Operational impact of the fleet mix to manage outbound capacity

A study on the operational impact of the fleet mix during the outbound peak hours at Schiphol Airport

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

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Thesis

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Preface

The aim of this research is to identify the operational impact of the fleet mix on the outbound capacity at Schiphol airport. This research is written to finalize the Bachelor of Science in Aviation with specialization Operations at the Amsterdam University of Applied Sciences. The graduation period for this thesis was from February until mid-July 2020.

This research is initiated by the Knowledge and Development Centre – Centre of Excellence, which is a cooperation with Air Traffic Control the Netherlands, Amsterdam Airport Schiphol, and Royal Dutch Airlines. The research and analyses during this period where very challenging especially due to the circumstances around COVID-19. I would like to thank everyone who supported me to come to the final results. Therefore I would like to thank my company supervisor, Centre of Excellence, and the Amsterdam University of Applied Sciences supervisor Catya Zuniga for supporting me, giving the required feedback, and keeping me in the right direction.

Within Air Traffic Control the Netherlands, who facilitated this research, I would like to thank Huy Vû for providing me the datasets, feedback on the chosen methodology, and information about the programming language Python.

As final, I would like to thank my fellow students who are graduating at the Centre of Excellence for their support and fun activities while we could.

Ashley Scheenloop,
14 July 2020

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List of Abbreviations

AAS	Amsterdam Airport Schiphol
A-CDM	Airport Collaborative Decision Making
ACNL	Airport Coordination Netherlands
ANOVA	Analysis of Variance
AOBT	Actual Off-Block Time
ASRT	Actual Start-up Request Time
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATOT	Actual Take-Off Time
AUAS	Amsterdam University of Applied Sciences
AXOT	Actual Taxi-Out Time
CISS	Central Information System Schiphol
CMA	Capacity Management & Analytics
CoE	Centre of Excellence
CPDSP	Collaborative Pre-departure Sequence System Planner
CTOT	Calculated Take-Off Time
H	Heavy aircraft
J	Super aircraft
KDC	Knowledge & Development Centre Mainport Schiphol
KLM	Royal Dutch Airlines
L	Light aircraft
LT	Local Time
LVNL	Air Traffic Control the Netherlands
M	Medium aircraft
NMOC	Network Manager Operations Centre
Q1	Quartile 1
Q3	Quartile 2
RDY	Ready
SID	Standard Instrument Departure
Std	Standard Deviation
TAX	Taxiing
TOBT	Target Off-Block Time
TSAT	Target Start-up Approval Time
TTOT	Target Take-Off Time
UTC	Coordinated Universal Time
WTC	Wake Turbulence category

Definitions of terms

Afternoon	From 12:00 until 18:00 LT.
Declared capacity	The hourly available capacity of 74 flight movements.
Evening	From 18:00 until 23:00 LT.
Fleet mix	The amount of aircraft divided into the four Wake Turbulence Categories L, M, H and J during each peak hour.
Morning	From 06:00 until 12:00 LT.
Peak hour	The peak hour is defined as the hour with the highest amount of flight movements (realization).
Realization	The realization is defined as the number of flight movements in a hour.
Start capacity	The available capacity at a certain runway combination during departure.
Start-Up process	The process time from the final update of the target off-block time giving by the ground handler (TOBT) until the aircraft starts pushback (AOBT).
Subprocess 1	The process time between the final update of the target off-block time giving by the ground handler (TOBT), until the target pushback approval time is issued by LVNL (TSAT).
Subprocess 2	The process time between the target pushback approval time is issued by LVNL (TSAT), until actual pushback (AOBT).
Target Time	Relates to the airport milestone, and serves as a contract time between the partners related to achieve that milestone.
Taxi-Out process	The process time from the start of the pushback (AOBT) until the aircraft takes off (ATOT).
Time reference	The time references under the A-CDM principles, related to the milestones.

Summary

In 2019 Amsterdam Airport Schiphol (AAS) had one of the most flight movements across Europe with 499,444 flights. To facilitate the future growth of air traffic movements, relevant stakeholders like airlines, airports, Air Traffic Flow Management (ATFM), Ground handlers, etc. must cooperate efficiently to make optimal use of the available capacity and eliminate delays. One solution to ensure optimal use of the available resource and capacity amongst others is to monitor the implementation of Airport Collaborative Decision-Making (A-CDM) principles. The CDM is successfully implemented since May 2018 at AAS (Schiphol Airport, 2019), together with around 29 airports across Europe. The main benefits of the CDM regarding capacity are (Eurocontrol Airport CDM Team, 2017):

- Reduce delays
- More efficient use of facilities
- Reduce environmental impact
- Increase capacity
- Fuel efficiency

For Schiphol airport and its associated partners, it is important to monitor the associated collaborative objectives to obtain the expected benefits. Previous research has been conducted by the department Capacity Management & Analytics at LVNL, to analyse the capacity and demand balance. Their objective was to find a general cause as to why the Declared capacity (peak hour capacity of 74 flight movements) is not reached during the outbound peaks. Based on their conclusion the following characteristics play a key role: runway combinations, fleet mix, and lack of demand at the runway.

Runway combinations and the fleet mix play perhaps two of the most important roles at capacity. It is important to understand how much impact these characteristics have on the overall efficiency of the capacity. The monitoring of this Declared capacity is performed by comparing the actual number of movements (realization) to the Declared capacity according to Airport Coordination Netherlands (ACNL) that works in cooperation with Air Traffic Control the Netherlands. At the outbound phase, the realization is measured by the number of flights that take-off from the runway in a certain period of time. However, before the aircraft takes-off, it goes through several phases and processes. All these phases are connected to each other. Therefore, bottlenecks before take-off can take place, resulting in not reaching the Declared take-off capacity. Furthermore, each of these phases and its corresponding processes have different success factors and restrictions that affect the capacity. As an example, it is easy to see that a certain fleet mix active in a period of time will have a different sequence than with another fleet mix distribution. As a result, the following main objective is analysed:

Developing a monitoring framework for the outbound Capacity as one of the main strategic objectives of the A-CDM approach at Amsterdam Airport Schiphol by analysing the accuracy of the Declared capacity in the so-called outbound peaks using a hybrid methodology based on process and data analysis.

To increase demand, first, it has to be properly defined, identified, measured and analysed. Parallel, a study of the main success factors or restrictions is carried out. This allows to identify the gap between planned- and actual operations together with its main success factors or restrictions. It allows to propose a strategic measure to increase demand. In this sense, the capacity could be monitored in certain periods of time and phases of the flight (Eurocontrol Airport CDM Team, 2017). Monitoring capacity at the pre-tactical level will allow to assess capacity assets and needs; formulate and implement capacity development strategies, and monitor/evaluate capacity development efforts. For these purposes, analysing the accuracy of the forecasted demand at key moments for all partners such as the landing, in-block, off-block, and take-off, is a key element for a strategic decision-making process.

The time references under the A-CDM principle (Airport Collaborative Decision-Making) are used to analyse the accuracy of the forecasted demand during the outbound phase. With the use of these references, the outbound phase can be divided into two main processes: the *Start-Up* process and *Taxi-Out* process. The *Start-Up* process begins when the final Target Off-Block Time (TOBT) is updated by the ground handler until the aircraft starts the pushback (AOBT). The *Taxi-Out* process starts from the AOBT until the aircraft takes off (ATOT). Within the *Start-Up* two subprocesses are identified. With *subprocess 1* from the TOBT until the pushback approval is issued (TSAT). Subsequently, *subprocess 2* that happens from the TSAT until AOBT. For each (sub)process the significant difference between the four Wake Turbulence Categories (WTC) is established through descriptive statistics and a statistical Analysis of variance test. Also, the significant differences throughout the dayparts (morning, afternoon, and evening) were established, since it was seen that the behaviour of the each daypart differs. Besides, all the processes and WTCs are compared based on the time spent in the process.

The results show in the comparison of the realization with the Declared capacity that only 18% of the peak hours reached that capacity. Besides, the evening shows a totally different behaviour, and has the highest share in reaching that capacity (52%). However, it must be noted that in the evening 2247 aircraft where active. In the morning this was 2038 and afternoon 2029. The difference is also seen in the distribution of the fleet mix. Here, the evening shows less variety with the highest share of 88.7% of WTC M. Overall WTC M dominates in all dayparts with 83.6%. Besides, it is seen that WTC J is only active in the afternoon and evening. During the month a total of seven different runway combinations were used, where 36L-36C and 18L-24 are the most frequent. It should be noted that not all combinations have the required start capacity for reaching the Declared capacity. Also, in these combinations, a difference is seen in behaviour between the evening and other dayparts.

In the outbound phase, each combination significantly differs based on the average time spent in the process. A heavier WTC results in more time spent. Besides, it is seen that overall in the evening there are less significant differences. However, on average the time spent is longer. This can be caused by the less variety in the fleet mix during the evening. On a limited scale, this relation is also seen between the morning and afternoon. Also in the analysis towards the Realization vs the Declared capacity the same relation is seen, whereby less variety in fleet mix reached the capacity more often. Overall an operational impact of the fleet mix on the outbound capacity can be seen. Which is mainly caused by the differences is time spent. This impact, however, is different for every (sub)process and WTC. Whilst J shows the most difference during the *Start-Up* especially in the afternoon and in subprocess1. L, M and H show the biggest difference in the *Taxi-Out*. Also, the variety of the time spent on the fleet mix is the biggest in subprocess 1 and Taxi-Out.

When focussing on the (sub)processes, the following can be observed. Different than the outbound phase, is in the *Start-Up* all WTCs spent more time than WTC H. Again, a different behaviour is seen in the evening where other WTCs spent more time than the morning and afternoon. Also it is seen that WTC J behaves much more extreme in the afternoon. *Subprocess 1* does not differ much from the *Start-Up*. The majority of the time spent in the *Start-Up* happens in this subprocess. Here the biggest differences in time spent are with L and J. In contrast to *subprocess 1*, *subprocess 2* shows a different behaviour. Here the smallest differences are seen between the WTCs. Where WTC L behaves differently than the other categories, with a maximum of 05:20 min mean difference. As final, the *Taxi-Out* differs from the *Start-Up*, where bigger differences are seen between the WTCs. Where frequently combination H, M has the smallest difference, now it is the biggest. Just like the outbound phase analysis, a heavier WTC spent more time during Taxi-Out, with exception of J.

Following-up research must demonstrate why this operational impact of the fleet mix on the outbound capacity exists, and how this can be eliminated. This is required to make optimal use of the available capacity at the airport, to accommodate future growth, and to eliminate delays in the outbound phase.

1 Introduction

This research is conducted within the Centre of Excellence (CoE) which is part of the Knowledge & Development Centre Mainport Schiphol (KDC). The founders of KDC are Royal Dutch Airlines (KLM), Air Traffic Control The Netherlands (LVNL), Amsterdam Schiphol Airport (AAS), and Ministry of Infrastructure and Water Management. With a shared goal to find innovative and valuable solutions for the sustainable development of AAS. The CoE consist of a cooperation of research partners between the Amsterdam University of Applied Sciences (AUAS) and the Technical University Delft. The AUAS focusses on 'Capacity Management' which is also related to the subject of this thesis, in particularly the outbound phase (KDC, 2020). In the following subchapters, the subject of the assignment will be explained clearly.

In 2019 AAS had one of the most flight movements across Europe with 499,444 flights (Schiphol Group, 2020). According to Schiphol Group (2020) the airport has a restriction of 500,000 flight movements till 2021, after this time reference the airport can grow to 540,000 flight movements for each operational year (Rijksoverheid, 2020). This limit is set by local governments, Ministry of Infrastructure, aviation stakeholders (AAS, airlines etc.) and residents living around the airport . This to ensure the balance between the growth in flight movements, local environmental quality, and noise reduction (Schiphol, 2020). To facilitate the future growth of air traffic movements, relevant stakeholders like airlines, airports, Air Traffic services (ATC), Ground handlers, etc. must cooperate efficiently to make optimal use of the available capacity and eliminate delays. It is therefore important that on-ground processes are monitored and analysed. To make optimal use of the limited land and airside capacity, predictability and accuracy of the flight are important to monitor to further control the aspects to achieved overall goals. One solution to ensure optimal use of the available resource and capacity amongst others is to monitor the implementation of Airport Collaborative Decision-Making (A-CDM) principles. The CDM is successfully implemented since May 2018 at AAS (Schiphol Airport, 2019), together with around 29 airports across Europe. The main benefits of the CDM regarding capacity are (Eurocontrol Airport CDM Team, 2017):

- Reduce delays
- More efficient use of facilities
- Reduce environmental impact
- Increase capacity
- Fuel efficiency

To increase demand it has to be first properly defined, identified, measured and analysed. In parallel, a study of the main success factors or restrictions should be carried out. This will allow to identify the gap between plan operations and actual ones together with its main success factors or restrictions. This will allows to propose a strategic measure to increase demand. In this sense, the demand could be monitored in certain periods of time and phases of the flight (Eurocontrol Airport CDM Team, 2017). Monitoring this at pre-tactical level will allow to assess capacity assets and needs; formulate and implement capacity development strategies and monitor and evaluate capacity development efforts. For these purposes, analysing the accuracy of the forecasted demand at key moments for all partners such as the landing, in-block, off-block, and take-off, is a key element for a strategic decision-making process.

For Schiphol airport, it is important to monitor the departure capacity on a pre-tactical phase. Previous research has been conducted by the department Capacity Management & Analytics at LVNL. Their objective was to find a general cause as to why the Declared capacity (peak hour capacity) is not reached during the outbound peaks. Based on their conclusion the following characteristics play a key role: runway combinations, fleet mix, and lack of demand at the runway.

Runway combinations and the fleet mix play perhaps two of the most important role at capacity. Therefore, it is important to understand how much impact these characteristics have on the overall efficiency of the capacity. The monitoring of this Declared capacity is performed by comparing the actual number of movements (realization) to the Declared capacity according to Airport Coordination Netherlands

(ACNL). At the outbound phase, the realization is measured by the number of flights that take-off from the runway on a certain period of time. However, before the aircraft takes-off, it goes through several phases and processes. All these phases are connected and therefore, bottlenecks before take-off can take place. This results in not reaching the Declared capacity at the runways system. Furthermore, each of these phases and its corresponding processes have different success factors and restrictions that affect the capacity. As an example, it is easy to see that certain fleet mix active in a period of time will have a different sequence that other with a different fleet mix.

1.1 Problem statement

During the several months of operations at Schiphol in 2019, the Declared capacity of 74 flight per hour was not reached on diverse occasions; hence, a deeper analysis to understand this gap is required. In addition, a framework for monitoring capacity on the outbound phase of the flight at pre-tactical level which integrated the effect of two main factors; the fleet mix and runway combination is required.

1.2 Research objective

Developing a monitoring framework for the outbound Capacity as one of the main strategic objectives of the A-CDM approach at Amsterdam Airport Schiphol by analysing the accuracy of the Declared capacity in the so-called outbound peaks using a hybrid methodology based on process and data analysis.

1.3 Research question

'What is the operational impact of the fleet mix on the outbound capacity at Amsterdam Airport Schiphol under the A-CDM principles?'

- Which (sub) processes can be identified during the outbound phase of the flight at Schiphol Airport?
    - *When does the Outbound phase start and end at Schiphol Airport?*
    - *What is the objective of each subprocess?*
    - *Which triggers each process to start?*
    - *What time reference can be identified as the beginning and end of each process based on the Airport Collaborative Decision-Making process (CDM)?*
    - *Which activities are happening in between the time references?*

- What are the outbound peak hours at Schiphol Airport?
    - *What is the outbound capacity at Schiphol airport?*
    - *What is the definition of capacity at Schiphol airport?*
    - *What is the amount of flight movements during this outbound peak?*
    - *Which runways are in use during these peaks?*
    - *What is the fleet mix distribution during this peak hours?*

- What is the operational impact of the fleet mix in each (sub)process?
    - *What is the time spent for each WTCs in each (sub)process?*
    - *How is the data spread?*
    - *What is the difference between the WTCs in each (sub)process?*
    - *Are there differences during the day?*

1.4 Research relevance/significance

Air traffic movements are growing each operational year. Therefore, it is important to make optimal use of the available capacity for operational and financial reasons. Also, airports need to make optimal use of their capacity since the expansion of the infrastructure is not always a solution. Looking at AAS, the airport is restricted has when it comes to infrastructure expansion. For airports like AAS, it is therefore a priority that they make optimal use of their resources to accommodate the future air traffic demand. Also, it is important to understand the operational processes in the outbound phase since there is little available knowledge. Furthermore, as addition to previous research. It can be seen how long each WTC takes in a subprocess. This information can be used for the KDC partners, and creates more situational awareness.

1.5 Research scope

The research is focused on the outbound phase of the flight at AAS. The outbound phase starts when the final update of the Target Off-Block Time (TOBT) is given by the ground handler and ends at the Actual Take-Off Time (ATOT) of the aircraft. The data and statistical analysis will contain data of all the flight movements for the month of July 2019. This data includes the final updates of the Time references under the A-CDM principles. Therefore previous updates will not be taken into account. Besides only the impact of the fleet mix and will be taken into account during *normal* operation. The reasons behind this impact is excluded. The flight movements of the data will include passenger aircraft, cargo aircraft, and general aviation. Helicopters departing from the runway '*HEL*' is out of the scope and removed from the dataset. Due to complexity and time reasons, for this research one outbound peak is established for the morning (06:00 till 12:00), afternoon (12:00 till 18:00), and evening (18:00 till 23:00) Local Time (LT) for each day.

1.6 Research Design

In Figure 1 the four phases that are conducted during this research are stated in a logical order. Phase 1 will consist of finding and understanding the relevant literature required to answer the main question (chapter 1.6.1). The second phase will focus on the data and statistical analysis which is performed to find the quantitative impact (chapter 1.6.2). The third phase (chapter 1.6.3) is to finalize the results and the decision-making tool.

Figure 1 Process flow methodology

1.6.1 Phase 1 - Desk research

The first step is to understand the literature related to the subject. In Figure 2 the different main subjects that were researched are stated in a logical order.

