is a key success factor for an APOC to function. The reticence towards data sharing amongst stakeholders, including competitors, is a much dreaded property of Total Airport Management. The lack of trust amongst actors of the airport system, and the sensitivity of raw data, withhold stakeholders to invest in the philosophy of Total Airport Management.

Data sharing requires a standardization of the used data in all stakeholders' processes. The SWIM-program from SESAR provides the platform to share and create operational data to the airport system. Data security requires the system to be resistant to cyber-attacks, and be redundant in case of disruptions. Furthermore, all parties should strive for a common goal when using the data, and deliberate misuse of the system should be punishable.

In order to benefit most from the (theoretical) functionalities of an APOC, data sharing should be unchallengeable. Thus, everything should be done to overcome any doubt for the stakeholders. Data sharing should be anonymous to such extent, that benefits are gained, but individual situations cannot be assessed during the D_0 operation, to prevent actors from blaming others.

It is possible to build a certain trust in the system by phased implementation, moving through post-operation analysis, to test other possible solutions to operational challenges. Once the systems have proven their worth, trust amongst actors will grow, enabling the implementation of the tools in an APOC in the D_0 operation.

Blame game towards just culture
The psychological side of collaboration is out of scope to this research, but it must be stated current airport operations does not stimulate a just culture. While Pateman et al. (2016) suggests trust and reciprocity are influencing the outcome of collaboration, service level agreements discourage transparent operations. As transparency currently merely provides the contracting party with a stick to hit the dog. This so called “blame game” should transition to a just culture, where actors work collaboratively to optimize use of available resources. This requires a culture change of all organizations to the airport system.

8.2 Manageable processes in an APOC

When all data is shared, the ideal setup of the APOC will combine the functionalities of all of the following systems:

DMAN ***(Departure management)*** Tactical controller assistance system optimizing the air traffic flow from the gate to the departure runway. (Toebben & De Nijs, 2007)

SMAN ***(Surface management)*** Automated routing and guidance system for optimizing the surface operation. (Dr. Strasser, 2010)

AMAN ***(Arrival management)*** Tactical controller assistance system optimizing the air traffic flow from entering the TMA to touchdown. (Toebben & De Nijs, 2007)

PaxMan ***(Passenger management)*** The main tool to synchronize and harmonize airside and landside operations, by monitoring and assessing the passenger process. (Classen, 2012)

TMAN ***(Turnaround management)*** Acts as an integrated link between air traffic control and apron control and calculates all A-CDM and ground handling times as well as reliable TOBT. (Press release from Siemens & Airport, 2012)

Since multiple stakeholders are either responsible or contributing to the processes affected by the tools above, all stakeholders should contribute to the system, benefitting the airport system as a whole. Therefore it is recommended to come up with a widely supported structure to motivate each actor to contribute to the system, and to adhere to its rules.

To conclude, data sharing is key to the feasibility of APOC implementation. Since stakeholders at Schiphol airport are currently not eager to jump in, a supported structure should be draft to overcome reservedness. Trust should be built amongst system actors, to enable close collaboration in an airport operations center. It is indispensable the system should be as resistant as possible to cyber-attacks, and redundant in case of (deliberate) disruptions.

9 Conclusions

Airports improved their predictabilty over the years by implementing the use of departure planning information (DPI) messages. By sharing information with EUROCONTROL, predictions have become more accurate and stable than before the use of DPI messages. The next step in airport predictability is the integration of the airport operations plan and the network operations plan (AOP-NOP integration). The airport operations center is the intended linking pin between the airport operation and the network manager. The question at Schiphol airport remained:

How does the implementation of an airport operations center (APOC) improve capacity management at Amsterdam Airport Schiphol?

To prove added value for an APOC at Schiphol airport, this research:

1. applied the APOC vision of total airport management to Schiphol,
2. identified inefficiencies in the current CDM-processes, and
3. recommended necessary requirements for the implementation of an APOC.

9.1 APOC enabling total airport management at Schiphol

Total airport management combines landside processes with airside processes, increasing predictability, at the cost of complexity. (Depenbrock et al., 2012) The airport operations center is the physical (or virtual) center where all stakeholders in airport operations come together. All stakeholders share information from their data systems (like flight details, turnaround manager and passenger processes) to use as input to simulation and planning tools, optimizing the operational use of capacity and resources.

Schiphol airport is a major node in the European network, so sharing data with the European Network Manager Operations Center (NMOC) becomes inevitable for a stable operation. The APOC will be the connection between local airport operations, and European integration. By collaboratively deciding on capacity measures, gaps between airport actors are bridged. The uniformity of these measures will improve capacity management.

9.2 TSAT instability partly caused by actor' behavior

Airport predictability is a key success factor for efficient capacity management. Currently, resource allocation is optimized based on target startup approval times (TSAT). However, airport environments are versatile and dynamic systems: the fluctuations of TSAT cause numerous planning issues, and unnecessary workload for ground handling agents, air traffic controllers, apron controllers and flight crew/pilots. By minimizing TSAT fluctuations through earlier and more complete data sharing in an APOC these fluctuations are partly decreased.

Sharing data provides insight to all stakeholders in the effects of actions. This research concludes that airlines are reserved with regard to updating the estimated off block times (EOBT). The majority of EOBT updates take place only after the initial scheduled time of departure. This results in ATFM measures imposed upon by EUROCONTROL, to reserve air space capacity which is not used, thus spilling capacity.

On a local level, ground handling agents update the target off block times (TOBT) of flights, to represent the expected time for end of ground handling. They are trained to be as accurate as possible, to make optimal use of outbound capacity. However, the data analysis has proven frequent TOBT updates within the TSAT-window. These updates are not required for a smooth operation, and are considered counterproductive.

The effects of these behavorial habits will become evident to all stakeholders once an airport operations center is implemented. Currently, problems arise when actors are unaware of their actions' consequences to the airport system. By rewarding good behavior (and when the reward is high enough), airport actors are likely to adjust to desired behavior.

9.3 Data sharing is key to capacity management improvement

A thin line exists between an actors' choice to strive for commercial goals, and their willingness to optimize the airport system. In other words, if the costs of compliance are too high, the actors' choice to noncompliance is to be expected. Therefore, it is important to understand requirements for successful implementation of an airport operations center.

Before implementation of an airport operations center should start, all stakeholders at airport Schiphol should feel confident with its role and function within the airport operations. Creating a common vision and goal is a requisite for success.

Once decided an airport operations center is desired, technical barriers should be broken down. Since data sharing is key to the feasibility of APOC implementation, a safe and secure sharing of data should be guaranteed. Currently, stakeholders at Schiphol airport are not eager to comply with a higher instensity of data sharing. To enable close collaboration in an APOC, mutual trust should be created amongst airport actors.

Finally, air traffic management, *ergo* airport operations, is an environment with high standards with regard to safety, and a low tolerance to errors. This means all simulation and planning tools must have proven trustworthy before actual implementation in the live operations.