Figure 2 Process flow desk research

The first step in the desk research is gaining the general knowledge of AAS. This includes the operating hours, characteristics of the airport, and Demand. Next, the CDM implementation at AAS is researched to understand the overall objective and content. This includes the understanding of which information is being shared, the stakeholder's interests, and the operational processes. This information can be obtained from Eurocontrol's (Eurocontrol Airport CDM Team, 2017) and AAS's CDM manuals (Schiphol Airport, 2019) which can be found on the internet and the company's websites. Other used sources for understanding the processes are scientific articles and papers. These sources can be accessed through the HvA's databases (HvA, n.d.). Besides that, Eurocontrol provides free courses regarding the understanding of the CDM process, these courses give an overall view of the general CDM process. During this phase, it is important to focus on the differences between the time references under the CDM principles, The Milestone approach, and activities in the processes.

The third step covers the definition of capacity used at AAS. This includes the method of the different stakeholders that define capacity at the airport. Overall this step is used to get a better overview of the meaning and interpretation of capacity at AAS. This information is gained by reading scientific articles and papers (HvA, n.d.) and the intern server of LVNL.

The final step is to zoom-in to fully understand the outbound phase of the flight at AAS under the CDM principles. Here the beginning and end of the identified processes are described including their subprocesses. Besides, the objective of each process, process description, activities, and related CDM time are stated in this part. During this process, the outbound phase is divided into three main processes *Start-Up*, *Taxi-out*, and, *Take-off*. These main processes are based on the available data of the time references and grouped by the different activities. The required sources can be found in the related CDM manuals and scientific articles on the internet. Besides, the procedures during the departure phase of LVNL can be found on their intern server (LVNL, n.d.). Also during this phase, the possible operational influences of the fleet mix and runway combinations on the outbound capacity are described coherently with the process. Besides the required knowledge to understand the processes in the departure phase of the flights like layout, usage, and decision making is added.

1.6.2 Phase 2 – Data and statistical analysis

After phase 1 is finished, phase 2 - Data and statistical analysis can start. In Figure 3 the processes during this phase are displayed in a logical order.

Figure 3 Process flow data and statistical analysis

The data for this research is obtained from the Capacity Management & Analytics (CMA) department at LVNL. It contains all the departing flight movements of the month of July 2019 at AAS. This means cargo flights, commercial, non-commercial and helicopters. The substantive data consist of the Time references[4] that are used in the outbound phase. Besides this the flights characteristics amongst others like Flight number, Destination, Gate, Wake Turbulence Category (WTC), Engine Type, Number of engines, Runway, are available. This data will be analysed in the programming language *Python.* This is used for the connectivity between the department of CMA since the produced codes will be used as a tool for further research on the subject and is the best fit for the type of analysis.

As next the provided raw data needs to be prepared for the analysis. At first all the 31 excel files are combined to one. Here the rows containing the string 'HEL' in the column runway are removed, since helicopters are not in the research's scope. Secondly the column 'ATOT' will be sorted in ascending order for later purposes in finding the peak hour. As next the file is uploaded into Python were several functions are used to check the columns on deviation in data and data types. It is important to check for the correct data types, for example that numeric data is indeed numeric and not defined as a string. Finally all non-required columns can be hidden to create a clear overview.

The final step, data and statistical analysis, is divided into two parts:

Part one: Accuracy of the realization vs Declared capacity at the outbound peak hours

The first step in the data and statistical analysis is to identify the outbound peaks and coherent time windows. This data will be used for further analysis. With these outbound peaks, it can be seen if the Declared capacity of 74 flight movements per hour is reached or not, based on the realization. Since AAS is an hub airport, multiple peak hours can be established during the day. Therefore, the data is divided into three dayparts: morning, afternoon and evening. For this research one outbound peak is stated for the morning (06:00 until 12:00), afternoon (12:00 until 18:00), and evening (18:00 until 23:00) Local Time (LT). At first, the Realization (amount of flight movements within an hour) is determined for each flight. This calculation is performed for each row of the column 'ATOT' and counting the number of flights till - 3600 seconds. The unit seconds is chosen for more accuracy since the column 'ATOT' is displayed as hour: minutes: seconds. The maximum amount of flight movements (Realization) for each day and each daypart is an outbound peak hour. When the Realization is lower than the 74 flight movements, it is stated as Declared capacity not reached. All the data of the peak hours – 3600 seconds are combined in one data frame to identify the fleet mix distribution and used runway combinations. To provide more detail of the behaviour of the peak hours and runway combinations, the data is displayed in a boxplot. A boxplot is used to display the distribution of the data by a summary of five values of a dataset minimum, first quartile (Q1), median, third quartile (Q3), and maximum. It will tell something about the values of the outliers, how tight the data are grouped if it is symmetrical, and if the data is skewed (Galarnyk, 2018).

Part Two: Analyse impact fleet mix on (sub)processes

For each process and subprocess the same method of analysis is applied. At first a general overview of the time spent in the (sub)processes per WTC is analysed. For each (sub)process this is done by the time

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[4] These time references are the final and last updated versions. Any updates are out of scope.

difference between the two time references stated in Chapter 3. Due to the huge differences in samples a statistical test is performed. A One-way analysis of variance (ANOVA) is used to establish statistical differences between the means of the four WTCs (Statistics How To, 2020). This eliminates the coincidence of the differences between the WTCs. The assumption is made that the samples are normally distributed. For this test no equal sample sizes are required, however, the statistical power is less when the deviation in sample sizes are larger. Before this test is performed two hypotheses are established, where:

H0: There is no significant difference between the WTCs time spent in the *(sub)process*.
H1: There is a significant difference between the WTCs time spent in the (*sub)process*.

Here '*(sub)process'* is replaced by the coherent analysis. For this test, a 95% confidence interval is used where $p \geq 0.05$ accepts H0. However, the ANOVA test does not establish between which categories the difference occurs. If the ANOVA gives a significant difference, a Tukey post hoc test is performed to find which categories are significantly different. Since there are unequal sample sizes, the Tukey-Kramer Method is used (Statistics How To, 2020). When performing this test in Python, the program automatically checks is the sample sizes are equal or not and gives the correct output. The Tukey-Kramer test will be presented in a table with the following columns: Category 1, Category 2, Mean difference in min, P-adjusted, and Reject. Each row represents a possible combination between groups (Category 1/2).The mean difference in min is presented as a positive or negative number. This is calculated by Category 2 – Category 1. Therefore a positive mean difference presents that Category 2 has a higher mean, and spent more time in the (sub)process. The P-adjusted is the P-value, which is adjusted for the multiple groups to eliminated error.

After the overall view of the (sub)process, the differences between the dayparts are analysed. Since, in Part One of the data and statistical analysis different behaviour could be seen. This is done by the Measures of Central Tendency and spread and by performing a statistical tests. A statistical test is performed due the huge differences in sample size. A Two-way ANOVA is used to analyse the statistical interaction and difference between the groups (Verplancke, 2019). Again the assumption is made that the samples are normally distributed. Also, for this test no equal sample sizes are required, however, the statistical power is less when these samples have a huge deviation. Before this test is performed two hypotheses are established, where:

H0: There is no significant difference between the time spent of the WTCs in the different dayparts.
H1: There is a significant difference between the time spent of the WTCs in the different dayparts.

Also for this test, a 95% confidence interval is used where $p \geq 0.05$ accepts H0. This test will not only demonstrate the individual impact of the groups but also the interaction. Just like the overall view A Tukey-Kramer post hoc test is used to find the significant differences within the groups.

1.6.3 Phase 3 – Finalize findings and recommendations

In the final phase, the conclusions of each chapter is made. This will help the reader to understand the most important findings in that chapter. Afterwards the discussion is written to interpret the findings and to link it with the processes. As final the recommendations are made regarding further research on the subject. During this phase the whole thesis is checked for any inconsistencies, layout, clear and complete explanations, complete graphs/figures, etc. Secondly the code that is used for the analysis is changes to a user-friendly program. This results in combing several codes to one, renaming the object, and adding explanations.

2 Background information

AAS is located in the Netherlands (Western Europe) and is the main and only airport to facilitate direct intercontinental connections for the Dutch economy. The airport operates day (07:00 until 23:00 Local Time) and night and identifies itself as an airport with a hub function, focusing on network quality and destination portfolio; there are also some major carriers that use AAS for point-to-point operations (Royal Schiphol Group, 2020). At a hub airport it is essential to have sufficient capacity during peak hours since the level of competition is large for connection passengers. Especially since AAS has a relatively low local market (Zuidberg & Vinkx, 2017). The hub function also means that during the day there are different peak moments for arriving and departing aircraft (LVNL, n.d.).

In 2019 the airport facilitated 80.5 million passengers and 496,826 flight movements (Schiphol Group, 2020). From these movements 92,202 (18.6%) where intercontinental flights and 404,624 (81.4%) where European flights[5] (Schiphol Group, 2020). These flights fly to currently 317 destinations which are serviced by 79 different airlines (Schiphol Group, 2020). according to the Centre for Aviation (2020) the airports serve a number of 83 airlines. This could be explained by the fact that Schiphol Group (2020) does not include the cargo operators. The airline with the most flight movements (54.9%) on the airport is KLM Royal Dutch Airlines which also has its home base there (Centre for Aviation, 2020).

This demand determines the peak characteristics of departing and arriving aircraft. The most important characteristics are:

- **Charter and low-cost carrier/scheduled ratio:** Low-cost carriers tend to avoid the competitive slot to decrease ticket costs and strive for maximum aircraft usage.
- **Long-haul/short-haul:** Short-haul flights are usually frequently scheduled to maximize utilization and peak in the early morning and late afternoon. Long haul is scheduled for a convenient arrival time, for crew planning purposes.
- **Geographic location**: This can determine the fleet mix on the airport depending on when the distance is long range, or short range from the destination.
- **Nature of catchment area**: Airports with a bigger catchment area will have more demand. Overall smaller aircraft are required than when the catchment area is low.

Depending on these characteristics the daily demand and therefore also the peak hours might differ each day/week/hour (J.Ashford, Stanton, A.Moore, Coutu, & R.beasley, 2013). Due to the hub function of the airport a high deviation in the fleet mix and multiple peak hours can be seen. However, based on the day to day demand, the actual peak hours can deviate from Table 1. As can see there are a few differences when comparing the winter period with the summer period. This mainly depends on the demand characteristics during these periods.

Table 1 Peak hours winter period 2019/2020 (Schiphol, 2019) and (Zuidberg & Vinkx, 2017)

Outbound peak winter LT	Outbound peak Summer LT
07:00 – 07:40	07:00 – 07:19
09:20 – 11:00	09:20 – 10:39
12:00 – 13:00	11:40 – 12:39
14:20 – 15:20	14:00 – 14:59
16:40 – 17:40	16:20 – 17:59
19:20 -22:00	20:00 – 21:39

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[5] Schiphol Group (2020) defines European flights as destinations that are within the European continent. So distinction between Schengen and non-Schengen are not taken into account.

2.1 Collaborative Decision Making at Schiphol airport

EUROCONTROL's (2017) objective is to achieve seamless and safe air traffic across the European airspace. To provide these services, accurate data of when the aircraft enters their controlled airspace[6] is required. This information is maintained with the implementation of the CDM. The common objectives for all stakeholders are amongst others:

- The improvement of predictability and on-time performance of the operation
- Reducement of cost
- Optimize the use of airport infrastructure and reduce current congestions
- Flexible pre-departure planning
- Reduce apron an taxi-way congestion

The implementation of the CDM is a local process for every airport with EUROCONTROL's CDM manual (2017) as a facilitator. This since the implementation might differ due to the unique conditions and/or characteristics of the specific airport (Eurocontrol Airport CDM Team, 2017). The main challenges of getting the desired results are the conflicting interest of the different stakeholders, the sensitivity of the data and the security and data ownership concerns. Without overcoming these challenges, the CDM will become a bottleneck in the daily operation. In the context of this research the CDM at AAS is used for optimal use of the available capacity and is an initiative between handlers, airlines, LVNL and AAS. With a shared goal to improve the decision-making process by sharing operational data and to improve the turnaround process (Schiphol Airport, 2019).

CDM consists of the six elements concept which are all implemented at AAS since 2018 (Schiphol Airport, 2019). However, according to EUROCONTROL (2020) not all elements are connected to EUROCONTROL's Network Manager Operations Centre (NMOC) or need to be improved. The first element is the *information sharing* which is the essential foundation for all the other elements. The objective of this element is to share the required information of the flight to the relevant stakeholders. The second element is *The Milestone Approach* to create situational awareness by keeping track of the flight progress. EUROCONTROL has a total of 16 Milestones divided over the phase of a flight: *Inbound*, *Turnaround* and *Outbound*. All Milestones are recommended to be implemented. However, the airport has a total of 12 milestones implemented, which are marked with a red circle in Figure 4. As one can see milestones 7 and 8 are combined to one milestone. Generally the inbound is described as flying towards the destination airport. When this aircraft is connected with a connecting flight, several processes need to be carried out (turnaround). This included making the aircraft ready to continue the flight. When the flight is ready to depart towards the destination, the outbound phase starts.

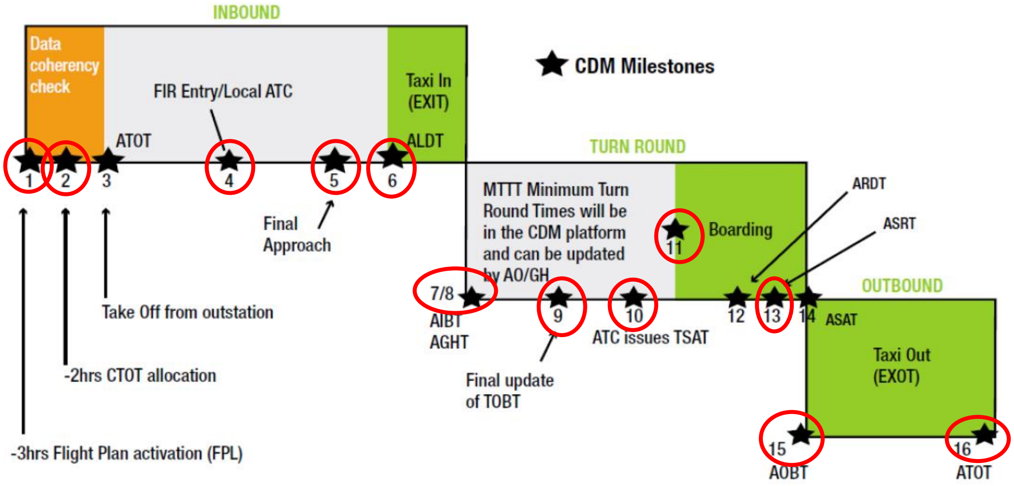

Figure 4 Milestones Schiphol Airport

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[6] An airspace which is defined when air traffic control service is provided in accordance with the airspace classification (J.Ashford, Stanton, A.Moore, Coutu, & R.beasley, 2013).

The third element is the *Variable Taxi Time,* to ensure the predictability of accurate take-off times at complex airports. For AAS this element is very important due to the high possible runway combinations, changes and the complex layout of the airport. The fourth element is the *Pre-departure Sequence* which establishes the off-block sequence, taking into account operational constraints and preferences of operators. This element ensures the maximum capacity during the outbound phase. The fifth element is *Adverse Conditions* which achieves collaborative management during periods of (un)predicted reductions of capacity. Looking at the overall weather in a year at AAS, this element is crucial. The final element *Collaborative Management of Flight Updates* strives for quality of arrival and departure information between the NMOC and in this case AAS.

AAS is connected to NMOC through the Departure Planning Information. The shared information is used to improve the network planning and to create situational awareness at EUROCONTROL (Schiphol Airport, 2019). This information is collected in the existing Airport Central Information System Schiphol (CISS). The sources of information can be the ground handler, LVNL or airline systems. The goal of CISS is to make data available to all stakeholders to create situational awareness, calculate estimations of CDM time references, etc. (Eurocontrol Airport CDM Team, 2017).

2.2 Definitions and terminology

2.2.1 Definition of capacity

The term capacity is used worldwide in multiple industries. In the aviation industry the definition of capacity is pretty much the same, but the details might differ. The following definition of capacity is given by the International civil aviation organization (International civil aviation organization, 2001):

‘*A measure of the ability of the ATC*[7] *system or any of its subsystems or operating positions to provide service to aircraft during normal activities. It is expressed as the number of aircraft entering a specified portion of airspace in a given period of time, taking due account of weather, ATC unit configuration, staff and equipment available, and any other factors that may affect the workload of the controller responsible for the airspace*.’

EUROCONTROL (2003) adds that the fleet mix and system capabilities also need to be taken into account. Furthermore, capacity can be divided into two sub-categories: Sector and Declared capacity. The sector hourly capacity is defined as the maximum number of flights that can enter in an hour safely in a sector. Where the Declared capacity is the number of flights enters each hour, assessed by the Air Navigation Service Provider (in this case LVNL) (EUROCONTROL, 2003).

2.2.2 Definition of Capacity at Schiphol Airport

At many airports around the world runways are running near to their capacity during peak periods. An independent slot coordinator allocates the number of slots available for arrivals and departures for these airports. With the use of slots, the available capacity is ‘controlled’ and therefore avoids any surprises and over-capacity (J.Ashford, Stanton, A.Moore, Coutu, & R.beasley, 2013).

The Declared capacity at AAS is determined in a cooperation LVNL and ACNL. They specify the Declared capacity as ‘’*the highest substantiated capacity per hour during a “mode” of the ATM*[8] *system which can be achieved depending on the runway combination.’’*. The mode is defined as an inbound peak, outbound peak, off-peak and night.

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[7] Air Traffic Control

[8] Air Traffic Management

Table 2 Operational capacity summer 2019 (ACNL, 2018)

ATM mode	**Possible within period from – to (UTC)**	**Nominal[9] capacity per hour**		**Nominal capacity per 20 minutes**	
		IFR Arrivals	**IFR Departures**	**IFR Arrivals**	**IFR Departures**
Day: departure peak mode	05:00-19:39	36	74	12	25
Day: arrival peak mode	05:00-19:39	68	38	23	13
Day: off peak mode	04:00-04:39	24	30	8	10
	04:40-04:59	24	40	8	14
	05:00-20:39	36	40	12	14
	20:40-20:59	36	25	12	9
Night mode	21:00-03:59	24	25	8	9

ACNL provides the Declared capacity (number of slots) for the summer and winter period each operational year. This capacity is based upon the maximum legally binding of 500,000 aircraft movements (Rijksoverheid, 2020) and the operational runway capacity provided by LVNL. The Declared capacity is divided into departure and arrival peak mode and off peak mode. Hereby for the summer (Table 2) period[10] the local time is UTC + 2. However ,LVNL states that the overall capacity of the airport is defined by assuming an average traffic mix of <1% Super jets (J), ~15% heavy (H), ~85% medium (M) and <1% light jets (L). For the outbound peak a number of 74 aircraft can be handle in the runway combination 06/36L+36C or 18R/24+18L between 06:30 and 22:30. This is based on the required staff and available capacity (Hoogerbrugge, VEM Performance Standard Summer 2019, 2018).

2.3 Flight characteristics

In this research, the flight characteristics: fleet mix (WTC) and runway combinations are researched during the peak hours. The main focus here lies on the WTCs. The fleet mix is seen as the amount of aircraft of each WTC in a peak hour. The runway combinations are used for further substantiation. Princeton (n.d.) states that the runway capacity is limited due to the characteristics of the aircraft performance like aircraft type and aerodynamics, which are related to the minimum separation between aircraft. Besides that the Human factors (pilot training, experience, skills etc.) and the direction of the aircraft destination can also have a major influence.

One of the main problems of not reaching the available runway capacity is the minimum separation between aircraft due to safety reasons (Paullin). For every runway several Stander Instrument Departures (SID) are available to guide the aircraft into the desired sector. By sequencing aircraft with different SIDs for departure the minimum separation is minimal, which results in a higher runway capacity. By aircraft that follow different tracks with a minimum of 45 degrees a separation minimum of one-minute is used. Aircraft who follow the same track and fly 74km/h (40kt) or faster counts a two-minute separation minimum. For following aircraft with a separation of 760m or less between runways counts a three-minute separation. Besides these minimum separations, the separation is also depending on the WTC. This is based upon the maximum take-off weight or aircraft type. The following categories are used:

- Super (J) → A380
- Heavy (H) → ≥ 136 000 kg
- Medium (M) → > 7000 kg and < 136 000 kg
- Light (L) → ≤ 7000 kg

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[9] The nominal capacity is the volume of the runways operating to its brim.

[10] Summer period is defined as the period from March 31, 2019, through October 26, 2019;30 weeks (ACNL, 2018).

3 Outbound phase under the CDM principles

A flight can be divided into three phases: Inbound, Turnaround, and outbound. In the focus of this research, the impact of the fleet mix is analysed during the outbound phase. This outbound phase can be divided into three main processes based on the time references used in the milestone approach and coherent activities. The three processes are *Start-Up*, *Taxi-Out*, and *Take-off*, which will be explained in the following-up sub-chapters.

3.1 Start-Up

According to the Milestone approach the outbound phase starts at Milestone 15 using the reference time called Actual Off-Block Time (AOBT); however, at AAS (2019) the outbound phase starts when the final update of the TOBT is issued by the ground handler. Therefore, this definition is used further in this work. This results that the Milestone 9 is included in the outbound phase.

The first process in the outbound phase is the *Start-Up,* which can be seen in Figure *5*. The main objective of this process is to inform the relevant CDM partners that the aircraft is commencing to leave the parking stand which is the first step to depart. During *Start-Up* the Ground Controller, the cockpit crew and Ground Handler have the responsibility to achieve the shared objective.

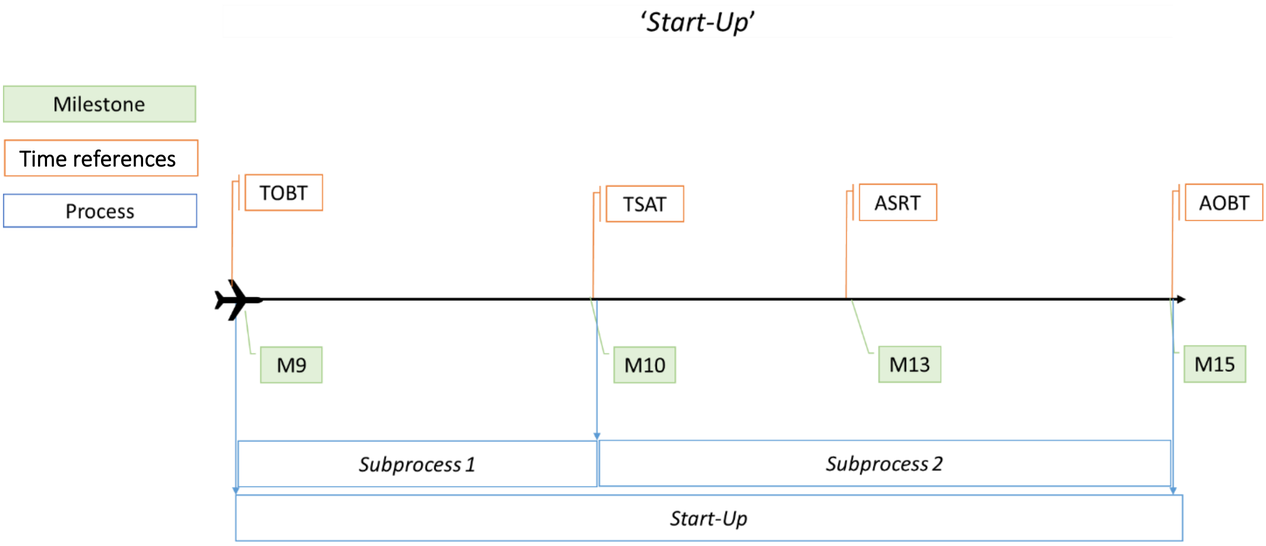

Figure 5 *Start-Up* process visualization

The first time reference according to the CDM in the *Start-Up* is when the final update of the TOBT is issued by the ground handler (Figure 5). This is used to indicate when the ground handling processes is target to be finished. At AAS this means the boarding activities are done and handling equipment is removed from the aircraft with aircraft doors closed. An accurate TOBT is important for the departure planning of the airport and the ATFM across Europe since it is used for departure (planning) calculations. Also, it will result in a more optimal and stable Target Start-up Approval time (TSAT) and provide clear intentions for on-ground operations. Any deviation of the TOBT between the real-life state therefore can have huge influences on the outbound phase.

The next time reference is the TSAT (milestone 10). This represents the expected start-up/pushback approval time for the aircraft and is issued by LVNL. The TSAT is calculated for each flight by the Collaborative Pre-Departure Sequence Planning System (CPDSP) with the TOBT as an input (Figure 6). The TSAT is amongst other parameters/time references used for pushback management, which is advised to be available five minute before the given TSAT (Eurocontrol Airport CDM Team, 2017).

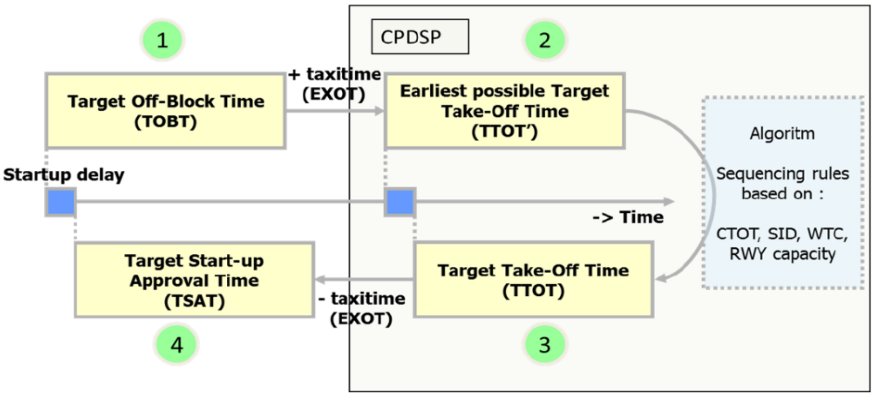

Figure 6 Collaborative Pre-Departure Sequence Planning system

In the TSAT window (-/+ 5 minutes) the pilot calls for the Actual Start-up Request Time (ASRT), which provides start-up clearance. The ASRT is issued by the Ground Controller which has the competence to delete or update the ASRT when the aircraft is not ready or is unable to pushback (LVNL, n.d.). When the ASRT is approved the pilot communicates with the pushback driver to start pushback. The *Start-Up* ends when the AOBT is reached (Figure *5*), which will be explained in the following subchapter.

As seen in Figure 5 the *Start-Up* can be divided into two subprocesses. The ASRT is a dynamic time reference which takes place before or after the TSAT. Therefore, it is excluded from the analysis. This results that the moment from the final update of the TOBT is issued until the pushback approval is issued by LVNL (TSAT) is referred to as *subprocess 1*. The moment from the pushback approval time (TSAT) until the aircraft starts pushback (AOBT) is referred to as *subprocess 2*.

3.2 Main drivers and implications of flight characteristics Start-Up

3.2.1 The fleet mix on the Start-Up process

During the *Start-Up* the aircraft is parked at the gate/apron. At AAS a total of eight piers – B, C, D, E, F, G, and H/M are available (Figure 7). Here the D-pier is a mix for Schengen, and non-Schengen aircraft. The E, F, and G pier are used for non-Schengen aircraft and are mainly flight with wide-body aircraft. Piers H and M are mainly used for low-cost carriers which make use of small-body aircraft. As final Piers, B, and C are also used by small-body aircraft for Schengen flights.

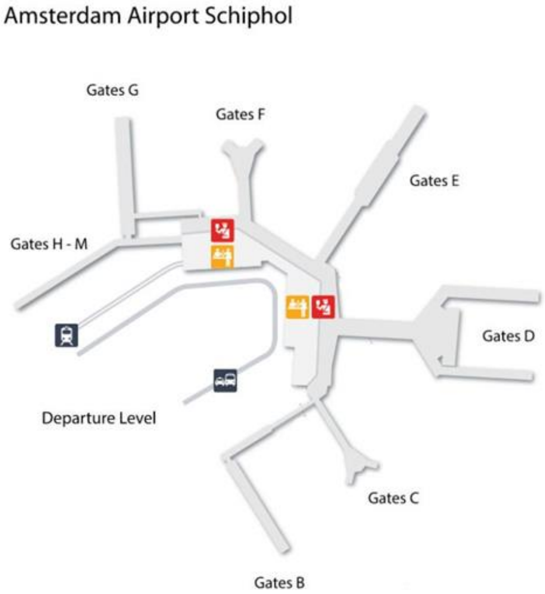

Figure 7 Layout of the gates/piers at Schiphol Airport

The gate assignment process is a complex part and is done by the airport. The Gate planner considers the origin and its destination, duration of ground time, airline preferences, and length and wingspan of the aircraft. To get a better insight at which aircraft type can park at which pier the airport published the documents Overview Aircraft Types (Schiphol Airport, 2018) and Aircraft Stand Table (Schiphol Airport, 2020) to show the possible parking positions. With the characteristics of each pier in mind, it can occur that during *Start-up* an aircraft needs to wait to pushback when another aircraft nearby is pushing back. When there is less variety regarding the fleet mix, aircraft may be parked close to another and therefore the time spent in the *Start-Up* might increase.

To push back the aircraft, a pushback truck is needed. Here the fleet mix may have an influence on the capacity since not all the pushback trucks can handle all the aircraft types. Depending on the (number of) resources the ground handlers at AAS own, less variety in fleet mix during operation can form a bottleneck (KALMAR MOTOR AB, 2020). This may also be seen in *subprocess 2*, as previously described.

3.2.2 The runway combinations on the Start-Up process

During this process the aircraft is parked at the gate/stand, where the aircraft needs to wait for the target pushback approval time. As stated in Chapter 3.1 the algorithm behind the CDSP determines the pushback approval time. In this system the factor of the assigned runway is taken into account. A more detailed description of the runway characteristics is explained in Chapter 3.6.2. When a runway combinations is chosen with a lower start capacity, because of the weather of environment conditions. The time until the pushback approval may take longer. Therefore, in *subprocess 1* and the overall *start-up* the time spent can be longer. Also when a lot of aircraft need to depart from the same runway, the waiting time for pushback approval might be longer.

3.3 Taxi-out process

The second process of the outbound phase is the *Taxi-Out,* starting at the moment when the aircraft starts pushback (AOBT) and finish when the aircraft takes off (ATOT) (Figure 8). The main objective of this process is to inform the relevant CDM partners that the aircraft is taxiing towards the assigned runway to take-off. During the *Taxi-Out* process the Ground Controller, the cockpit crew and Ground Handler have the responsibility to achieve this shared objective.

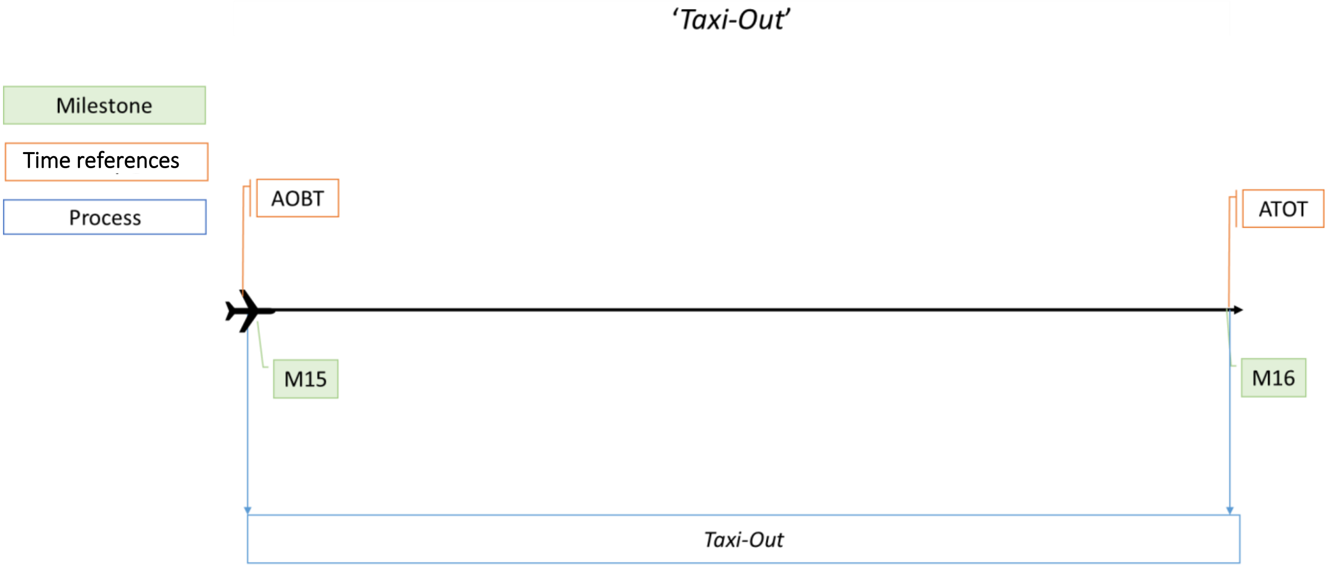

Figure 8 *Taxi-Out* time reference visualization

During normal operation taxiing starts when the aircraft can move on his power, except during the start[11] and landing[12]. However, this moment has no available time reference under the A-CDM principles. According to the CDM manual (Eurocontrol Airport CDM Team, 2017) the actual taxi-out times will be presented by AXOT (Actual Taxi-Out Time). This is calculated by the time references ATOT – AOBT. Therefore, the *Taxi-Out* starts when the aircraft starts pushback (AOBT). At AAS the AOBT represents the pushback of the aircraft or vacating the parking position. However, LVNL determines the AOBT based on the redline crossing on the apron when the flight status changes to 'TAX' (Schiphol Airport, 2019). Both definitions are used as an input for the final AOBT and will overwrite any previous AOBT. When the aircraft is off block, the pushback is in progress. During pushback, the engines of the aircraft are turned on. When a pushback is not required, the engines are turned on the moment the AOBT is reached. The pushback trucker is temporarily responsible for the safety of the aircraft when the pilot gives the conformation 'Break released'. According to LVNL (n.d.) there are two pushback options possible, standard pushback and alternative pushback. For every apron, at AAS a standard push-back direction is determined. When an alternative pushback occurs, this direction is changed. When the pushback is not starting one minute within the approval the permission expires, to assure the Ground Controller has no unexpected pushbacks than can form a hazard or bottleneck. At many stands the push-back limit is determined by a white line, which the Ground Controller can use to determine if two aircraft next to each other can be pushed-back at the same time.

To start taxiing towards the assigned runway, the pushback truck needs to be disconnected from the aircraft. This is done by showing the pilot the gear pin for conformation. During this moment the 'ALL CLEAR' sign is given by the Ground Controller on the taxiway[13] to start taxiing (LVNL, 2016). Hereby, the taxi-routes are standard for each gate/runway combination. According to annex 11 (International civil aviation organization, 2001) these routes should be simple, direct and designed to avoid traffic conflicts.

Once the aircraft arrives at the runway, the responsibility is transferred from Ground Controller to the Runway controller. The runway controller is responsible for the traffic in Schiphol Control Zones 1,2 and 3 and the available runways. Before the aircraft arrives at the runway it frequently holds at the runway-holding position. For runways longer than 900m the aircraft needs to hold 50m from the runway edge. The Cockpit checks need to be completed prior line-up, besides that the pilots should ensure commence to take-off roll immediately after take-off clearance. This way checklist requirement is kept to a minimum on the runway and no capacity gets lost. Once the aircraft reaches the runway the frequency is changed from Ground Controller to Runway controller, which gives the approves for take-off (LVNL, n.d.)

The *Taxi-Out* ends when the ATOT is reached, which will be explained in the following chapter.