To conclude, unanimous support to the role and function of an APOC is a requisite for successful implementation. Once an APOC is implemented, it is expected to function as the linking pin between the airport operations plan and the network operations plan. By providing insight in behavior, resulting in improved stability of TSAT, the path to improved capacity management at Amsterdam Airport Schiphol is smoothened.

10 Discussion

The expectations of this research were to identify system' weaknesses in the data, to provide the sector with new, valuable insight to improve the system. Ultimately, this must lead to the implementation of an airport operations center, enabling total airport management at Schiphol airport. The free interpretation of data in this research has been brought to a minimum, to expose the challenges currently faced. This discussion focuses on the three themes of the research.

10.1 Applying the APOC vision to Schiphol

The SESAR concept for an airport operations center is an initiative to further optimize airport operations after an airport has fully qualified as a CDM-airport with NMOC. It is however an initiative under development, meaning there is currently no airport in the world which has an APOC as described by EUROCONTROL and DLR (Günther et al., 2006). There have been live tests, to prove the added value of an airport operations center, but these have not undeniably proven the APOC as an improvement. It must however be said that the success of these trials depend on the success criteria determined for the research.

By applying the APOC vision to Schiphol, a common view on the stakeholder groups and the scope of an airport operations center has been created. The exact function of the APOC is still to be decided, but this is largely dependent on the willingness of airport actors to contribute to this center. From the airport perspective, the APOC will be the obvious choice to manage capacity and function as the pivot between the European network and the local airport operations.

10.2 Analyzing (in)efficiency in the CDM operations

With data analysis, the choice of data determines the value of the analysis. The age old credo for modeling "CICO (Crap In equals Crap Out)" implies the data used should not be disturbed by unwanted information blurring the actual data to be researched. To prevent this from happening, the raw data files from CDM were collected and cleaned by the researcher.

Due to the absence of terminal data, it seemed a valid choice to focus on the CDM outbound movements. Since it was not able to model the airport and use the terminal and flight data as input, the choice was made to quantify inefficiencies in the current system. By improving the weakest link in the chain, the total strength of the chain improves. Thus, by tackling the challenges in the current CDM at Schiphol, total airport operations would improve, benefitting all stakeholders.

Data selection
One of the main principles of data science is the use of large datasets, to overcome inaccuracy of data. In this research, the researcher did not validate the findings to a different data set. Instead, the researcher used two different weeks of operation to test the replicability of the research design. It is debatable whether the choice for two weeks (although reflecting different conditions: one in- and one outside holiday season) reflect the situation at the airport. Another possibility would have been to analyze the operation of the same month in two different years.

The choice of the data set was based on an automatically computed figure which presented the startup delays per 10 minutes for the months August & September. The decision to use the chosen two weeks might have had a significant influence on the operation mirrored in the data, whilst the decision itself seemed rather arbitrary. The researcher aimed to have two disturbed days of operation, and five nominal days, but did not define a nominal day. Although the graph depicted two highly deviating days of operation, it was uncertain as to why these deviations occurred. It might as well have been possible the disturbances influencing the airport operations are rare phenomena.

10.3 Recommending requirements for implementation

The recommendations for successfully implementing an airport operations center are based on expert' hands-on experience with large projects, available literature and conclusions from the data analysis. However, large projects like these are impossible to predict. The complexity of multiple stakeholder' views on the function and role of the APOC is the first challenge. The stakeholders will likely collide in the challenging combination of perspectives: commercially driven organizations and organizations not solely driven by cost, but focused on safety and efficiency.

This report is meant as a first step towards the implementation of an airport operations center at Amsterdam Airport Schiphol. Risks are however, stakeholders will use this report in their battle for capacity. Conclusions on behavior are general and were never intended to be used in the blame game. A transition from the blame game to a just culture is needed for an APOC to work, and may prove to be the most challenging first step to intensified collaboration. Mutual trust is key when closely collaborating, and when not all agreements can, nor should be fixed in formal contracts.

Although this report is a good *entre* to an airport operations center, it does not grant the longed answer to the questions of cost and leadership: nor the investment costs, nor their potential benefits are quantified. A thorough cost & benefit analysis for all stakeholders might be relevant to the decision making process. The organizational structure and the decision making process in the APOC should be defined and agreed upon before initiation phase of APOC and Total Airport Management at Amsterdam Airport Schiphol.

11 Recommendations

11.1 The road to APOC

The research concluded the implementation of an APOC to be the logical next step in the development of capacity management at Schiphol Airport. Nonetheless, major projects in history have proven a lack of trust and vision can create a never-ending process of implemenatation.

The following five steps are recommended for the implementation of an APOC:

1. Create a shared and valued goal for an APOC towards TAM.
2. Build a database with historical data from all stakeholders.
3. Analyze historical data for post-operations analysis.
4. Design operational improvements and test alternative scenarios.
5. Implement the APOC scenario and planning tools in the D_0 operations.

For the implementation to be successful, the following stakeholder groups should be contributing in the development of an airport operations center: airlines (KLM Royal Dutch Airlines, Transavia, easyJet), air traffic control (LVNL), airport operator (AAS), ground handling agents (Menzies, Swissport, KLM Ground services) and meteorological institute (KNMI). The CDM-process provides a lot of data on flight movements, but it should be enriched with data from the airport operator (terminal processes) and ground handling agents, c.q. airlines (turnaround processes). With this enriched data, simulation and planning tools could be developed and tested, before the actual implementation in an APOC.

11.2 Future improvements in airport system

To remove subjectivity in the data, and to stimulate change to a culture where honest mistakes are forgiven, data objectivity should be maximized. By automating most of the processes of data collection, this is achieved.

The assigned delay codes should be determined by automatic decision-trees based on their most relevant delay. This increases the usability of the data for analytical purposes and increases the chance lessons are learned from the analysis, losing the CICO principle for this analysis.

11.3 Future research

Close collaboration with universities, due to their independent stance towards airport opeations, is recommended for both post-operations analysis and new analytical evaluation of concepts like APOC. Their views are not blurred by commercial interest, thus less biased towards any of the organizations.

Further impact analysis of an APOC on the daily operations is recommended to reach optimal fitness to the airport system.

A cost structure for both investment costs and profit sharing should be designed. It should take the financial structures of the involved organizations into account, including their availability to bear risks.