3.4 Main drivers and implications of flight characteristics Taxi-out

3.4.1 Impact fleet mix Taxi-Out

Research shows that inefficiencies of the taxi-route come from runway congestion and are reduced by stand holding. The main constraint during these taxi-routes is related to the safety of the aircraft, which requires separation to avoid collisions on the ground. Another routing constraint is the speed, acceleration for passenger comfort, aircraft/taxiway segment based on weight, and width and the turning angle (J.Guépet, O.Briant, J.P.Gayona, & R.Acuna-Agost, 2015). Longer taxi-times can also be caused when aircraft need to wait to access the runway. Instead of waiting at the gate with engines off, it waits before the runway (Murça, 2017). Marça (2017) also states than when more aircraft are active on the surface, the average taxi-out times increases. Therefore, when more aircraft of a higher WTC (more separation) are

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[11] The start is defined when the take-off clearance is given.

[12] The landing is defined as when the landing clearance if given till the speed of the aircraft on the ground is fast decreasing, or when the aircraft left the runway.

[13] The taxiway is as a strip for aircraft to transport from the parking position to the runway and vice versa (ACRP, 2012).

active, even longer taxi times are expected. Other factors associated with the uncertainty of taxi times depend on the route and gate location.

At AAS the A380 has several restrictions when it comes to taxiways. Some taxiways are not available, or with guidelines, for the aircraft due to his long wingspan. The same applies to other aircraft types. Multiple taxiways have limits when it comes to wingspan. Therefore, the AXOT may take longer for an aircraft with a higher WTC than a smaller (Lufthansa Systems, 2020). Looking at the runway combinations, the knowledge discussed in chapter 3.2.1. can be combined. Aircraft with a high WTC may take longer to taxi due to the geographical location of the gate and/or assigned runway combined with taxiway limitation, and seperation.

3.4.2 Impact runway combinations Taxi-Out

The taxi times differ when different runways (combinations) are used. As can see in Figure 9 Schiphol airport layout the runways are spread over the area. A large distance is seen between the gates and departure runway 36L. Therefore, when this runway is used, the taxi times will be longer. The gates at the airport are in a half circle. If the assigned runway is on the opposite side of the airport, the taxi times will increase. It can also occur that during a peak hour the used combinations are changed. When an aircraft needs to change during taxiing this will also increase the taxi times.

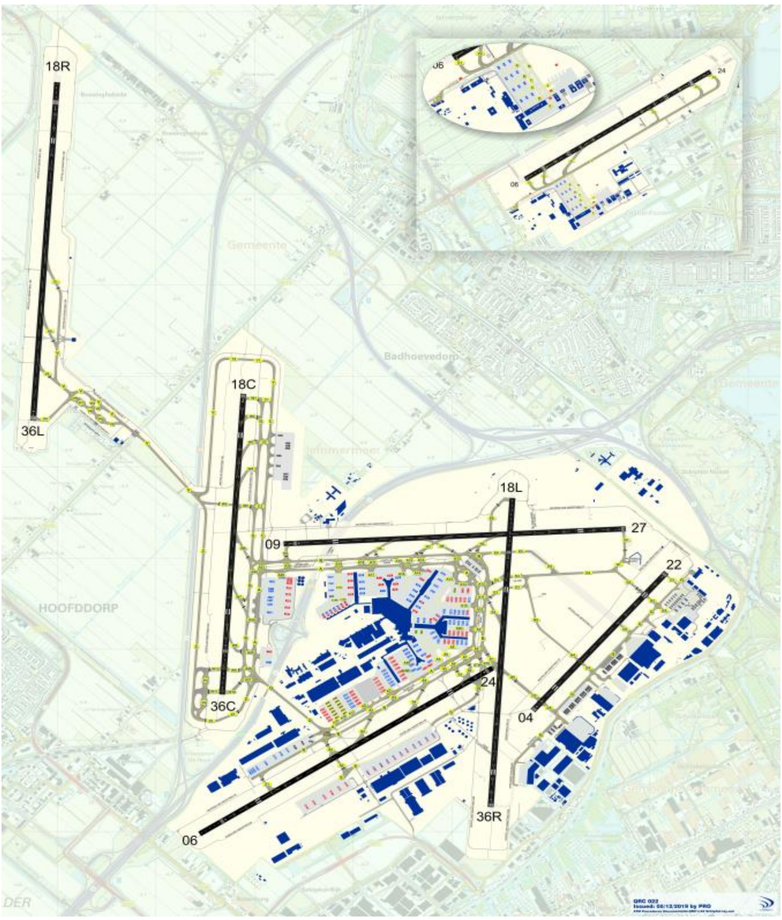

Figure 9 Schiphol airport layout (LVNL, n.d.)

3.5 Take-off process

The last process of the departure phase is the *Take-Off,* the time references can be seen in Figure 10. The main objective of this process is to inform the relevant CDM partners that the aircraft has Take-Off and is flying towards the destination. During *Take-Off* the Runway Controller and the cockpit crew have the responsibility to achieve this shared objective.

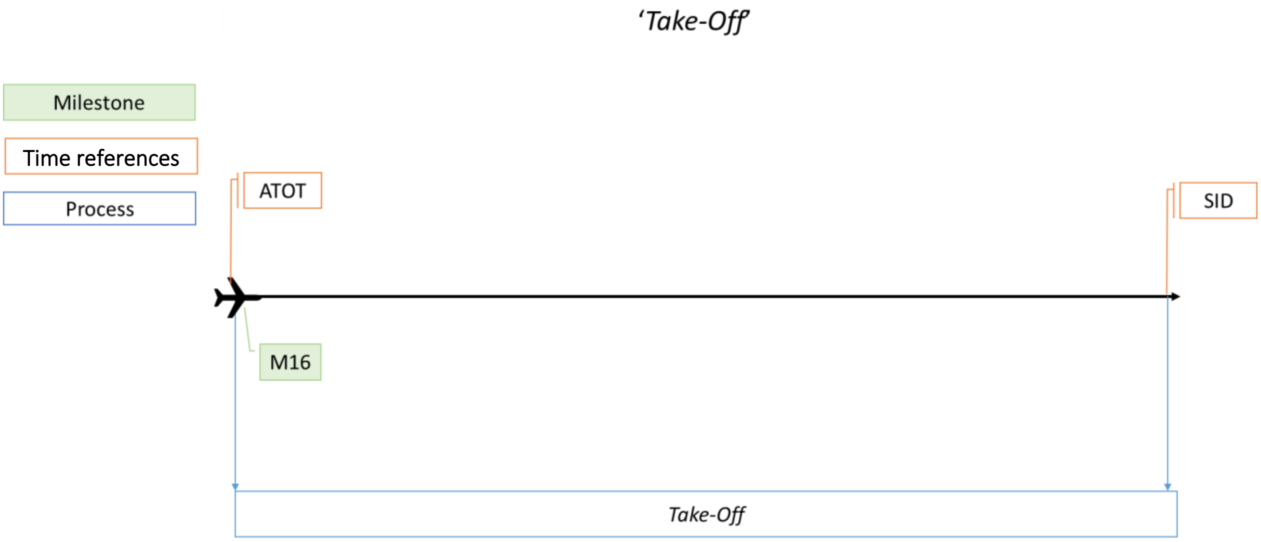

Figure 10 *Take-Off* time reference visualization

The *Take-Off* starts when the ATOT is reached, which is when the aircraft takes off from the runway[14] and the wheels detach from the ground. The ATOT triggers the Flightstate to 'AIR' and is provided by LVNL or from the Aircraft Communications Addressing and Reporting System when this is equipped (Eurocontrol Airport CDM Team, 2017). In an ideal situation the Target Take-Off Time (TTOT) and the CTOT should be equal to the ATOT. The CTOT is a fixed time the aircraft must take-off to keep its place in the airspace. The TTOT is based on other time references and used for planning purposes. After the ATOT is reached the aircraft set course towards the SID. These SIDs are designed for optimal use of the airspace, to minimize noise nuisance and limit environmental impact. The SIDs are generally displayed and therefore for every runway a specific route towards the SID is required. Sinds there is no accurate available data of at what time the aircraft reached the SID, this process is not taken into account in the analysis.

3.6 Main drivers and implacations flight characteristics on Take-off

3.6.1 Impact fleet mix Take-Off

Table 3 shows the required separation between the WTCs during take-off.

Table 3 WTC separation runway (LVNL, n.d.)

WTC	Separation minimum	Separation minimum intersection
Super → Heavy	2 min	4 min
Super → Medium	3 min	4 min
Super → Light	3 min	4 min
Super → Super	1 min	4 min
Heavy → Medium	2 min	3 min
Heavy → Light	2 min	3 min
Medium → Light	2 min	3 min

---

[14] A runway is defined as a strip on which aircraft take off and land (ACRP, 2012).

As one can see, when there are different WTC active in the same sequence, the capacity of the runway will be significantly lower than when the same WTC is operated. Also, aircraft with a relatively high WTC require more separation. Here the capacity will be lower than when low WTC is active.

3.6.2 Impact runway combinations Take-off

Looking at the runway combinations the number and operational use of the runways have a substantial effect on the capacity. When depend runways are in use the capacity will be significantly lower than independent runways. Besides a departure runway has more capacity than when it is used for arrival (ACRP, 2012). As can see in Figure 9 the runway layout at AAS is complex and dependent runway use often occur.

For any given airport the runway combinations vary due to weather conditions, the mix of arrivals and departures. In some weather conditions some runways (combinations) may not be available, which can reduce the capacity (ACRP, 2014). The runway layout of AAS is built based on the different wind directions that occur during a day so that the aircraft can always depart and land against the wind. However, the airport never uses all the available runways at the same time.
The runways use for each mode:

- Night (23:00 – 06:00 LT)→ One runway for landing and one for departure
- Off peak mode → One runway for arrivals and one for departures
- Inbound peak mode → Two runways for arrivals and one for departure
- Outbound peak → One runway for arrivals and two for departures
- In special circumstances four runways can be used

For these modes multiple combinations are available, which is primarily determined by weather conditions. Besides that at AAS environmental rules play a significant role in using certain runway combinations. For each runway combination, the runway capacity is determined based on the cloud base condition (visibility) 'good', 'marginal' and 'limited visual conditions'. These modes can increase aircraft separation and therefore decrease of runway capacity (Zuidberg & Vinkx, 2017). LVNL (n.d.) confirms this decision process, but adds the so-called 'preference order'. This preference list is part of the 'Nieuwe Normen-en Handhavingsstelsel' and is used when multiple runways are available, to minimize noise nuisance, environmental impact, etc. Sometimes three departing or arriving runways are in use, which is usually in the combination with the Oostbaan 04-22. This is the is the shortest runway at the airport and is mainly used for general and small aviation or when the other runways are unavailable if possible (LVNL, n.d.).

When two departing runways are in use, the aircraft is assigned to that runway which is preferable to the direction of destination (SID). This can lead to uneven distribution of the aircraft between two runways. The active runway also has a huge influence on taxi-times, occupation of parking positions, taxi-routes and handling of the airspace around AAS which results in an impact on the whole Dutch airspace. Therefore changes in runway combinations have a huge impact on the surrounding processes (LVNL, n.d.)

Each runway combination has a specific available start capacity. Therefore, it is possible that some runway combinations do not have the capacity of 74 flight movements during the outbound peak. Also, the visibility plays an important role in runway capacity. An overview of this capacity can be seen in *Appendix II Outbound peak runway capacity*.

3.7 Conclusion

AAS identifies itself as an airport with a hub function combined with carriers who adopt a point-to-point operation. In 2019 the airport facilitated 496,826 flight movements with a limit of 500,000 movements. KLM operates the most flight from the airport (54.9%) which is also the home base of the airline. To make optimal use of the available resources and capacity the CDM is adopted at AAS. The CDM is fully implemented at the airport since 2018 and is an initiative between Ground Handlers, airlines, LVNL and

AAS to improve the decision-making process. The Declared capacity for the outbound peak at AAS is 74 flight movements. This number is depended on the available runway capacity, the legally binding of 500,000 movements each operational year and the average traffic mix. To analyze the impact on the actual capacity, the outbound phase is divided based on the available time references according to the CDM in *Start-Up* and *Taxi-Out*. Hereby the *Start-Up* can be divided into two subprocesses.

4 Accuracy of the realization vs Declared capacity at peak hours

As stated in the methodology (Chapter 1.6.2) the first phase of the data and statistical analysis consists of the identification of the peak hours in each daypart. Figure 11 shows these time windows for the morning (07:58 - 11:10 (UTC[15] +2)), afternoon (11:48 - 17:45 UTC + 2), and evening (17:00 – 22:22 UTC +2) for the whole month. An overlap can be seen between the afternoon and evening of 45 minutes. However, it should be noted that only one peak hour occurred between 17:00 - 18:00 in the evening window. Therefore, without this outlier the evening has a time window of 21:37 - 22:22. Also, due to multiple variables the realization varies each day which causes the Declared time windows (orange) to differ from the found ones (black) in Figure 11. It is chosen to consider this deviation to properly identify the highest realization in each daypart for each day. Besides, it can be seen that in the afternoon, the timeframe of the peak hour deviates throughout the month, which causes a bigger range in the time window.

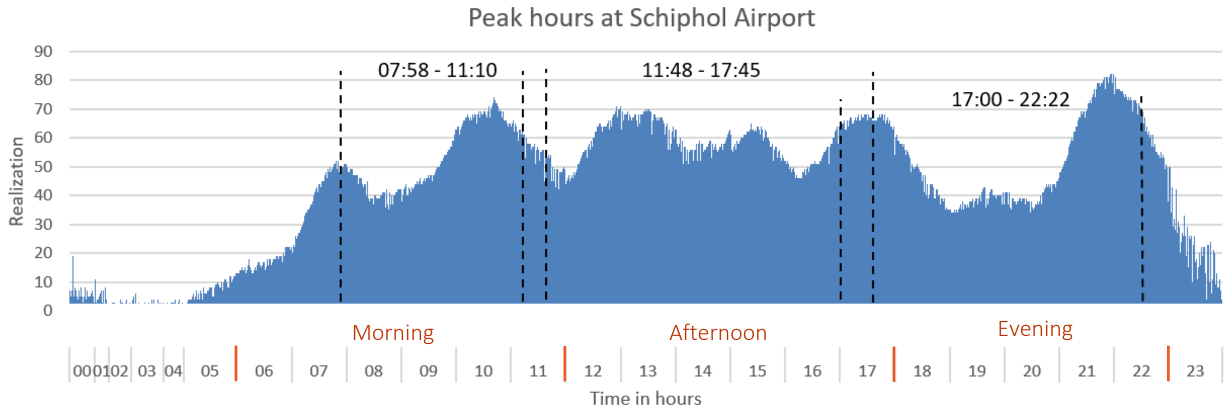

Figure 11 Peak hours at Schiphol Airport

Figure 12 shows the realization of the peak hours, divided by the dayparts, against the Declared capacity to establish the performance of the peak hours. It can be seen that in the morning the Declared capacity is only reached once (3%). In the afternoon this is never reached. For the evening this is in the cases (16 of 31, 52%). This results in only 17 peaks of the total 93 (18%) have reached the declared capacity were the evening plays the biggest role. In the evening of July 24th, a drop of the realization is the result of a fuel problem that occurred at AAS (Schiphol, 2019). This problem might also influence the peak hours after that day. The fuel problem is considered as an abnormal situation and left out of the scope of the analysis. This also applies for the morning on July 20th. Possible reasons are searched like abnormal weather conditions, news articles, and abnormal circumstances. However, no reason can be found, but it can be seen that this data point is exceptional.

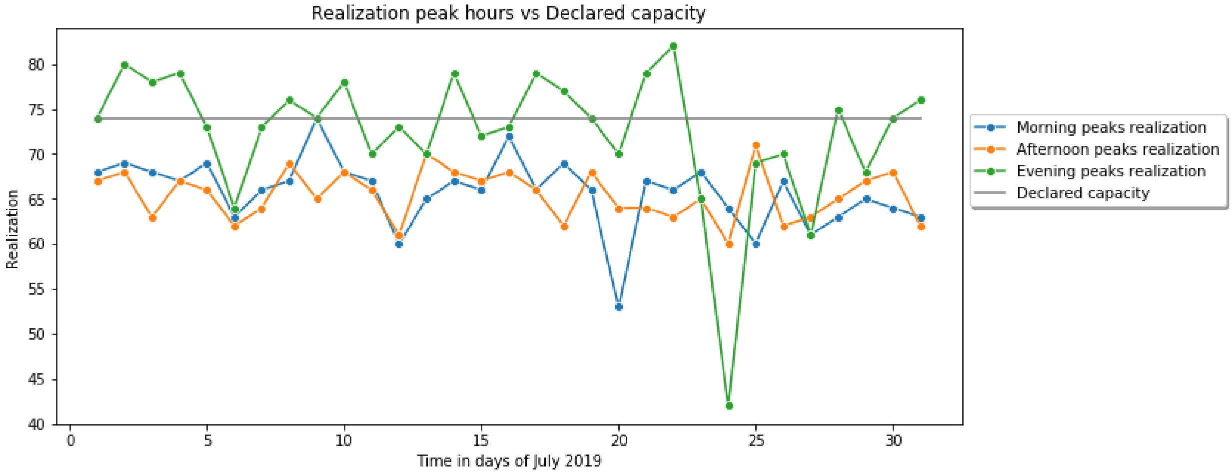

Figure 12 Realization peak hours vs Declared capacity

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[15] Coordinated Universal Time

Figure 13 shows the difference from the Declared capacity (74 flight movements) for each daypart. Here the 0 on the x axis represents the Declared capacity. A negative difference presents the number of flights that can be added to reach the Declared capacity. A positive difference represents the number of flights that where above the Declared capacity. In the morning, a total of 2038 aircraft were served, with an average of 66 each peak. This number is considerately lower than the Declared capacity and has an negative difference of 7.83 aircraft on average. A negative difference is also seen in the afternoon with an average of 8.55, where 2029 aircraft were served in total. It can be seen that the morning and afternoon behave similarly, were at most times an negative difference of eight aircraft occurred (median). It is clear that the evening has a different behaviour, but still has an average negative difference of 0.5 aircraft. Here 2247 aircraft with a daily average of 72 were served, which is higher than the morning and afternoon. It leads to a higher probability to reach the Declared capacity in the evening. The evening shows the biggest spread in data, which results in less consistency during the month. The exact values of Figure 13 can be found in Appendix III *Measures of Central Tendency and spread*, Table 15.