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A. Appendix: Document information

Document information	
Initiating process	Not applicable
Document type	Thesis
Title	Implementation of an airport operations center (APOC) at Schiphol airport: improving capacity management?
Part	All
Initiated by	MT – KDC
Document number	KDC 2018/0010
Version number	1.0
Version date	February 1, 2018
Status	Final version

Abstract
Introduction After qualifying as a CDM airport with NMOC, Amsterdam Airport Schiphol considers the implementation of an airport operations center to further improve capacity management. By exposing inefficiencies in (the current version of) A-CDM, the choice to implement an airport operations center to improve capacity management is bolstered. **Method** To expose the inefficiencies in A-CDM, and the added value of an airport operations center, data analysis was performed on CDM data: 2 weeks of raw CDM outbound data (n ≈ 10.950f lights). The focus was on Estimated Off Block Times (EOBT), Target Off Block Times (TOBT) and Target Startup Approval Times (TSAT). These variables were linked to behavior of ground handling agents, airlines and influences of weather to prove the magnitude of external influences. Expert validations were used to verify the findings of the data research. These findings were translated to recommendations for implementing an airport operations center at Amsterdam Airport Schiphol. **Findings** The research proved TSAT to be an unstable predictor for airport operations, since it is highly influenced by actors' behavior. To improve capacity management, stakeholders should share data more intensely. However, they are reserved towards sharing data, as they are afraid of misuse or misinterpretation of shared data. **Conclusions** A successful implementation of an airport operations center would improve accuracy and predictability of the airport system, but requires major contributions to the program by all stakeholders like data sharing.

Keywords		
Actors' influence on airport system	Data sharing	TOBT management
Airport operations center (APOC)	EOBT management	Total Airport Management (TAM)
Capacity management	Schiphol airport	TSAT instability
Collaborative Decision Making (CDM)	SESAR2020	

Security classification
Unrestricted

Change log

Version	Version date	Sections	Remarks
0.1	01-18-2018	EOBT management	Initial document
1.0	01-02-2018		Final document

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B Appendix: Reflection & Process evaluation

General retrospective on KDC-internship
I feel priviliged to have had the honour to do my internship not just with a single company, but with the KDC representing the main actors in the Dutch aviation sector. My intentions for this internship were to learn where my knowledge could be applied in practice, and where my skills and knowledge were lacking. This internship lifted some fog on my knowledge and its applicability in practice. It proved me situations where my knowledge was not yet to my own standards, and where my skills lacked and needed to improve.

My biggest challenge has been (for some time) to live up to my own standards of perfection, before being satisfied with the results. At the start of the internship, I focused on proving the added value of an APOC at Schiphol. Although I did not have the knowledge, skills, or time to prove the added value of an APOC, my ambitions were to prove it nonetheless. It is my (bad) habit to knowingly strive for goals which are (slightly) out of reach. Unfortunately, I tend to be (too) passionate, and speak out my ambitions. This leads to situations where I do not only have to myself, but have the feeling I have to prove others as well.

Although I have not been able to prove the added value of an airport operations center the way I wanted in the first place, I do feel I have succeeded in creating new knowledge for the Dutch aviation sector. This research is a solid first step towards total airport management at Amsterdam Airport Schiphol, and the role of an APOC in this philosophy.

Learning experiences during internship
I have had two real situations during my internship I could use in future to improve myself. Both of them were near the end of the internship, when the deadline creeps closer. The first was the moment I found out my data analysis was focused on the wrong input variable. The second was the feedback I received on my report and writing style.

Data analysis lost value When I finished my data analysis, I was ready to start drafting up the final report. Luckily I joined an interesting lecture from two aviation specialists on the University of Applied Sciences on CDM at Amsterdam Airport Schiphol. During this lecture I noticed the focus on TOBT, rather than EOBT. Since my focus in the data analysis had been on EOBT until then, my conclusions were not as valuable to the sector as I hoped. I therefore decided to start all over with the data research, but this time focus on TOBT.

The reason this happend is mainly because I misread the user manual, and was too stubborn to validate my research method (once more) with the CDM experts. Although it set me back quite a bit, I took the time and effort to do the data analysis again. This eventually led to a broader understanding of the data streams at Schiphol and their relation to EUROCONTROL. For future research, I will however take the time to validate my research method with experts before diving into the analysis itself, saving valuable time in the end.

Feedback on writing style After finishing my draft report, I asked multiple persons to review my document. I received valuable feedback on the content of the research, which I processed in the final version of the report. Too my surprise however, I also received feedback on my writing style and thought processes in the report. These were hazy, and should have been clearer to the reader.

At the time of the feedback, I was actually offended by the feedback. To me, nor the thought process, nor the writing style were an issue. I challenged this feedback amongst multiple peers, but never found the answer I was looking for. Indeed, I just wanted someone to convince me I was right all along. Let's just say the acceptance phase was longer than strictly necessary.

I took my losses however, and decided to rewrite the document. After some time, most of the feedback has gotten more value to me, and I agree to some extent my thought process is not always clear to others when I write it out.

For future situations, I will ask others for feedback on written transcripts some time before the deadline, so I can incorporate the missing links in the text.

Process evaluation

The process of the internship was well structured due to the agile/SCRUM approach of the internship. We had 'sprint'-reviews every two weeks, ensuring one to deliver something tangible. Although it was hard for me to get used to the 'one task at a time'-policy of SCRUM, structuring the tasks, and dividing them into small tasks proved valuable.

The time management of the internship, meaning the length and distribution of certain tasks might have been slightly off though. In retrospect, we took too long to forge a thorough research question, and were uncertain as to what we actually wanted to research. I have the feeling that after 10 weeks, halfway down the internship, I finally understood what I wanted to research and how.

To ensure this will be faster during new research, it is important to focus less on the actual research in the beginning. To me, understanding the problems faced by the client is most important. If we both know what the problem is, it is only then that I can start a research on how to solve it (or improve the situation for that matter).

One usually gets the question at the end of a process: "Would you do it again?" The answer would be "Yes, I would. But I would change some things along the process.".

C Appendix: SESAR initiatives

The acknowledgement of bottleneck issues originating at airports and restricting the future transport system moved the European Union to invest in a European ATM research-program: SESAR, Single European Sky ATM Research ***SESAR Deployment Program ed. 2017***. The SESAR-program (later referred to as SESAR) strives for four High-level Goals:

1. Enable a threefold increase in capacity by reducing ground- and air delays.
2. Enable a 10% reduction of environmental effects of air transport.
3. Reduce the costs of ATM services to airspace users across Europe by at least 50%.
4. Improve safety performances by a factor of 10.

These High-level Goals are to be achieved through three phases of SESAR:

1. Definition phase; aiming at identifying the expected performance requirements of the next generation ATM systems, as well as the most suitable solutions to achieve them.
2. Development phase; puts in place the necessary research and development activities to produce the necessary technological elements.
3. Deployment phase; aiming at deploying throughout Europe the results of the ATM solutions developed and validated by the SESAR Joint Undertaking.

Chapter 4 of the thesis describes the existence of multiple SESAR (Single European Sky ATM Research) initiatives within the total airport management philosophy. Chapter 4 *EUROCONTROL: Total Airport Management* explains the airport operations center as envisioned by SESAR, and its translation to the Schiphol case. Furthermore, it lists the following six SESAR initiatives:

- System wide information management (SWIM),
- Extended horizon functionality of AMAN,
- Performance based navigation in high density TMAs,
- Automated assistance to controller for surface movement planning and routing,
- Flexible use of airspace,
- Time-based separation for final approach.

Since these initiatives enhance the total airport management philosophy, and possibly the understanding of value for total airport management at Schiphol, each is briefly explained hereafter[16].

System wide information management (SWIM)
The SWIM concept enables ATM business with understood quality information delivered to the right people at the right time. Given the transversal nature of SWIM which is to go across all ATM systems, data domains and business trajectory phases (planning, execution, post-execution), and the wide range of ATM stakeholders, it is not expected that one solution or technology will fit all. Global interoperability and standardization are essential, and SWIM is expected to be an important driver for new and updated standards.

For SWIM to work, pilots, airport operations centers, airline operations centers, ANSPs, meteorological service providers and military operations centers are required to work together in

[16] Each of these explanations are based on the 'European ATM Master Plan Level 3: Implementation view', version 2017.

information sharing. Information like flight trajectory, aerodrome operations, meteorological data, aeronautical data, surveillance data, and capacity & demand should be shared to operate towards common goals.

Extended horizon functionality of AMAN
Arrival management (AMAN) usually has a horizon of 100-120 NM, by extending the AMAN horizon to at least 180-200 NM from the arrival airport, the TMA capacity can be optimized. By enabling the exchange of information to enroute airspace, delays may be resorbed by reducing speed in early phases of arrivals leading to reduction of holdingand vectoring, which has a positive impact in terms of fuel savings.

Performance based navigation in high density TMAs
RNAV1 or RNP1 specifications allow an aircraft to fly a specific path between two 3D-defined points in space. Both classifications mandate a level of lateral accuracy of ±1 NM 95% of the flight time. The RNP1 specification is an extension to the RNAV1 specification, including on-board performance monitoring and alerting.

RNP1 capability requires the input from global navigation satellite systems (GNSS), but provide flexible, environmentally friendly procedures for departure, arrival and initial approach in TMAs. The benefits of Performance Based Navigation have proven in mountainous areas like Cajamarca, Perú and La Serena, Chile, where challenging approaches are possible due to PBN. Its use in high density TMAs seems self-explanatory due to the improved accuracy and optimized TMA procedures.

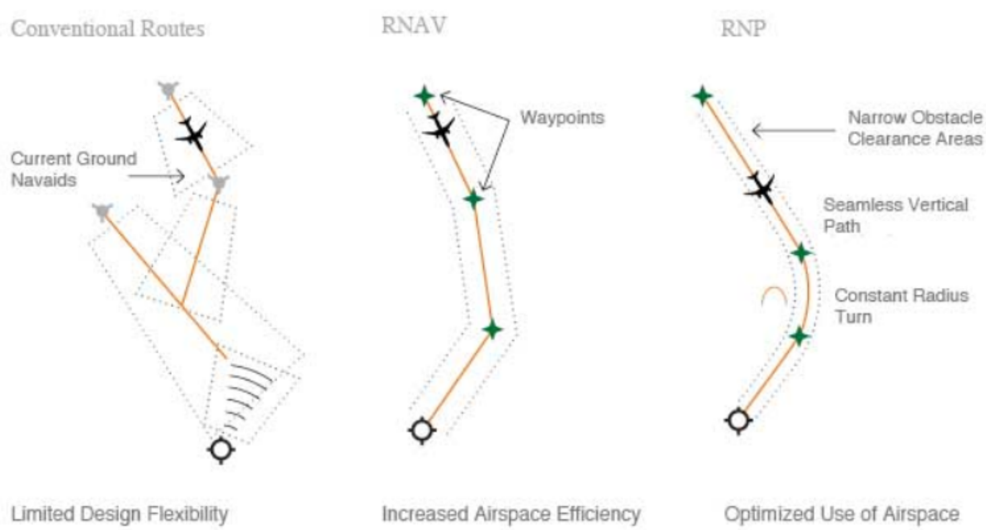

Figure C.1: Advantage of PBN in relation to conventional navigation (Boeing, 2008)

Automated assistance to controller for surface movement planning and routing
The A-SMGCS (Advanced-Surface Movement Guidance and Control System) routing service provides the generation of taxi routes, with the corresponding estimated taxi times for planning considerations. This function calculates the most operationally relevant route which permits the aircraft to go from stand to runway and vice versa. The controller working position allows the controller to manage surface route modification and creation if deemed necessary. Eventually the concept of A-SMGCS will lead to improved efficiency and safety, due to increased controllers' situational awareness for all ground movements and potential conflicts resolution.

Flexible use of airspace (FUA)
The concept of flexible use of airspace is that airspace is no longer designated as "civil" or "military", but considered as one continuum and allocated according to user requirements. Any necessary segregation of airspace is temporary, based on actual usage in a given time-period. Through a closer civil-military partnership and exchange of real-time airspace management information, advanced FUA will enhance the efficiency of airspace use providing the possibility to manage airspace reservations more flexibly in response to airspace user requirements.

Time-based separation for final approach
Current separation of flights is based on the IFR approach and is determined by wake turbulence separation (WBS) and radar separation minima. This separation is distance based and independent of the aircraft speed. Time-based separation (TBS) consists in the separation of aircraft in sequence on the approach to a runway using time intervals instead of distances. It may be applied during final approach by allowing equivalent distance information to be displayed to the controller taking account of prevailing wind conditions. Radar separation minima and WBS parameters shall be integrated to help the controller consider the effect of headwind on final approach. Time-based separation ultimately must lead to reduced holding times and more consistency of separation delivery on final approach.

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D Appendix: Breakdown analysis Target Startup Approval Time (TSAT) inaccuracy

All of the figures in this appendix visualizing CPDSP recalculations are based on the historical CDM data log files of Schiphol airport, for the periods 14-20 August & 4-10 September, 2017. The total size of the dataset is approximately 10.000 outbound flight movements.

Target Startup Approval Time (TSAT) is an output of airport system, calculated by the CPDSP (Collaborative Pre-Departure Sequence Planner), triggered by the CDM milestones. It is this TSAT per flight, which is being used as input to the optimization problem of resource allocation, for both Schiphol and airlines.

This appendix elaborates on challenges related to the instability of the TSAT, and identifies some causes to this instability. Possible solutions to the posed challenges are suggested to create a more stable airport system.

Unstable TSAT unfit for predictable operation

To understand the magnitude of the problem created by an unstable TSAT, having an overview of the system creates a feeling for its use in airport operations. The TSAT is calculated by the CPDSP, a system determining the outbound sequence for the airport, based on CTOT-regulations for flights (Calculated Takeoff Time), available runway capacity (and configuration), requested SID (standard instrument departures), Wake Turbulence Category. This optimization problem is solved for all flights, structuring the outbound sequence in a stable and predictable flow, minimizing ATC workload.