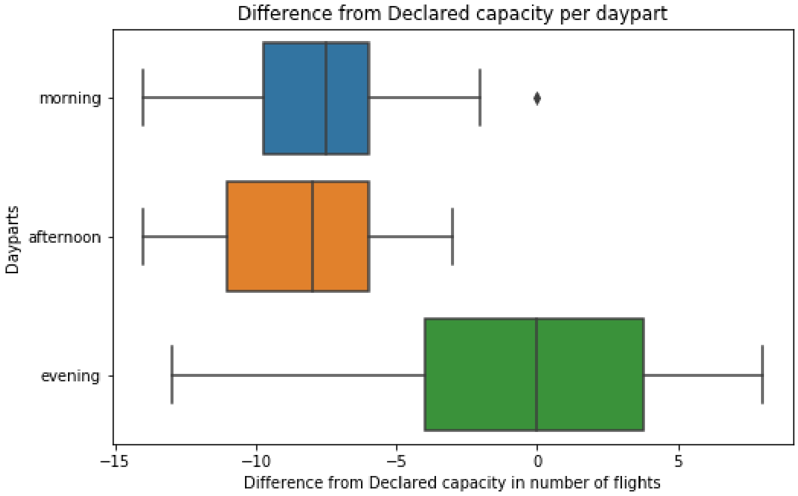

Figure 13 Difference from declared capacity per daypart

4.1 Distribution of fleet mix

Figure 14 shows the distribution of the fleet mix in an overall, the morning, afternoon, and evening outbound peak hours. Furthermore, Figure 15 shows the distribution for each day during the month for all peak hours. An overview of each day during the month for every daypart can be seen in Appendix IV *Fleet mix overview*.

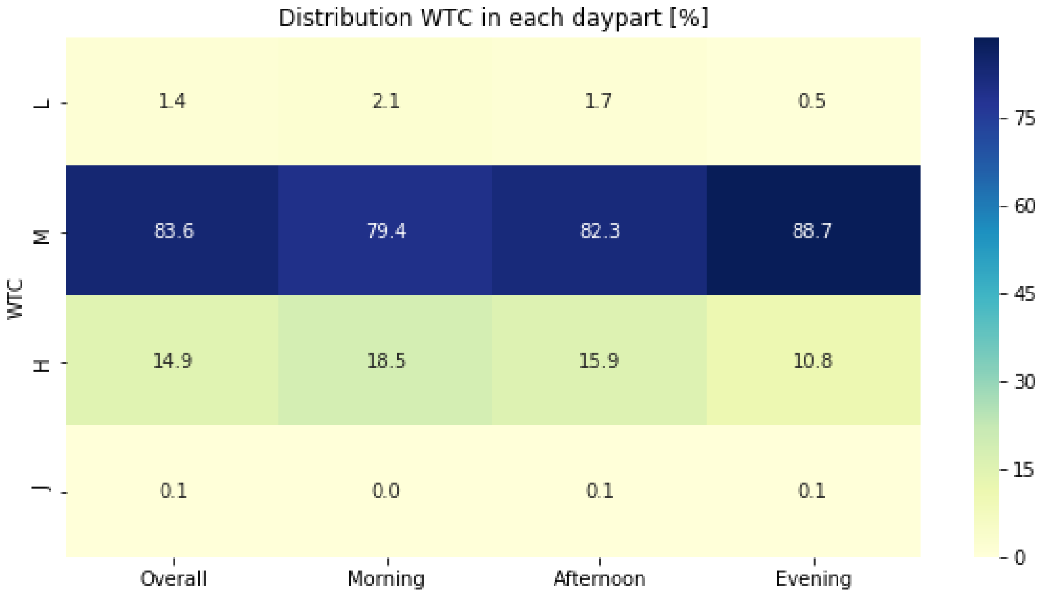

Figure 14 Distribution WTC in each daypart in percentage

WTC M: *Medium* aircraft most frequently occurs with 83.6% (5201 aircraft) in all peaks. This is followed by WTC H: *Heavy* with 14.9% (929 aircraft), L: *Light* with 1.4% (86 aircraft), and J: *Super* with 0.1% (3 aircraft). Besides, it can be noted that the distribution is approximately the same during the whole month (Figure 15). As explained before, on the 20th and 24th a drop in the amount of aircraft can be seen. Besides WTC J only occurs during three days (12, 29, 31). In the morning, a slightly different picture is sketched with a lower percentage of aircraft with WTC M (79.4%, 1576), and no J (0%, 0). However, a higher percentage is seen at WTC L (2.1%, 42) and H (18.5%, 367). Therefore, the morning has more variety in the fleet mix than the overall distribution. Besides WTC J seems to be inactive during the morning. The afternoon looks more similar to the overall view. Here the percentage of M (82.3%, 1670) and J (0.1%, 2) is slightly lower, while WTC L (1.7%, 34) and H (15.9%, 1670) are higher. Therefore, the afternoon shows less variety than the morning, but more than the overall. However, it should be noted that the distribution of the fleet mix varies throughout the month in the afternoon. The evening shows the least variety in the fleet mix with WTC M (88.7%, 1955) the highest percentage of all dayparts, while L (0.5%, 10), H (10.8%, 239), and J (0.1%, 1) occurred fewer times. The evening shows also the least variety throughout the month.

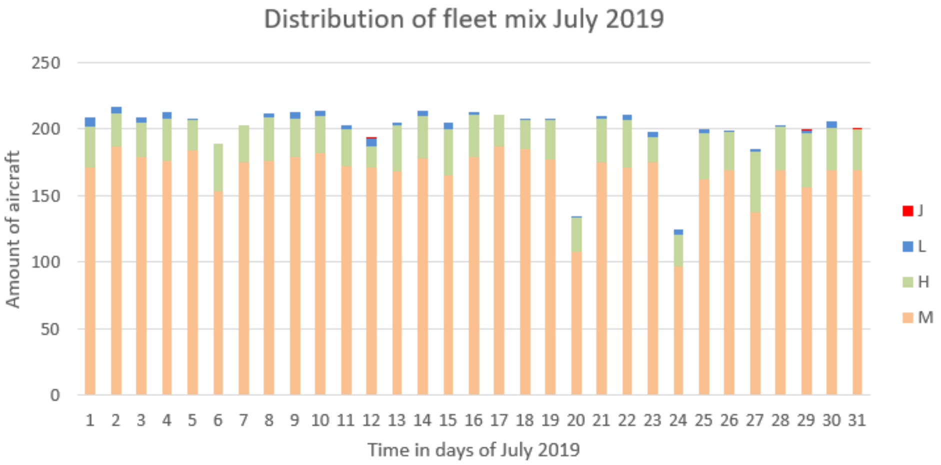

Figure 15 Distribution of the fleet mix July 2019

4.2 Identification runway combinations

As described in chapter 3.6.1, the runway combination plays an essential role in the realization. Figure 16 shows general information of the used runway combination and coherent realization for all dayparts.

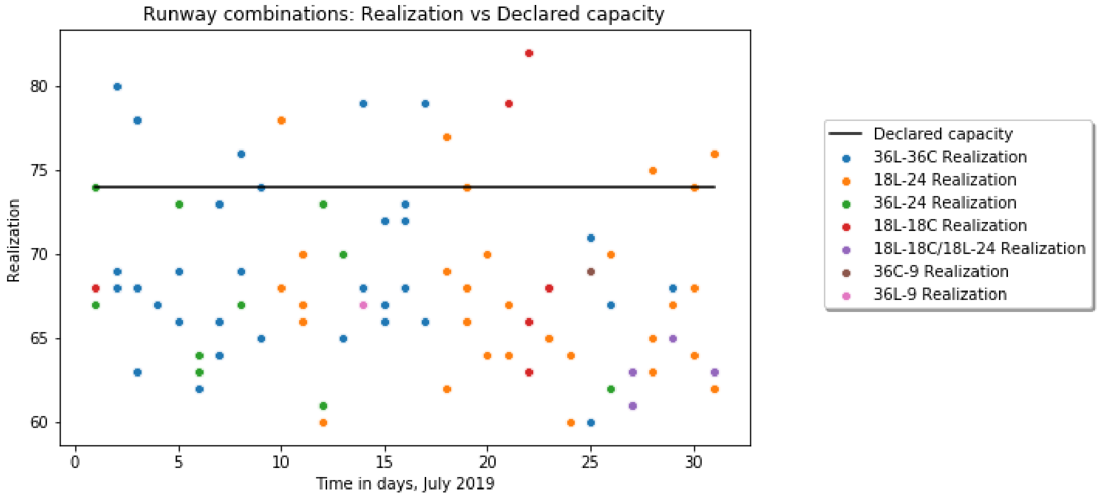

Figure 16 Runway combinations: Realization vs Declared capacity

For a clear overview, no distinction is made between the dayparts, therefore each dot represents one peak hour. This results that in one day three dots can be visible with the same colour. The general information of the used runway combinations is presented in Table 4.

Table 4 General information of used runway combinations

Runway combination	Frequency during the month	Number of reaching Declared capacity	Frequency of use during the morning	Frequency of use during the afternoon	Frequency of use during the evening	Maximum start capacity[16]
36L-36C	37	7	12	14	11	75
18L-24	32	6	9	13	10	73, 75, 72
36L-24	10	1	2	3	5	75
18L-18C	7	3	3	1	3	62, 75
36C-9	1	0	x	X	1	77, 77
36L-9	1	0	1	X	X	77, 80, 77
18L-18C/18L-24	3	0	3	x	X	x

It can be seen that seven different runway combinations are used. Here combination 36L-36C and 18L-24 are most common, with a share of 41% and 35% during the month. However, these combinations reached the declared capacity only 19% and 18% of the time. Out of all combinations 18L-18C most often reached Declared capacity (43%), but is only used in seven peak hours since other combinations are more preferred (LVNL, n.d.). As stated in Chapter 3.6.1 each combination has its characteristics that influence the maximum start capacity. Therefore, the maximum start capacity per combination is analysed to have a broader panorama than comparing. In Appendix II, a total overview of this start capacity for all combinations is given. As can see in Table 4 not all combinations have enough available start capacity to reach the Declared capacity in optimal conditions. Also, a change of combinations within a peak hour (18L-18C/18L-24) results in an even lower start capacity, compared when only one combination is used. No exact number can be given, but it can be assumed. Further attention is placed on the two main combinations used within the month, i.e. 36L-36C and 18L-24. It can also be seen that these two combinations have the same frequency of use, being between 10 to 14 times per daypart.

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[16] During normal circumstances. Multiple start capacities are given due to different possibilities in landing runways.

Figure 17 shows the realization against the Declared capacity for combination 36L-36C for each daypart. As stated before, 36L-36C has reached the declared capacity in 7 out of the 37 peak hours (19%). Now it can be seen that this occurred once in the morning, and six times in the evening. For the morning, this occurred during the 7th day together with the evening. Besides, the differences between the morning, afternoon with the evening peaks are relatively large, based on the Declared capacity realization. Also, all peaks have no consistency during the month. This particular combination is mostly used at the beginning of the month. Of the 17 days, during five this combination was used in all dayparts.

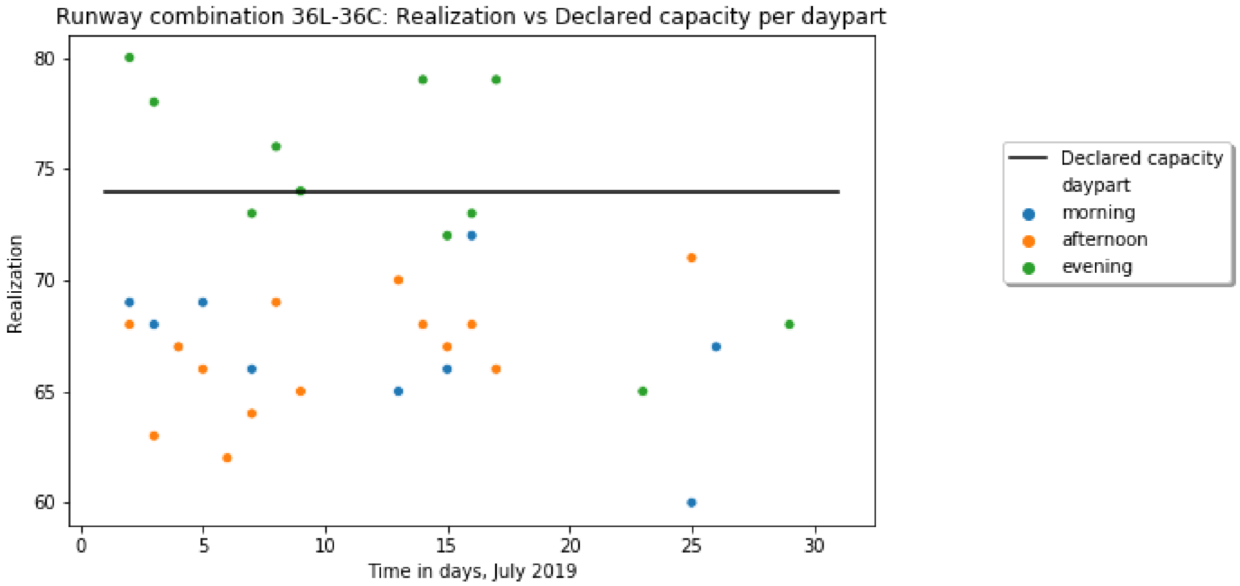

Figure 17 Runway combination 36L-36C: Realization vs Declared capacity per daypart

Figure 18 shows the realization against the Declared capacity per daypart for combination 18L-24. This combination reached the Declared capacity less times than 36L-36C (6 out of 34, 18%). Besides, only the evening participated in reaching this. In addition, this runway combination is used 34 times in 15 days only. Whilst 36L-36C is used 37 times in 17 days, which makes runway 36L-36C more preferable. However, when comparing these combinations, 36L-36C had on average more aircraft (70) during a peak hour than 18L-24 (67). Besides, this combination is mostly used during the end of the month in contrast to 36L-36C. of the total of 15 days, during five days this combination was used in all dayparts.

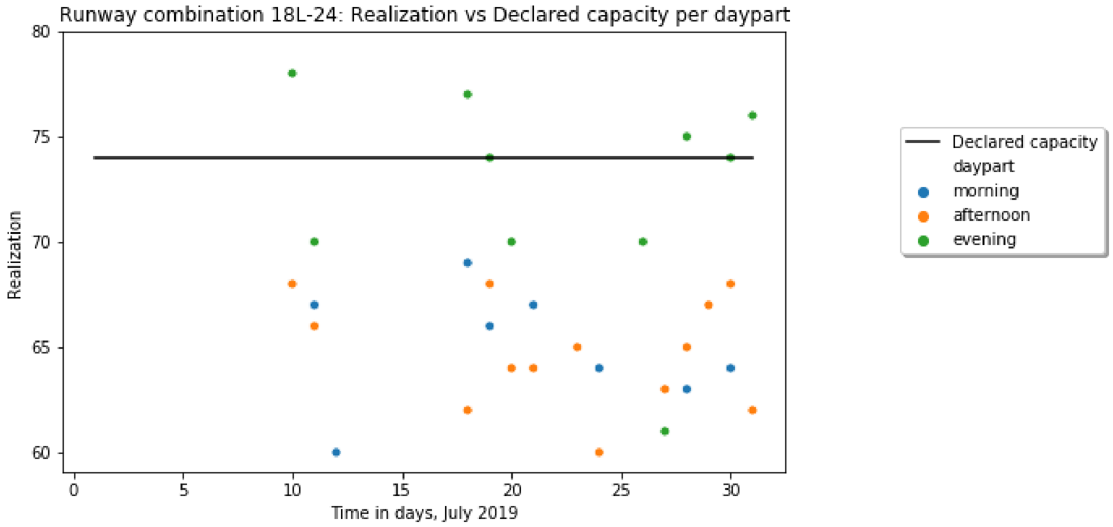

Figure 18 Runway combination 18L-24: Realization vs Declared capacity per daypart

Figure 19 shows more detail to the behaviour of these runway combinations. In Table 16 in Appendix III, more detailed information can be found. It can be seen that in both runway combinations the evening behaves differently, while the morning and afternoon quite are similar. Also, the evening is less consistent than the other dayparts in both combinations, with a spread of six aircraft, and a std of five. Also for both combinations in the morning the negative difference is seven aircraft, which means that more flights can be added in the peak hour to reach the Declared capacity. Also, higher means are seen for 36L-36C than 18L-24. The black panes represent 0.7% of the data, which can be seen in the morning and afternoon. The whiskers (left and right tails) connect the minimum and maximum value with the most frequent data. The whiskers represent 25% of the data on each site. Overall combination 18L-24 has a more negative difference than 36L-36C.

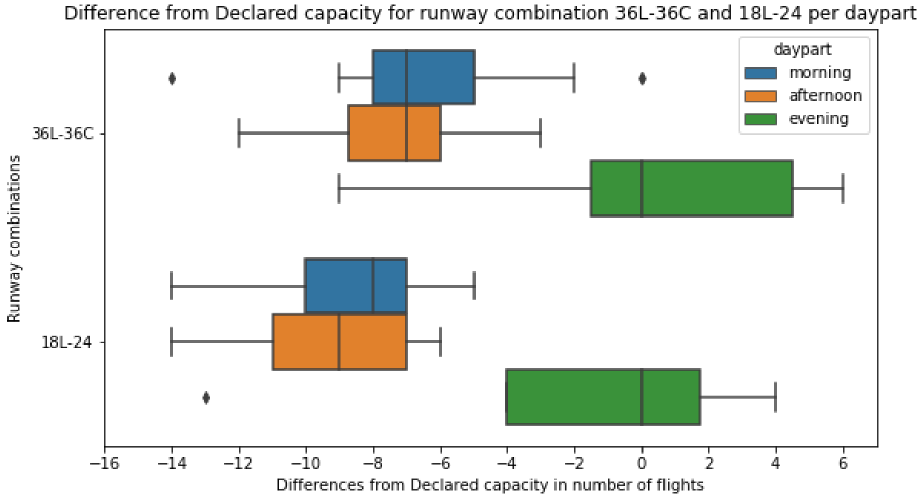

Figure 19 Difference from declared capacity for runway 36L-36C and 18L-24 per daypart

4.3 Conclusion

An overlap of the time windows between the afternoon and evening is seen, which gives a more detailed view of the outbound peak hours. In the afternoon a large spread in the time window is seen. Comparing the realization with the Declared capacity two outliers are seen which are caused by unnormal circumstances. This point are removed from the analyses. One of these outliers could also been seen in the evening time window. The evening shows a different behaviour, and has the most share in reaching the Declared capacity (94%). However this daypart has a large spread in data. The morning and afternoon behave quite similar. The median of a negative deviation (below the Declared capacity) is eight. It is important to note that the evening served around 200 more aircraft during the month. The difference between dayparts is also seen in the distribution of the fleet mix. The evening shows less variety with the highest percentage of 88.7%. The morning and afternoon differ in each WTC around 3%, were J is not active in the morning. Overall WTC M dominates the distribution of overall 83.6%. A total of seven different runway combinations are used, where 36L-36C and 18L-24 are the most frequent. In optimal condition 18L-24 has in two of three possibilities not enough available start capacity for reaching the Declared capacity. In 19% (36L-36C) and 18% (18L-24) the Declared capacity is reached. Also in this combination a large difference between the evening and other dayparts is seen. While 36L-36C is mostly used in the beginning of the month. 18L-24 is used at the end of the month.