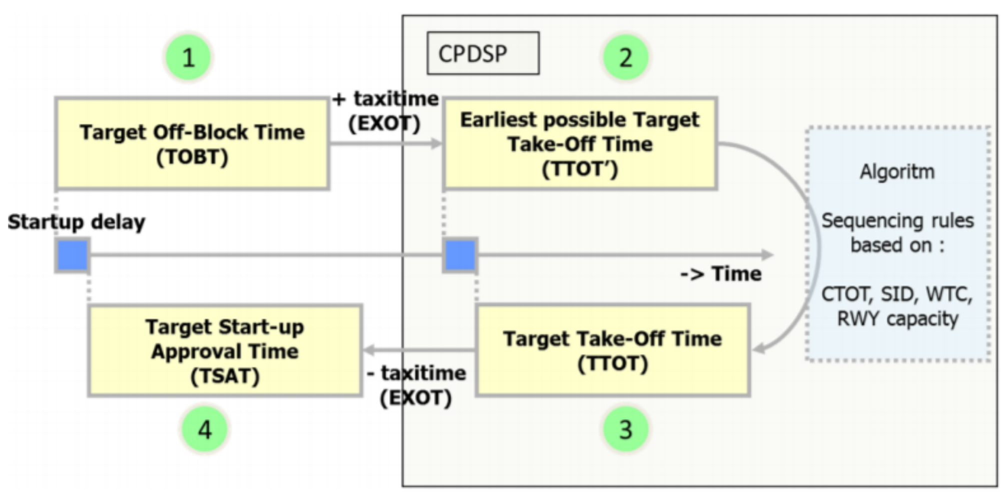

Figure D.1: The CPDSP algorithm for calculating TSAT times based on the taxi out time (EXOT) and outbound sequence. (Duivenvoorde et al., 2013)

The calculation by the CPDSP for TSAT follows the steps as presented in figure D.1, and is basically the Target Takeoff Time (TTOT) corrected for Taxi Out Time (EXOT). To reduce workload for ATC ground controllers, airlines (pilots) are not allowed to call "ready" more than 5 minutes from TSAT, the TSAT window [$TSAT_{-5\ min}$ – $TSAT_{+5\ min}$]. Thus, a direct effect of a stable TSAT around the time of departure is the reducing workload for both ATC and pilots.

Unfortunately, more challenges arise from the instable TSAT; aforementioned optimization of resources by both airlines and airport operator are based on TSAT. So, every TSAT deviation is directly effecting planning stability of airport users, and indirectly effecting the efficiency of the airport system.

E.g. the late arrival of a pushback truck at the apron, as a result of TSAT moving forward, ultimately creating an undesired (and possibly preventable) delay. Or the opposite situation, where the pushback truck arrives early at the apron, increasing the non-added value time of the pushback truck, while standing idle. This will result in a larger number of pushback trucks required to meet demand.

Figure D.2: Example of results from TSAT instability causing delays in the ground process.

Traffic pattern disturbing TSAT stability

Traffic at Schiphol is bundled, meaning the traffic is alternating between inbound and outbound peaks. This is the result of the seven wave system (see figure D.3) from main airport user KLM Royal Dutch Airlines. Their short haul network feeding their long haul network, of KLM and its alliance partners, presents traffic in wave patterns. The long haul flights are bundled to meet the circadian rhythm of travelers, preferably at the airport of departure and arrival.

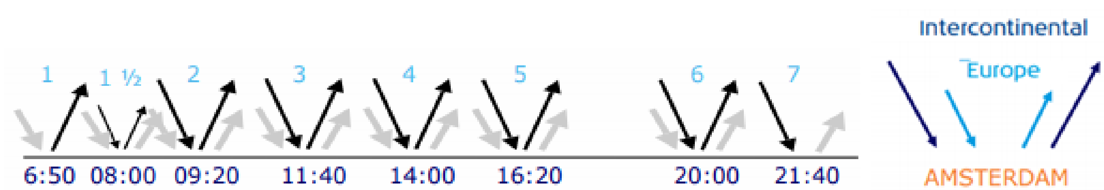

Figure D.3: The seven wave philosophy of KLM Royal Dutch Airlines, offering traffic at Schiphol Airport in seven waves, combining the short and long haul networks. (KLM, n.d.)

The addition of this long haul traffic, having a low frequency, with the high frequency short haul (European) network of both KLM and other airlines, results in the rather steady seven wave traffic occurrence, with intense peaks when compared to airports like Heathrow (offering a comparable number of traffic movements, but with a wider spread).

The traffic occurrence at Schiphol can therefore be elucidated using the principle of (pure) sound waves adding up. In figure D.8, the long haul traffic is represented by the 100 Hz frequency. Whereas the short haul network of KLM (functioning as feeder flights), and other airlines (maximizing the number of flight legs each day), are represented by the 200 Hz and 300 Hz wave pattern. The result is a wave pattern at Schiphol with a high amplitude when peaks of different waves align.

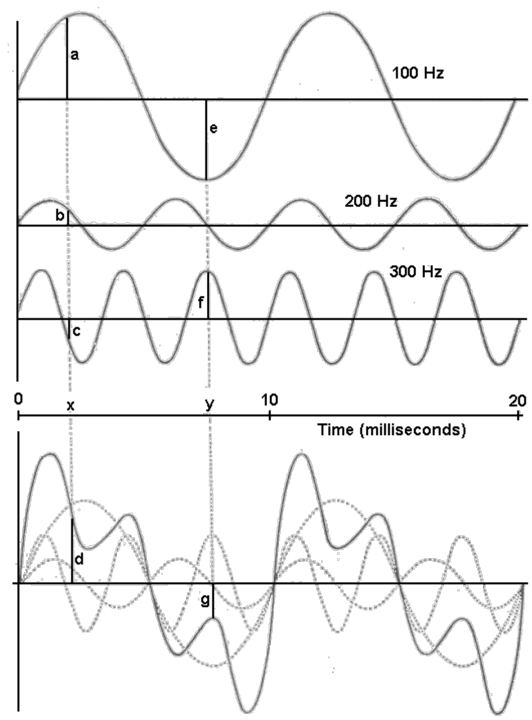

Figure D.4: Adding pure tones with frequencies of 100, 200 and 300 Hz, showing the addition effect of multiple wave patterns. (Mannell, 2008)

Schiphol is familiar with the wave pattern of their traffic, and anticipates to this challenge by changing their runway configuration (the active runways used for inbound and outbound) from 2 + 1 (2 Inbound runways, 1 outbound runway) in the inbound peak, to a 1 + 2 (1 inbound runway, 2 outbound runways) during the outbound peaks.

This change of runway configuration (the result of agreements with neighboring municipalities, and the complexity of the runway system at Schiphol) is one of the first sources of TSAT instability. The current outbound sequencing algorithm of the CPDSP cannot use another runway configuration other than the actual configuration. This makes the proposed TSAT in during inbound peaks (for flights in the outbound peak) rather useless, as it is calculated based on an available capacity almost half the capacity of the outbound peak.