5 Operational impact of the fleet mix on the outbound phase

This chapter includes the analysis of the impact of the fleet mix on the outbound phase. At first a overall view has been analysed. This regards the time spent in the outbound phase per WTC. Secondly the time spent in the outbound phase per WTC for each daypart (morning, afternoon and evening) has been analysed.

5.1 Overall view

At first, a general overview of the time that the aircraft spent in the entire outbound phase is analysed. As described in Chapter 3, the outbound starts from the moment the ground handler gives the final TOBT update until the aircraft takes off (ATOT). The data set shows that one aircraft of WTC L has no registered TOBT. Therefore, this aircraft will not be taken into account in further analysis.

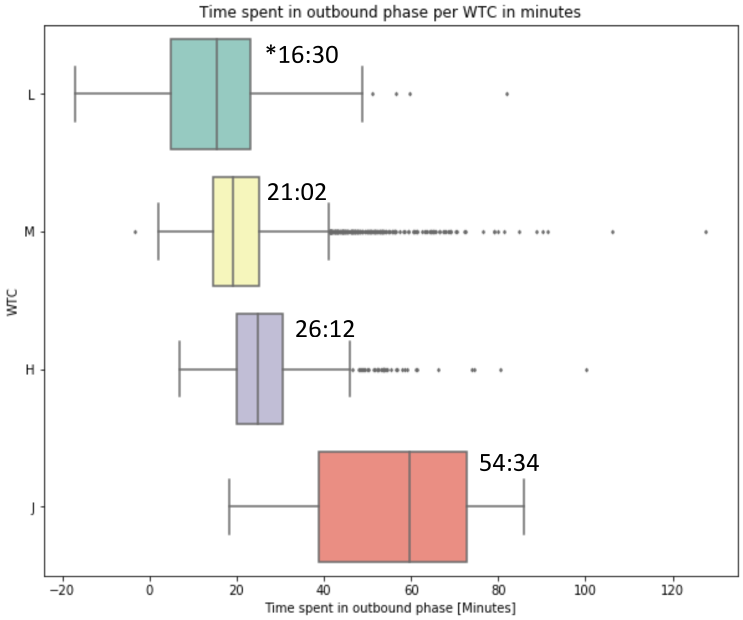

Figure 20 Time spent in outbound phase per WTC in minutes

In Figure 20 the time each WTC spent in the outbound phase is displayed. '*' presents the mean in min for each WTC. During the analysis, a data point was observed at -284 min. This point is removed from the analysis as this is seen as a non-representative outlier. Together with Table 17 in appendix III, it can be seen that the heavier the WTC becomes, a higher average is seen. In WTC L a negative time spent can be seen. This is the result of the time references under the CDM principle that are not updated correctly. Also, the std for each WTC is not lower than 09:26 min. This indicates that within each WTC category there is a considerate spread of data. The std is the highest in L (15:59 min) and J (34:08). This can be caused by the different sample sizes (Chapter 4.1). Besides it is seen that WTC J spent relatively more time in the outbound phase. However it should be noted that this sample only exists of three aircraft. As final it can be seen that especially in WTC M the maximum value is extremely high (127:39 min) compared to the average of 21:02 min). This also can be caused by the relatively big sample size (5201 aircraft).

An One-way ANOVA demonstrates that there is a significant difference in the time spent in the outbound phase of the WTCs with: F(3,6211) = 89.432, $p < 0.001$. The Tukey-Kramer post hoc test reveals (Table 5) that all combinations significantly differ from each other. Which means that obtaining that difference by chance is less than 0.1% ($p < 0.001$). Therefore, the differences are caused by WTC characteristics, procedures and activities. As explained in the methodology the mean difference is calculated by category 2 – category 1. Where a positive mean differences indicates that category 2 has a higher mean and with a negative category 1. The largest mean differences involve WTC J. Which on average differs with -38:04 min from WTC L, -33:32 min from M, and 28:22 min from WTC H. On average, WTC J spent more time in the outbound phase than the other categories.

Table 5 Tukey-Kramer results WTC for the whole outbound phase

Category 1	Category 2	Mean difference in min	P-adjusted	Reject
H	J	28:22	0.001	True
H	L	-09:42	0.001	True
H	M	-05:09	0.001	True
J	L	-38:04	0.001	True
J	M	-33:32	0.001	True
L	M	04:32	0.001	True

5.2 Dayparts

In Chapter 4 it was seen that the peak hours have a different behaviour, measured in demand realization, fleet mix and output consistency, throughout the day. Especially the behaviour of the evening differs significantly with the morning and afternoon. To identify the impact of different dayparts on the fleet mix, the following analysis is performed.

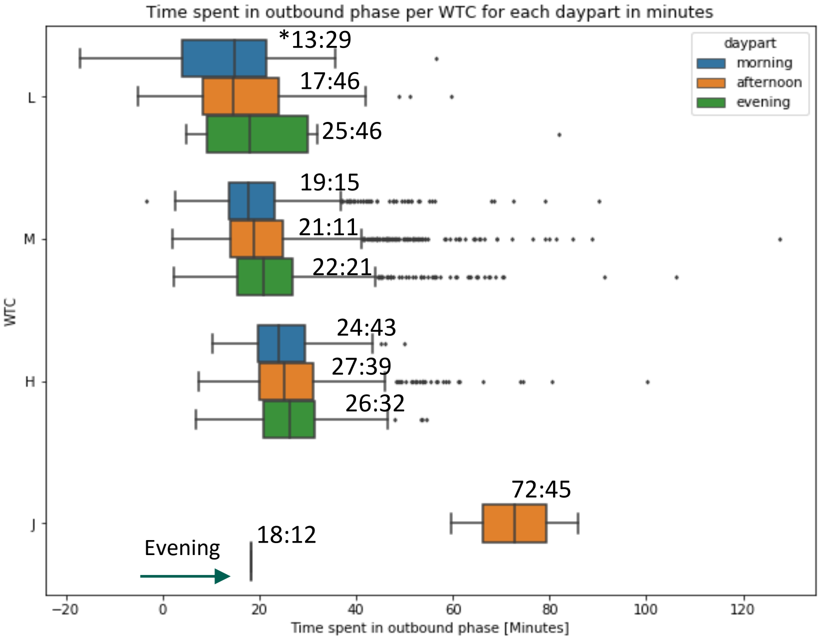

Figure 21 Time spent outbound phase per WTC for each daypart

In Figure 21, the time each WTC spent in the outbound phase is divided into the three dayparts. Again '*' represents the mean in min. Together with Table 18 in Appendix III *Measures of Central Tendency and spread*, the differences between the WTCs and the dayparts are established. The range of time spent increases during the day, with exception of J. The smallest differences during the day can be seen in M and H of around 03:00 min. It can be seen that WTC J in the afternoon shows an extensive behaviour compared to the other WTCs of an average 72:45 min. For M and H the std deviation is the highest in the afternoon (11:04 min, 12:19 min). Furthermore, the negative time spent in WTC L seems to be caused in the morning. Also, the high values of the time spent of WTC M occurs in all dayparts.

A Two-way ANOVA shows that there is a significant interaction with the dayparts and the time each WTC spent, with F(6,6204) = 5.761, p < 0.001. There is a significant difference between the dayparts in general with F(2, 6204) = 41.762, p < 0.001 and WTC with F(3,6204) = 97.764, p < 0.001. The Tukey-Kramer test shows the following (Table 8). For the morning, WTC J is not presented in the results since this WTC is not active in the morning peak hours. In the morning all combinations significantly differ. Here, combination H, L has the highest mean difference where H spent 11:13 min more time. Combination H, M has a mean difference of -05:28. In the morning WTC H spent on average the most time within the outbound phase. Also, within the afternoon all combinations significantly differ, except for combination L, M. For combination H, M the mean difference is larger with -06:28 min than in the morning. In the afternoon, the greatest differences are seen in combinations involving J. Where the mean differs more than 45 minutes.

In the evening, the only significant difference seen lies in combination H, M. However, in the evening combination H, M has the smallest mean difference compared with the other dayparts. Also for all the other combinations, a smaller mean difference is seen.

Table 6 Tukey-Kramer results for the whole outbound phase per WTC for each daypart

	Category 1	Category 2	Mean difference in min	P-adjusted	Reject
Morning	**H**	L	-11:13	0.001	True
	H	M	-05:28	0.001	True
	L	M	05:45	0.001	True
Afternoon	**H**	J	45:06	0.001	True
	H	L	-09:53	0.001	True
	H	M	-06:28	0.001	True
	J	L	-54:59	0.001	True
	J	M	-51:34	0.001	True
	L	M	03:25	0.3072	False
Evening	**H**	J	-08:20	0.8056	False
	H	L	-00:45	0.9	False
	H	M	-04:11	0.001	True
	J	L	07:34	0.8706	False
	J	M	04:09	0.9	False
	L	M	-03:25	0.6944	False

5.2.1 Conclusion

The average time spent in the entire outbound phase increases with a heavier WTC. Within the WTC the range of the data, which represents 50% of the data, is separated by a minimum of 10 min. Here a smaller sample size has a smaller range. Besides, the differences in min and max are extensive. A statistical test demonstrates a significant differences in all combinations. Here the biggest mean difference is 38:04 min in combination J, L, and smallest difference 04:32 min in L, M. In the evening, the differences are less significant, which also includes the smallest differences in mean. Here, the maximum mean difference is 08:20 min (combination H, J). However, the evening takes the most time for each WTC in the outbound phase, with exception of J.

6 Operational impact of the fleet mix on Start-Up

This chapter includes the analysis of the impact of the fleet mix on the *Start-Up* process. At first an overall view has been analysed. This regards the time spent in the *Start-Up* per WTC. Secondly the time spent in the *Start-Up* per WTC for each daypart (morning, afternoon and evening) has been analysed. The *Start-Up* can be divided into three subprocesses. Therefore, at first the *Start-Up* will be analysed, followed by *subprocess 1* and *subprocess 2*.

6.1 Overall impact on the start-up

As described in chapter 5.1.1 the *Start-Up process* happens between the moment the ground handler gives the final TOBT update until the aircraft starts push-back (AOBT). First, the impact of the fleet mix on the operation is analysed.

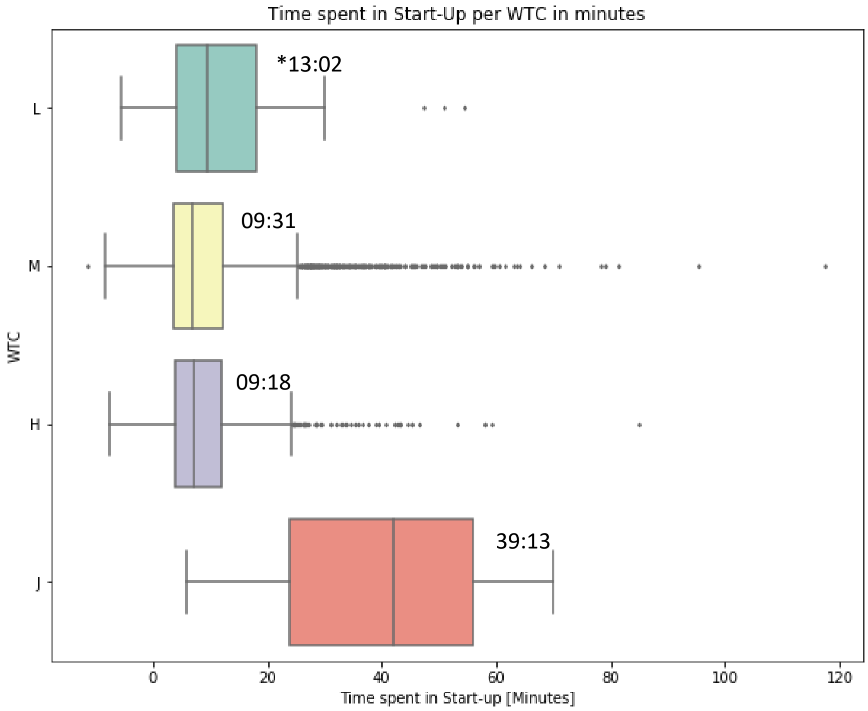

Figure 22 Time spent in Start-up per WTC

Figure 22 shows the time spent in the *Start-Up* for each WTC. The analysis includes an outlier at -284 min as seen in the outbound phase. Therefore, this data point is removed. Furthermore, WTC L has 53 out of 87 flights that have no registered AOBT. Also, 15 out of 5280 aircraft of WTC M have no registered AOBT. These are identified as non-commercial aircraft and depart from runway 22 and 04. The flights with missing time references are not taken into account during this analysis.

Together with Table 19 in Appendix III *Measures of Central Tendency and spread*, it can be seen that the WTCs behave more similar to each other than in the outbound phase (with exception of J). Especially M and H look quite similar based on the average which differs 00:13 min. Again it is seen that the larger spread (the box) is higher with the smaller sample sizes (WTC L, J). In the outbound phase it could be seen that M had a lot of values which spent a long time in the process (maximum of 127:39 min). It can be seen that these values are caused by the Start-up which has a maximum of 117:36 min. Furthermore, for both L and J the majority of the outbound phase is spent during the Start-Up. Where L spent 16:30 min and J 54:34 min. Also different than the outbound phase, on average WTC H spent less time than M and L. With a maximum difference of 03:44 min. Again large differences are seen with J.

A One-way ANOVA test demonstrates that the WTCs significantly differ in the time spent, with $F(3,6021) = 11.699$, $p < 0.01$. The Tukey-Kramer post hoc test reveals (Table 7) that only WTC J significantly differs from H and M. Here, J takes on average 29:55 minutes more than H and 29:42 minutes more than

M. Combination H, M does not significantly differ, and has a mean difference of 00:13 min. Remarkable is that on average all WTCs spent more time in *Start*-Up than WTC H.

Table 7 Results Tukey-Kramer post hoc test Start-Up per WTC

Category 1	Category 2	Mean difference in min	P-adjusted	Reject
H	J	29:55	0.001	True
H	L	03:44	0.1055	False
H	M	00:13	0.9	False
J	L	-26:11	0.001	False
J	M	-29:42	0.001	True
L	M	-03:31	0.1311	False

6.1.1 Dayparts

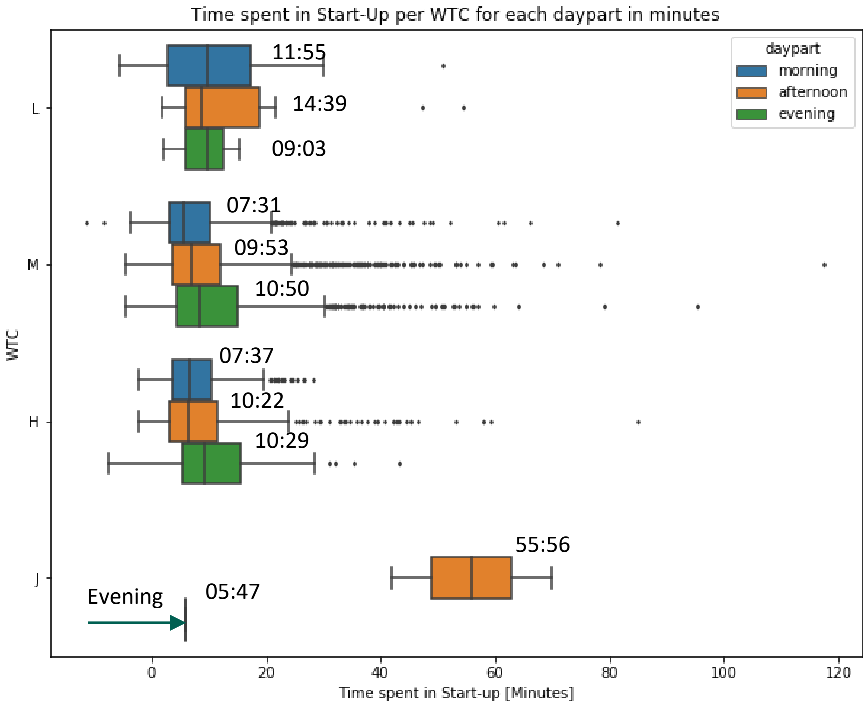

Figure 23 Time spent in Start-Up per WTC for each daypart

In Figure 23, the time spent (separated by WTC) during *Start-Up* is divided into the three dayparts. Together with Table 20 in Appendix III, multiple things can be observed. When looking to the median of L, M, and H, small differences are seen between the dayparts. For M and H the average time spent increases throughout the day, with a maximum of 03:20 min. This is not the case for L and J. The std of WTC L decreases to 08:00 min in the evening. For WTC M and H, the std is the lowest in the morning: 07:39 min and 05:31 min respectively. This is the highest in the afternoon: 10:27 min, and 12:13 min respectively. This result was also seen in the outbound phase. Just like in the entire outbound phase, a big difference (50:08 min) between WTC J in the afternoon and the evening can be seen.