Figure D.6 *(see next page)* shows the distribution of outbound flights, and their entry to the system, triggering a TSAT recalculation by the CPDSP. This is basically three hours before their scheduled time of departure adjusted for the day of operations ($EOBT_{initial}$). These triggers (referred to as new entry triggers), are influencing traffic by triggering recalculations. Since the peaks of current outbound traffic and future outbound traffic (flight entries to the CPDSP) align, this results in instability of the TSATs.

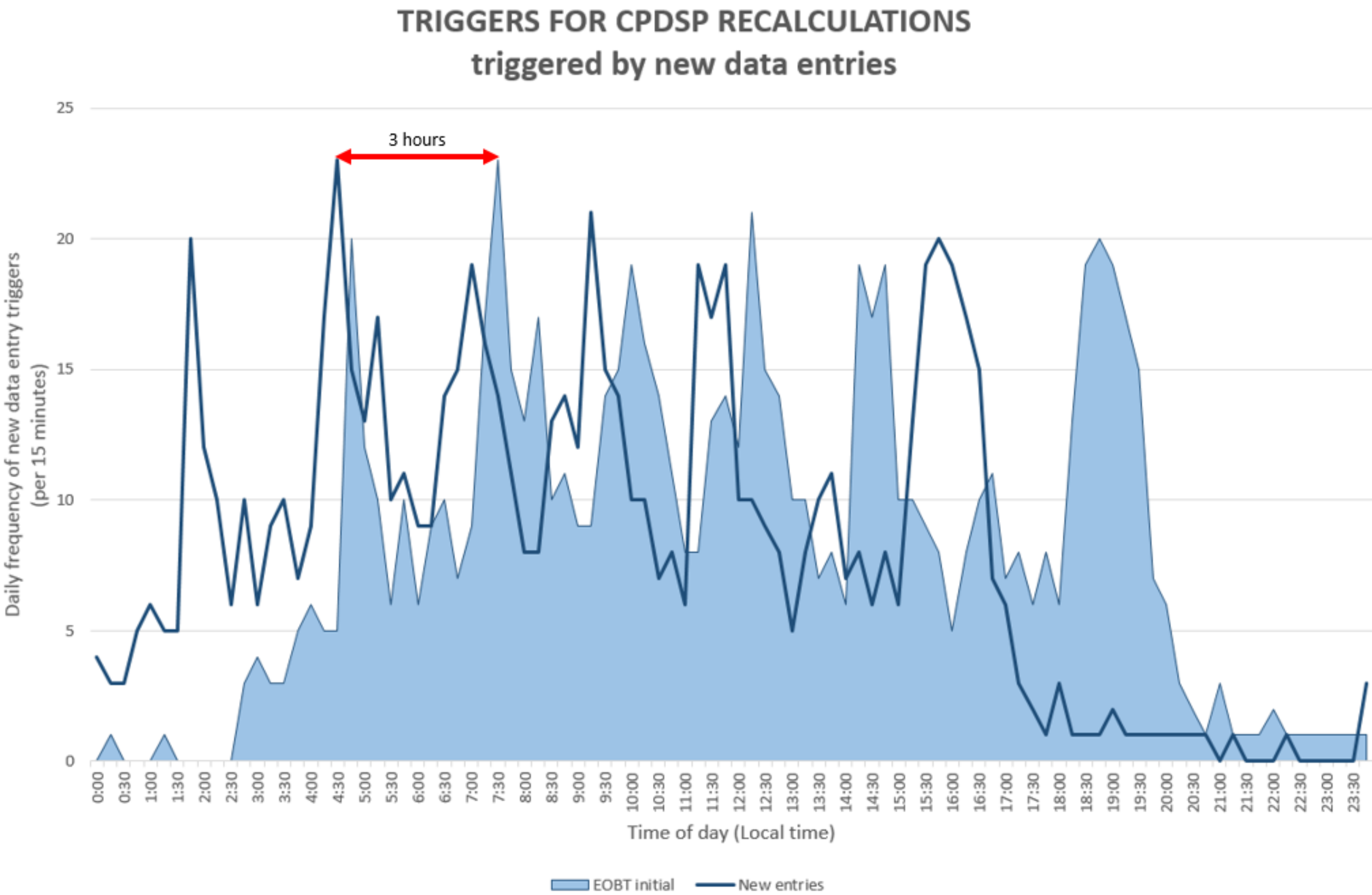

Figure D.5: TRIGGERS FOR CPDSP RECALCULATIONS:
New data entries to the system, 3 hours in advance of $EOBT_{initial}$

One might state the new entry to the system (at the end of the sequence) should not be of influence to the beginning of the sequence. However, flights which updated their target off block times (TOBT) to a later time, but still before their assigned target startup approval time (TSAT), did not trigger a revised outbound sequence. However, once another flight (like the new entry) triggers a recalculation of the outbound sequence, the updated TOBT will be used to determine the sequence. Possibly changing the order of the sequence, and most likely changing the assigned TSAT.

TOBT updates can trigger the CPDSP to recalculate TTOTs and TSATs in two instances. For the clearness of this report they are defined as a type-1 and type-2 TOBT update (visual representation of the TOBT update is given in the following schematic);

1. TOBT update where the $TOBT_n$ is earlier than $TOBT_{n\text{-}1}$.
2. TOBT update where the $TOBT_n$ is later than $TOBT_{n\text{-}1}$ AND later than assigned TSAT.