A Two-way ANOVA demonstrates that there is a significant interaction with the dayparts and the time each WTC spent, with F(6,6014) = 3.706, p < 0.001. Besides, there is a significant difference between the dayparts in general, with F(2, 6014) = 65.477, p < 0.001 and WTC with F(3,6014) = 11.783, p < 0.001. The Tukey-Kramer post hoc test (Table 8) shows only a significant difference in the afternoon when WTC J is involved. Here, the mean difference is a minimum of 41:17 min, were J spent more time. Furthermore, the behaviour of the evening is different. Where in the other dayparts WTC L spent more time than H and M, it is the other way around in the evening. This also applies to combination H, M, where H spent less time than M in the evening.

Table 8 Tukey-Kramer results Start-Up per WTC for each daypart

	Category 1	Category 2	Mean difference in min	P-adjusted	Reject
Morning	H	L	04:19	0.0815	False
	H	M	-00:06	0.9	False
	L	M	-04:24	0.0667	False
Afternoon	H	J	45:34	0.001	True
	H	L	04:17	0.3838	False
	H	M	-00:29	0.8827	False
	J	L	-41:17	0.001	True
	J	M	-46:03	0.001	True
	L	M	-04:46	0.2699	False
Evening	H	J	-04:42	0.9	False
	H	L	-01:26	0.9	False
	H	M	00:21	0.9	False
	J	L	03:16	0.9	False
	J	M	05:03	0.9	False
	L	M	01:47	0.9	False

6.1.2 Conclusion

In general, during the *Start-Up process* the WTCs behave more similar than seen in the outbound phase. For L and J the majority of the outbound time is spent during the *Start-Up*. Besides WTC H and M behave similar when looking to the Measures of Central Tendency and spread. Only a significant difference is seen in the combinations involving WTC J, where the minimum mean difference is 29:42 min. The lowest mean difference is within combination H, M with 00:13 min. It should be noted that on average, all WTCs spent more time in *Start*-Up than WTC H. When focussing on the dayparts, WTC J stands out in the afternoon with an average of 39:13 min. Besides, combinations involving J do only significantly differ in the afternoon, with a minimum mean difference of 41:17 min.

Different from the general outbound phase analysis is that WTC L spent more time than H and M in the *Start-Up process.* In the entire outbound phase, this is the other way around. This also applies to combination H, M. During *Start-Up*, M spent more time, and in the outbound phase, H does. Furthermore, the evening behaves different. In the morning and afternoon WTC L spent more time than H and M, unlike the evening. This also applies to combination H, M, where H spent less time than M in the evening.

6.2 Operational impact of fleet mix on subprocess 1

Within the *Start-Up process,* subprocess 1 is further analysed. This is from the moment the ground handler gives the final TOBT update until the pushback time (TSAT) is issued by LVNL. The purpose and activities of this subprocess can be found in chapter 3.1. Within the WTC L data set, one flights has no registered TOBT and three flights have no registered TSAT. These flights are not taken into account in Figure 24 and further analysis in this sub-chapter.

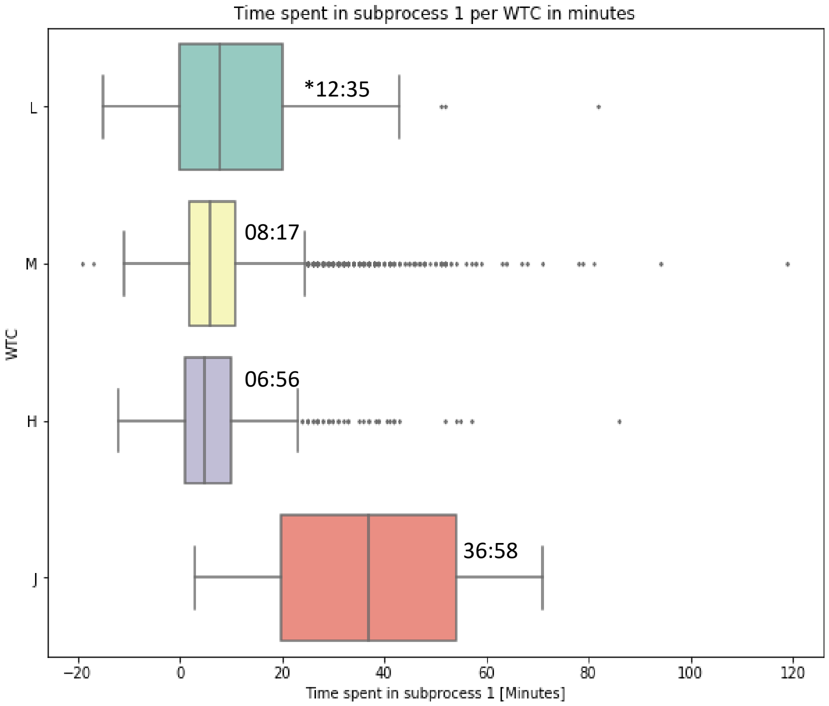

Figure 24 Time spent in subprocess 1 per WTC

Figure 24 shows the time spent in subprocess 1. Together with Table 23 in Appendix III , multiple results can be observed. Looking at the average time spent, the majority of the time spent of the *Start-Up* happens in this subprocess. The differences of these averages differ of a range from 01:00 to 03:00 min. As seen before, WTC M and H look similar, where the multiple data points of the boxplots differ around 01:00 min. Also, WTC J shows again the largest range and a high average of 36:58 min. While the average and std differ, the median of all the WTCs are very similar. Here the maximum difference is 02:00 min, except for J. Furthermore, just like the *Start-Up* WTC M and L spent on average more time than H. As seen in the outbound phase and the *Start-Up* WTC M consist of a lot of flights with a high time spent (maximum 119:00 min). Now it can be seen that this is caused during this subprocess. As final, WTC L and H have again the highest std of 16:18 min and 34:03 min. This may be caused by the relative small sample sizes.

A One-way ANOVA demonstrates that the WTCs have a significant impact on the time spent within this subprocess, with F(3,6205) = 20.397, $p < 0.001$. The Tukey post hoc test indicated (Table 9) that all combinations significantly differ, except for J, L. The smallest mean difference is in combination H, M (01:19 min), where on average M takes longer. This difference is higher than in the overall *Start-Up process.* The biggest difference is seen in combination H, J with a mean difference of 30:02 min, which is also higher than the entire *Start-up process*. Again, the differences between WTCs are comparable to the entire *Start-Up* process (Chapter 6.1).

Table 9 Tukey-Kramer post hoc test subprocess 1 per WTC

Category 1	Category 2	Mean difference in min	p-adjusted	Reject
H	J	30:02	0.001	True
H	L	05:39	0.001	True
H	M	01:21	0.001	True
J	L	- 24:23	0.001	False
J	M	- 28:41	0.001	True
L	M	- 04:19	0.001	True

6.2.1 Dayparts

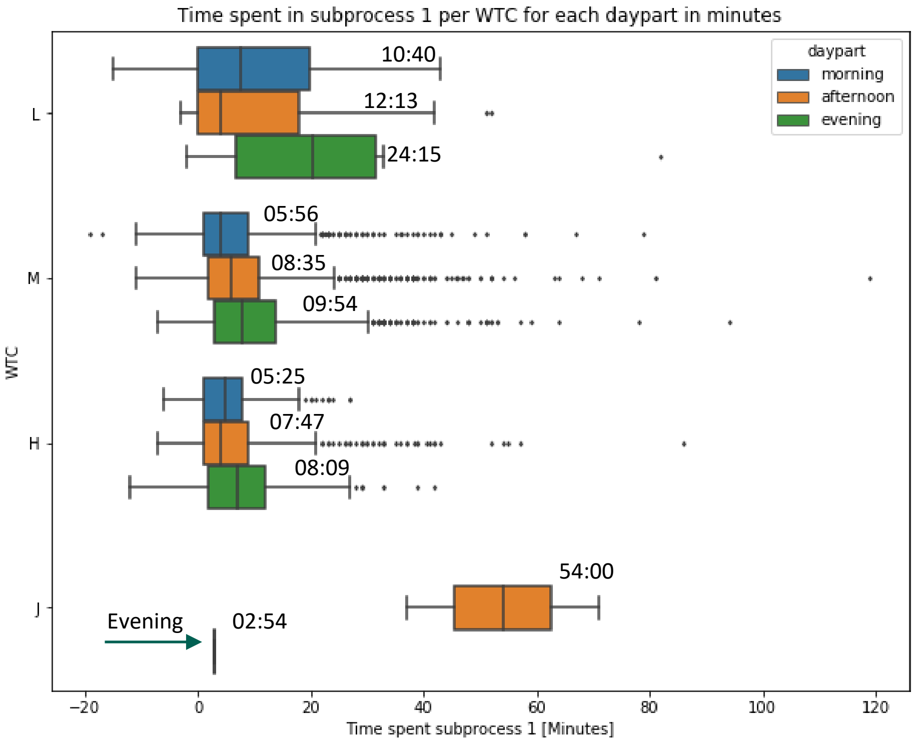

Figure 25 Time spent in subprocess 1 per WTC for each daypart

Figure 25 shows the time spent for each WTC in subprocess 1, divided by the three dayparts. Together with Table 24 in Appendix III the following can be observed. Just like the previous analysis, an extensive difference can be seen with WTC J in the afternoon. Here the morning has a relative low average of only 02:54 min). For the other categories, it can be seen that in general, the average, std and range increases during the day. Also within the WTCs, a difference between the dayparts can be seen. However, based on the median, the data sets differs with a maximum of 04:00 min throughout the day, except with WTC L in the evening. Within WTC L, the average time spent during the day differs around 12:00 min with the evening. Overall it can be seen that the evening has the highest average time spent compared with the morning and afternoon (exception of WTC J).

A Two-way ANOVA demonstrates that there is a significant interaction with the dayparts and the time each WTC spent, with F(6,6198) = 5.377, $p < 0.001$. For both variables (daypart and WTC) individually, a significant difference can be seen as well: the dayparts with F(2,6198) = 89.098, $p < 0.001$ and WTC with F(3,6198) = 20.363, $p < 0.001$. A Tukey-Kramer post hoc test shows (Table 10) that in the morning no significant differences are seen in combination H, M, with a mean difference of 00:31 min. In the afternoon, again, all combinations significantly differ with WTC J. The biggest mean difference in the afternoon is 46:13 min. In combination H, M a mean difference of 00:48 min is seen which is larger than the morning. In the evening no significant differences are seen between the combinations except for combination H and M. This combination has a mean difference of 01:45 min., which is the largest of all dayparts. Furthermore, WTC M spent more time during each daypart, while in the overall *Start-Up process* this only occurred in the evening.

Table 10 Tukey-Kramer results of subprocess 1 per WTC for each daypart

	Category 1	Category 2	Mean difference in min	P-adjusted	Reject
Morning	H	L	05:01	0.001	True
	H	M	00:31	0.4636	False
	L	M	-04:44	0.001	True
Afternoon	H	J	46:13	0.001	True

	H	L	04:26	0.1114	False
	H	M	00:48	0.5946	False
	J	L	-41:47	0.001	True
	J	M	-45:25	0.001	True
	L	M	-03:37	0.2243	False
Evening	H	J	-05:15	0.9	False
	H	L	16:06	0.001	False
	H	M	01:46	0.035	True
	J	L	21:21	0.147	False
	J	M	07:00	0.8711	False
	L	M	-14:21	0.001	False

6.2.2 Conclusion

Subprocess 1 looks similar to the general overview of the *Start-Up*. Looking at the average time spent, the majority of the time spent of the *Start-Up* happens in this subprocess. The differences of these averages differ of a range from 01:00 to 03:00 min. Here, also WTC H and M look similar, and a large spread is seen for WTC J. However, different than the *Start-Up*, a significant difference is seen in combination H, M, although it only has a mean difference of 01:21 min. As seen in the outbound phase and the *Start-Up* WTC M consist of a lot of flights with a high time spent. Now it can be seen that this is caused during this subprocess. When focussing on each daypart, this significant difference (between H, M) can only be found in the evening, with a mean difference of 01:46 min. Also, just like the *Start-Up,* WTC J behaves more extreme in the afternoon with a minimum mean difference of 30:02 min. Furthermore, it can also be seen that WTC M spent more time (on average) in this subprocess than H does during all dayparts. This is different than the (entire) outbound phase and *Start-Up.* Within WTC L, a larger difference in average time spent can be seen in the evening with the other dayparts.

6.3 Operational impact of fleet mix on subprocess 2

The other subprocess (*subprocess 2*) in the *Start-Up* is from the moment the pushback time is issued (TSAT) until the aircraft starts pushback (AOBT). Three aircraft with WTC L and 68 aircraft with WTC M do not have a registered TSAT. These are left out in this analysis.

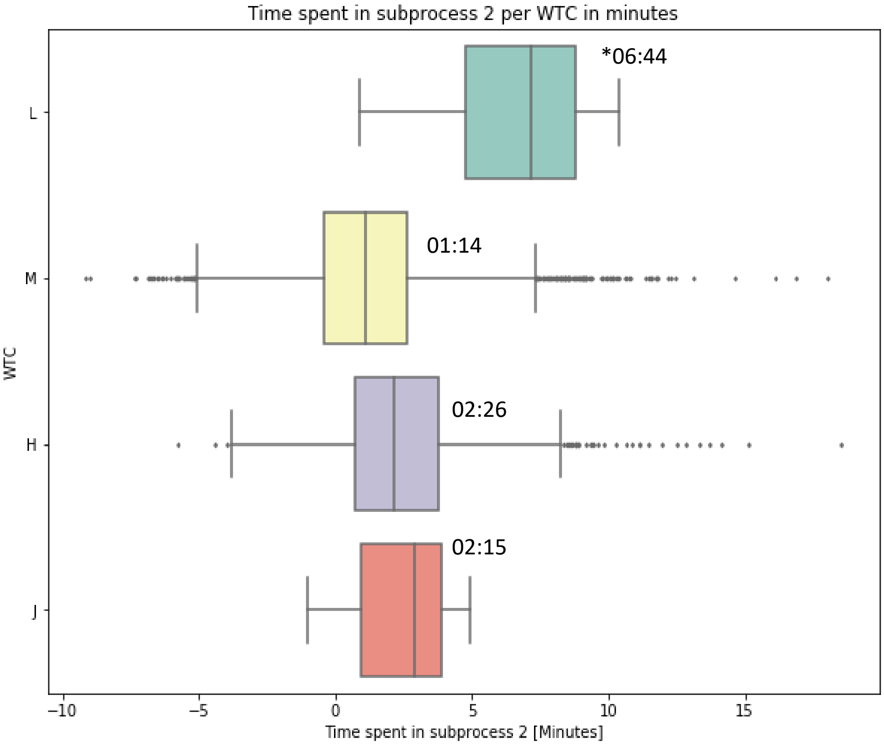

Figure 26 Time spent in subprocess 2 per WTC

Figure 26 shows the time spent in subprocess 2 per WTC. Together with Table 23 in Appendix III the following can be observed. At first sight a different picture is seen than the outbound phase, *Start-Up* and *subprocess 1*. Also, negative values in the time spent are seen. This time in WTC M, H and J. Small differences in average time between the WTCs can be seen. Here WTC M has the lowest mean (01:14 min) and median (01:06 min). Other than the other subprocess, there is a smaller difference between H and M. However, this is only 01:12 min compared to 01:21 (subprocess 1). Also, WTC J now looks more similar to the other categories. Besides, different than the other (sub)processes is that WTC L now spent the most time (on average). Also, the overall time spent is much lower than subprocess 1, where it was around 09:00 min for WTC M and H. Furthermore, the maximum values of M and H are now closer towards Q3 than it was in subprocess 1. Now the difference is around 15 min. In subprocess 1 this was around 90 min. As final, the std of the WTCs are similar and vary between 02:36 min and 03:02 min. It can be seen that a heavier WTC has a higher std.

A One-way ANOVA shows that there is a significant difference between WTCs, with F(3,6021) = 97.334, p < 0.001. A Tukey-Kramer post hoc test shows (Table 11) that all combinations have a significant difference, except for combination H, J, and M, J. Here, the biggest (mean) difference is in combination L, M with -05:30 min, and the smallest mean difference in H, J with -00:11 min. Different than the subprocess 1 and *Start-Up* is that WTC H spent more time than WTC M and J. Furthermore, as stated before, WTC L spent more time than the other categories.

Table 11 Results Tukey-Kramer post hoc test subprocess 2 per WTC

Category 1	Category 2	Mean difference in min	p-adjusted	Reject
H	J	-00:11	0.9	False
H	L	04:18	0.001	True
H	M	-01:12	0.001	True

J	L	04:29	0.0264	True
J	M	-01:01	0.9	False
L	M	-05:30	0.001	True

6.3.1 Dayparts

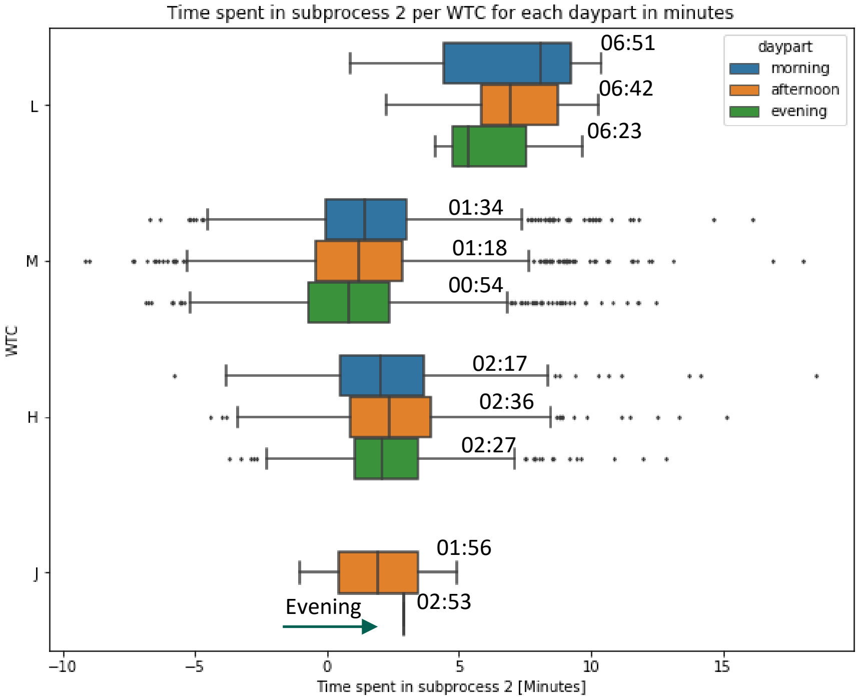

Figure 27 Time spent in subprocess 2 per WTC for each daypart

Figure 27 shows the time spent in subprocess 2 per WTC, divided by the three dayparts. Together with Table 24 in Appendix III the following can be observed. When comparing the dayparts in each WTC, a small differences of 01:00 to 02:00 min between the median, average can be seen. These differences are also smaller than in *subprocess 1*, where it differed between 03:00 till 14:00 min throughout the day (exception of J). The average time spent of the WTCs differ with a maximum of 00:28 min. The differences between Q3 and maximum values in WTC M and H, occur in every daypart. Also, the negative values in WTC M, H and J show no clear relation towards the dayparts. Since they occur in the morning, afternoon and evening.