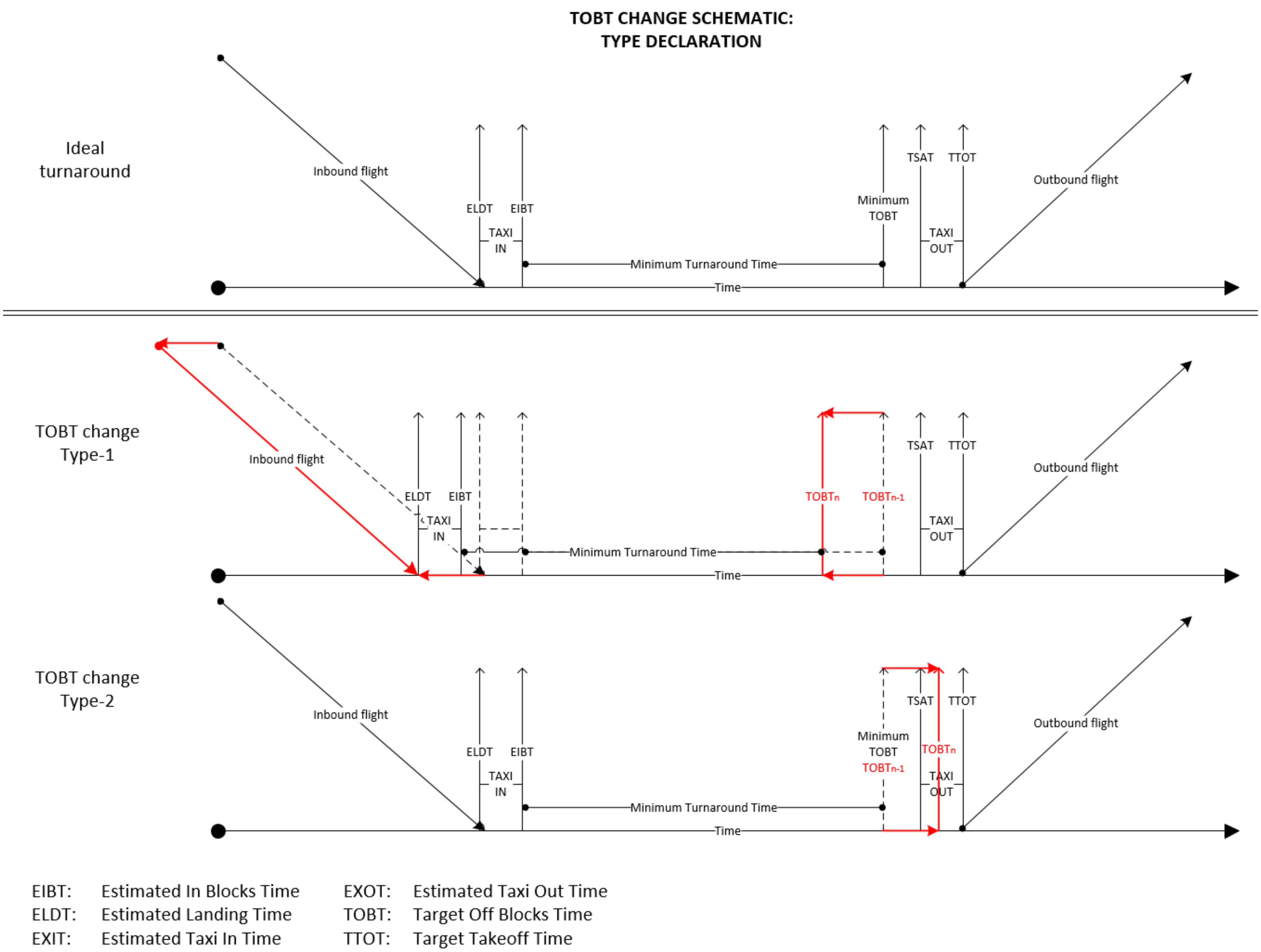

Figure D.6: SCHEMATIC: Type declaration of the TOBT changes triggering the CPDSP.

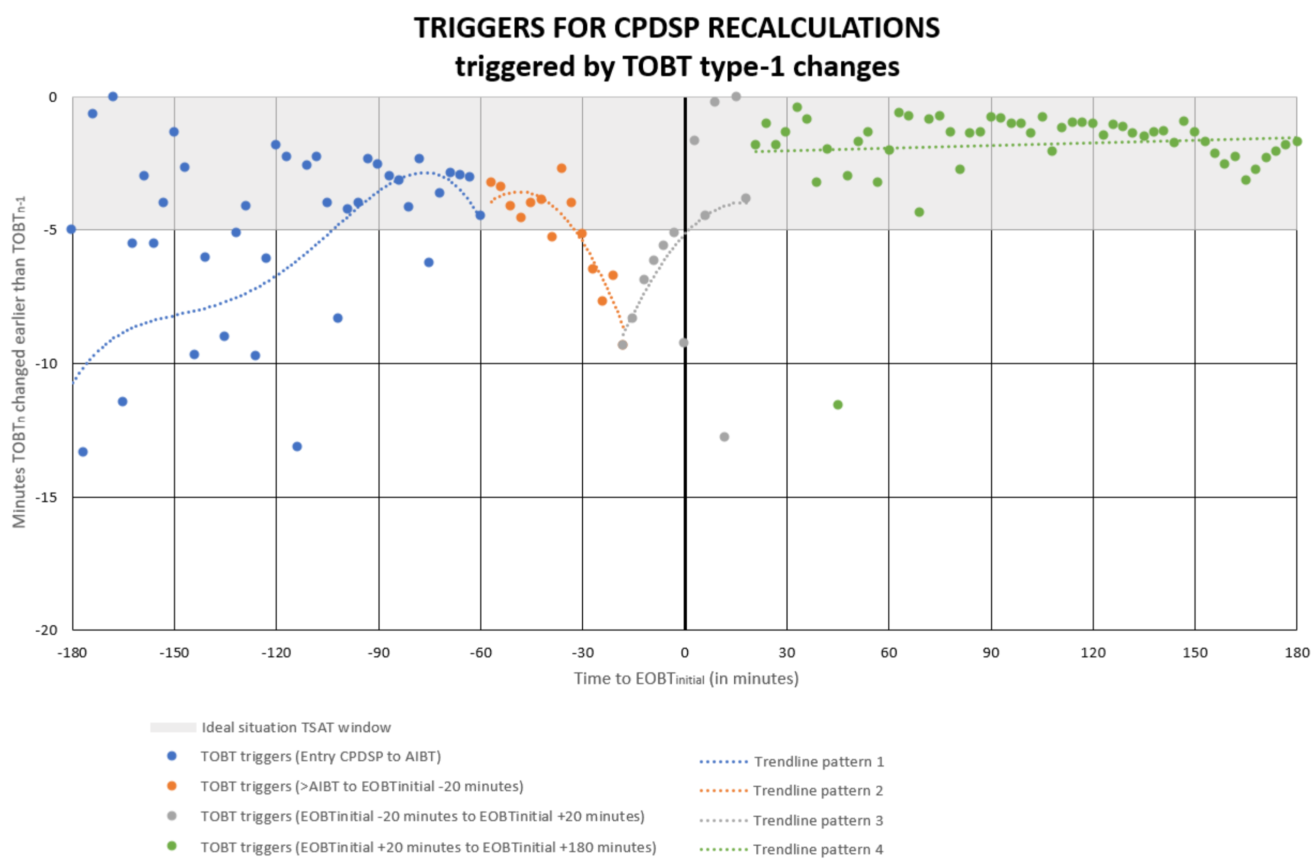

Figure D.7: TRIGGERS FOR CPDSP RECALCULATIONS: TOBT Type-1 updates to the system

TOBT type-1 changes explaining actors' behavior

The TOBT type-1 changes as explained in the schematic, have been plot and consolidated per three minutes for all situations against their respective $EOBT_{initial}$. The result bundles four different patterns:

1. BLUE PATTERN
   Deviations to flight plan, recalculations triggered by the system due to earlier ELDTs. Deviations stop when flight are in blocks.
   (System trigger: Undesired)
2. ORANGE PATTERN
   Optimistic behavior of ground handlers assuming earlier TOBT is feasible, possibly through surplus of assigned (and available) resources.
   (Ground handling agent trigger: Desired behavior)
3. GRAY PATTERN
   Realistic estimation of earliest feasible TOBT, as EOBT initial creeps closer.
   (Ground handling agent trigger: Desired behavior)
4. GREEN PATTERN
   Micromanagement of TOBT, triggered by ground handling agent.
   (Ground handling agent trigger: Undesired behavior)

The first pattern is an undesired system flaw, creating instability in the TSAT, without improving the actual predictability of the system. A solution to solve this undesired system effect is to make a CDM-entry ATC-non active (therefore not included in the sequence) until the flight's AIBT.

The second and third pattern present the expected (normally distributed) behavior of ground handling agents updating the TOBT to the earliest possible TOBT, to facilitate an early outbound for the airline. The last pattern presents unwanted micromanagement of the TOBT by the ground handler.

This behavior influences the airport system, by triggering recalculations of the CPDSP, while these minor adjustments are all within the new TSAT-window. Through training it is possible to raise awareness of this problem, and to prevent it in future.

TOBT type-2 changes explain natural delay behavior towards TOBT management

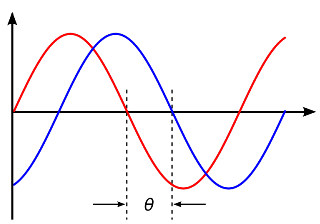

Figure D.8: Phase shift of a sine wave signal.

TOBT type-2 changes are identifiers for ground delays resulting from all causes related to ground handling and late inbounds. ATC delays, NMOC regulations and impactful weather are not direct influencing variables to the TSAT type-2 updates.

The TOBT type-2 updates align with the waves of outbound traffic, but have a negative phase shift ($\theta < 0$) in relation to the initial outbound schedule. Since not all flights are affected by delay, the maximum amplitude of the TOBT type-2 changes is almost half the size of the outbound peaks.

Furthermore, a clear circadian cycle can be distinguished from the data, which together with the buildup of delays (TOBT type-2 changes, figure D.9) result in the total distribution of TOBT type-2 triggers over the course of the day.

NMOC regulations impose startup delays, affecting capacity
CTOTs are gradually building over the course of the day due to the European traffic pattern, and a propagation of delays through late inbounds. To prevent the system from overloading, CTOTs are imposed upon departing aircraft, managing workload of air traffic services throughout Europe. Figure D.10 *(see next page)* visualize the CTOT regulations over the course of the day.

EOBT cannot deviate more than 15 minutes from TOBT, so the EOBT changes are an indicator for high deviation of the TOBT to initial EOBT. They are no direct trigger to the CPDSP, but are used as input to the EUROCONTROL capacity calculations (calculating the workload division over all the requested sectors used). High deviations of the TOBT (subsequently translated to an EOBT-update) are fed back to the airport system in the form of CTOTs: regulations restricting takeoff imposed on by EUROCONTROL to prevent overloading of sectors.

Conclusion
TSAT instability is caused by multiple factors, but shows inaccuracy caused by both software and liveware. The software related inaccuracy, like the early inbounds triggering a recalculation by the CPDSP can be solved by making new data entries ATC non-active in the CDM tool until AIBT. The The liveware related inaccuracy caused by micromanagement in TOBT accuracy (TOBT type-1 adjustments < 5 minutes), can be solved once awareness of the consequences has been risen amongst the responsible actors.

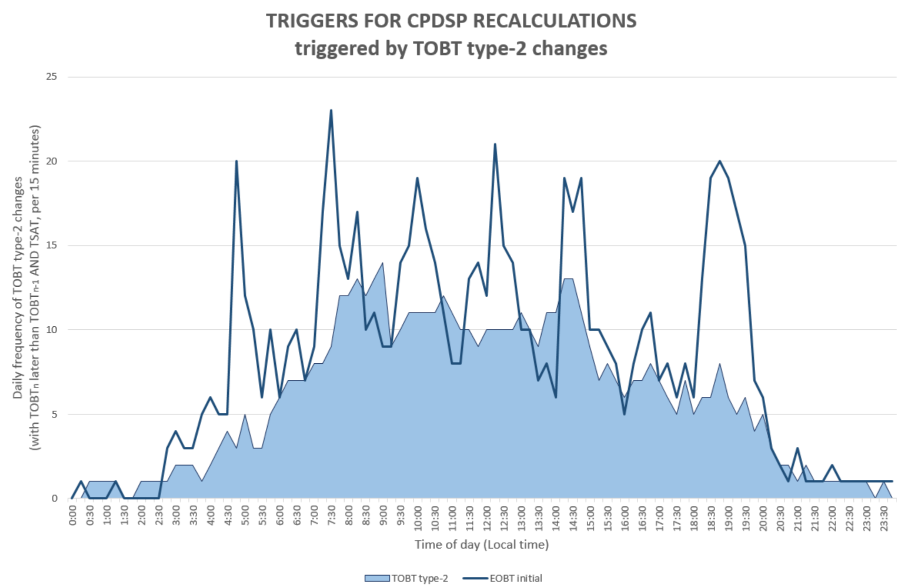

Figure D.9: TRIGGERS FOR CPDSP RECALCULATIONS:
TOBT Type-2 updates to the system

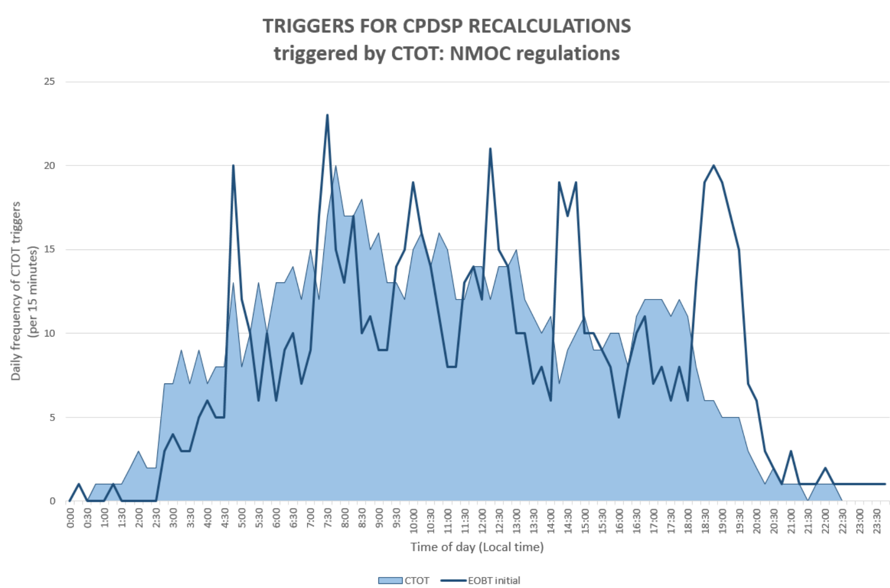

Figure D.10: TRIGGERS FOR CPDSP RECALCULATIONS:
Triggered by CTOT: NMOC regulations