A Two-way ANOVA demonstrates that there is a significant interaction with the dayparts and the time each WTC spent, with F(6,6014) = 2.365, p = 0.002. For both variables/groups (WTC and daypart), a significant difference is present for WTC, with F(3,6014) = 90.258, p < 0.001 and for daypart: F(2,6014) = 34.012, p < 0.001. A Tukey post hoc test reveals (Table 12) that all combinations significantly differ. Here combination H, M has a mean difference of -00:43 min. Compared to the other (sub)processes, WTC J does not excessively fall out in terms of time spent. The maximum mean difference is 04:47 min. Furthermore, in the afternoon and evening all combinations significantly differ, except for the combinations with J. In the afternoon and evening, combinations involving L have the biggest mean difference, with a maximum of 05:39 min.

Table 12 Tukey-Kramer results of subprocess 2 per WTC for each daypart

	Category 1	Category 2	Mean difference in min	P-adjusted	Reject
Morning	H	L	04:34	0.001	True
	H	M	-00:43	0.001	True
	L	M	-05:17	0.001	True

Afternoon	**H**	J	-00:40	0.9	False
	H	L	04:06	0.001	True
	H	M	-01:18	0.001	True
	J	L	04:47	0.1068	False
	J	M	-00:38	0.9	False
	L	M	-05:24	0.001	True
Evening	**H**	J	00:26	0.9	False
	H	L	03:56	0.0375	True
	H	M	-01:33	0.001	True
	J	L	03:30	0.6124	False
	J	M	-01:59	0.8459	False
	L	M	-05:29	0.001	True

6.3.2 Conclusion

Comparing this subprocess with subprocess 1 (Chapter 6.2), the overall results state a different picture. On average subprocess 1 takes about 08:00 min more time than subprocess 2 looked at WTC M and H. Other than the first subprocess, less difference in mean applies for combination H, M, while combinations with WTC J have no significant differences and smaller mean differences. The std of each WTC are quite similar and vary between 02:36 min and 03:02 min. It can be seen that a heavier WTC has a higher std. Also, during this subprocess, it can be seen that WTC H spent on average more time, whilst in the other subprocess this was M. Combinations including WTC L demonstrate the largest differences, with the largest mean difference of 05:30 min. During the day, the time spent for each WTC does not differ much with a maximum of 00:28 min. Furthermore, no clear relation can be seen between the dayparts, maximum values and negative values that occurred. Overall, in this subprocess the differences between the WTCs and the dayparts are minimal (with exception of L). Therefore, the impact of the fleet mix is minimal (with exception of L).

7 Operational impact of the fleet mix on Taxi-Out

This chapter includes the analysis of the impact of the fleet mix on the *Taxi-Out* process. At first an overall view has been analysed. This regards the time spent in the *Taxi-Out* per WTC. Secondly the time spent in the *Taxi-Out* per WTC for each daypart (morning, afternoon and evening) has been analysed.

7.1 Overall impact on Taxi-Out

The final outbound process is the *Taxi-Out.* This is from the moment the aircraft starts pushback (AOBT) until the aircraft takes off (ATOT). Derived from chapter 4.1, runway combination 18L-18C/18L-24 is different than the other combinations, and is seen as an outlier. This because a runway change during a peak hour may result in a longer AOBT-ATOT (*Taxi-out*) time. To enhance statistical power for conducting an ANOVA/Post hoc test, asymmetric outliers need the be reduced as much as possible. Therefore, 18L-18C/18L-24 is seen as an outlier because of its asymmetric and exceptional nature. Furthermore, aircraft without an AOBT and ATOT are removed from the analysis due to missing data.

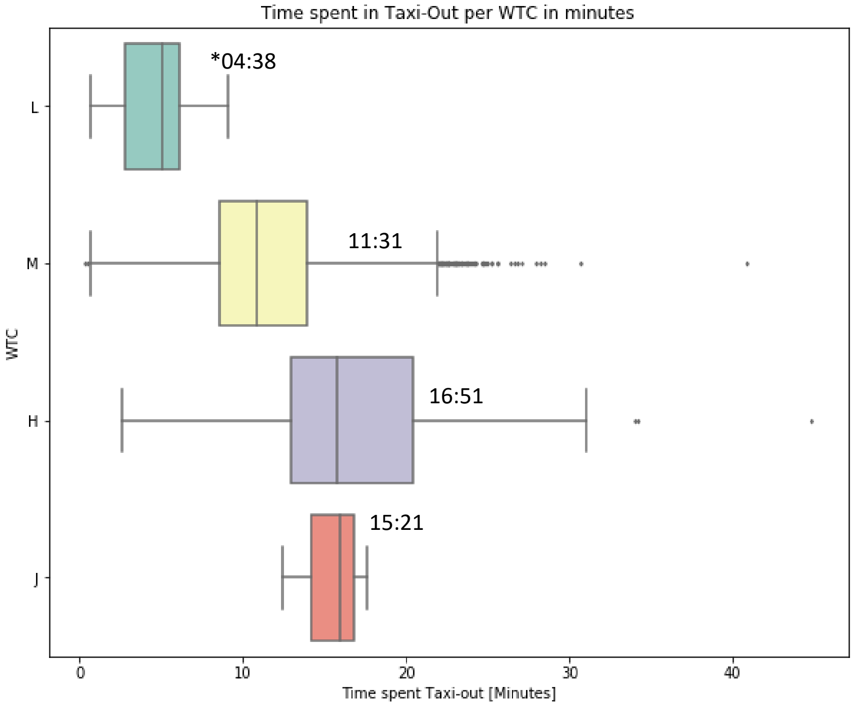

Figure 28 Time spent in Taxi-Out per WTC

Figure 28 shows an overall view of the time spent per WTC during *Taxi-Out*. Together with Table 25 in Appendix III, the following can be observed. Just like the outbound phase, a heavier WTC has a higher time spent (WTC J excluded). WTC H has the highest std of 16:51 min, the range is 07:25 min. The lowest values belong to WTC L, with a median of 05:05 min and an average of 04:38 min. WTC H and J share approximately the same median and mean, but differ in std. It can be seen that compared to the *Start-Up* WTC M and H show bigger differences in mean (05:30 min). These WTCs also spent more time in the Taxi-Out than the Start-Up. Furthermore, WTC L and J show a lower std than the Start-Up (02:08, 02:40). While this increases in the *Taxi-out* for M and H with around 02:00 min (04:13, 05:04).

A one way ANOVA states that there is correlation between WTC and the time spent during *Taxi-Out*, with F(3,6024) = 422.354, $p < 0.001$. The Tukey-Kramer post hoc test shows (Table 13) significant differences between all combinations, except H, J, and J, M. There is a higher difference in mean for combination H, M (-05:20 min) when comparing to the other processes. Furthermore WTC H, on average, spent the most time during *Taxi-Out.* This is different from the entire outbound phase, and the overall *Start-Up.*

Table 13 Results Tukey-Kramer post hoc test of Taxi-Out per WTC

Category 1	Category 2	Mean difference in min	p-adjusted	Reject
H	J	-01:30	0.9	False
H	L	-12:12	0.001	True
H	M	-05:20	0.001	True
J	L	-10:43	0.001	True
J	M	-03:50	0.4213	False
L	M	06:53	0.001	True

7.2 Dayparts

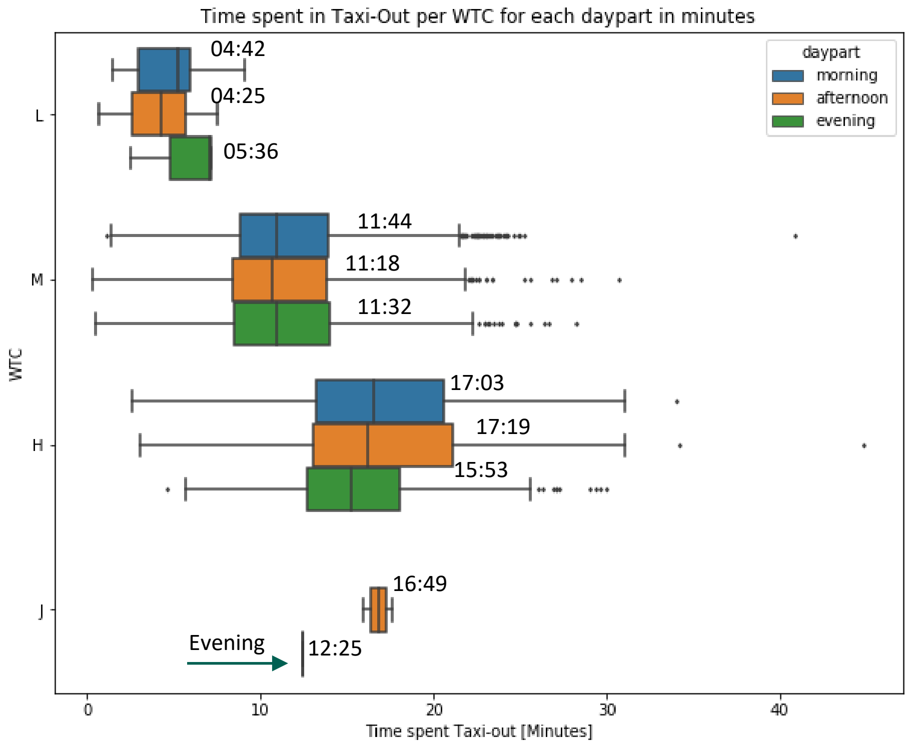

Figure 29 Time spent in Taxi-Out per WTC for each daypart

Figure 29 shows the time spent during *Taxi-Out*, separated by WTC and daypart. Together with Table 26 in Appendix III, it can be observed that within the individual WTCs, a small difference can be seen throughout the day. The average time spent is not (servery) affected by the number of flights operated and the dayparts. Different than the *Start-Up*, WTC J in the afternoon behaves more in line with the other WTCs. It can be seen that in the evening WTC L has a higher average and std (02:40 min) than the other dayparts. For WTC L in the evening the lowest amount of aircraft is seen during the day (0.5%). Also in the evening for WTC H the average differs with the other dayparts. Here the average is lower in the evening, with the smallest std (04:29). Also for this WTC, the lowest amount of aircraft are active in the evening (10.8%).

A Two-way ANOVA demonstrates that there is a significant interaction with the dayparts and the time each WTC spent during *Taxi-out*, with F(6,6017) = 3.087, p = 0.005. Significant differences are seen in the WTCs with F(3,6017) = 417.385, p < 0.001 and dayparts with F(2,6017) = 12.595, p <0.001. The Tukey post hoc test shows (Table 14) that in the morning, all combinations significantly differ. The largest mean difference can be found in combinations including WTC L. In the afternoon, all combinations significantly differ, except for H, J, and J, M. Here combination H, M has a mean difference of -06:05 min, which is higher than during the other processes. Again, big differences in mean are seen when WTC L is involved. As final, in the evening only combinations H, M (-04:21 min), and H, L (-10:17 min) show significant differences. Overall, the evening shows the smallest differences in mean between the WTC.

Table 14 Tukey-Kramer results of Taxi-Out per WTC for each daypart

	Category 1	Category 2	Mean difference in min	P-adjusted	Reject
Morning	H	L	-12:21	0.001	True
	H	M	-05:19	0.001	True
	L	M	07:02	0.001	True
Afternoon	H	J	-00:30	0.9	False
	H	L	-12:54	0.001	True
	H	M	-06:01	0.001	True
	J	L	-12:24	0.001	True
	J	M	-05:31	0.288	False
	L	M	06:53	0.001	True
Evening	H	J	-03:28	0.8144	False
	H	L	-10:17	0.001	True
	H	M	-04:21	0.001	True
	J	L	-06:49	0.4813	False
	J	M	-00:53	0.9	False
	L	M	05:56	0.0618	False

7.2.1 Conclusion

During *Taxi-Out,* bigger differences between the WTCs occur than during the *Start-Up*. It can be seen that J behaves more like the other categories than during the *Start-Up*. This can be seen in the overall overview, where only combination H, M significantly differs having a mean difference of 05:26 min. It is also the largest mean difference for combination H, M within the entire outbound phase. WTC J acts differently in the afternoon, which was also seen during *Start-Up*. However, it behaves more in line with the other categories. For both L and H a different average is seen in the evening. As final, the smallest mean difference for combination H, M is in the morning, for combinations involving J this is in the afternoon.

8 Discussion

For this research, one month of data is used to establish the operational impact of the fleet mix on the outbound capacity. This contains the month of July 2019, which is 2nd busiest month in that year based on the number of flight movements (Schiphol, 2019). Repeating the research with the same data will most likely provide the same results. However, the interpretation of the results might be not fully correct to the current circumstances around COVID-19, which changed the operation at Schiphol drastically. Therefore, in the future, the fleet mix and/or Declared capacity might change. Besides, with the construction of the A-pier which is planned to be finished at the end of 2020, the time spent in the processes of the WTCs might be different. Furthermore, the sample sizes of the WTCs have a extensive difference. Besides, these results might not be 100% reliable due to shortage of knowledge on the used program language of Python. These possible mistakes are eliminated as much as possible by presenting the results and methodology to an expert during this research. Also, related to COVID-19, seeing the operational side of the project in real life was impossible, which would create a better view on the subject. As final, working from a distance and time restriction may have a negative influence on the assignment.

The results show that in the outbound phase, the heavier the aircraft (higher WTCs), the more time it spent on average. However, the operational impact of the WTC differs for each process. This result was also expected. This expectation was also set for the (sub)processes. However, this is not always the case. The results also showed that only in the *Start-Up* and *subprocess 1* WTC J significantly differs from the other categories with an average time spent of 39:13 min and 36:58 min. While it was expected that this category would significantly differ in all the processes, due to the size, special guidelines, and separation rules. Furthermore, it was expected that differences between the dayparts are minimal. However, this is only the case in *subprocess 2,* where the maximum difference is 00:28 min.

In all the results it should be noted that the samples of WTC H and M are consideratly bigger in size. Therefore, a significant difference can occur while having a small difference is mean. During *Start-Up* process*,* the expectation of a higher average time spent with an heavier WTC is denied. The extensive mean difference in combinations H, J, and J, M in the *Start-Up* might be caused by apron handling restrictions the aircraft has. WTC J has special procedures for its wingspan, size, and height. On the apron, this includes the help of two AAS staff, before the aircraft can pushback (LVNL, n.d.). Also, the expectation was that there would be small differences throughout the day. However, it was seen that mainly WTC J behaves completely different in the afternoon. Further detail on the interpretation of the results are explained in subprocess 1 and 2.

In *subprocess 1* of the *Start-Up,* it was expected that the same operational impact of the fleet mix is seen as the *Start-Up*. However, the results show that this is not the case. Other than during the overall *Start-up*, combination H, M significantly differs, however since these samples are considerably bigger, the actual mean difference is only 01:21 min. Again combinations with WTC J have a mean difference around 15:00 min. Also, the expectation that a higher WTC would spent on average more time in the process was denied. WTC M spent on average 01:21 min longer than H. A reason could be that bigger separation is needed when a heavier WTC is active, resulting in longer waiting times. This reason might be related to the CPDSP, which issues the TSAT, which also explains why the mean differences are smaller in *subprocess 2* (TSAT till AOBT). The majority of the time spent in the *Start-Up*, is spent in subprocess 1. This may be caused by the fact that the aircraft needs to wait for pushback approval. It can be seen that in the afternoon WTC J has an extensive average time of 54:00 min. This may be caused by several reasons. This aircraft type has special restrictions, procedures and requires a larger separation for the following up aircraft during take-off. Therefore, the timing in the sequence is essential. This may lead to a longer waiting time on the ground. However, in the morning, the average of WTC J is only 02:54. It must be noted that this sample size consist only of one aircraft. This may be caused by a better planning, sequence or wrong updated time references. Also, WTC L shows a higher time spent than expected of 12:35 min on average. Especially in the evening the average time spent is high (24:15 min). This may be caused by the fact these WTC needs to fit in the air sequence. Since these flights depart from an independent runway (04-22) and are easily affected flying behind larger aircraft. They may have to wait longer in order to fit into the sequence. Also, since these aircraft are usually non-commercial and easier for ground handling, the target off-block time can be set sooner than expected. As final, in general it can be seen that the average time spent in the evening is higher. This may be caused by the larger amount of aircraft during this daypart. Besides, the high variation in WTC M is not caused by the different runway combinations. Here runway 18L-24 and 36C-36L are equally used.

In *subprocess 2*, after the target pushback approval is issued, the aircraft is allowed to pushback. It was expected that no significant differences (or smaller differences) are seen between the WTCs. However, the results show a significant difference in combination H, M, but only differ by 01:12 min. The reason could be a shortage of resources to start pushback, or when aircraft are parked close to each other, which means they have to wait. This subprocess confirmed the expectation that a heavier WTC spent on average more time in the process (with exception of WTC L). WTC L showed the biggest mean differences with a minimum of 04:18 with WTC H. These aircraft types are parked at Schiphol-East, and usually required no pushback truck. The extra time spent on average (06:44) may be caused by receiving the actual start-up approval after the target start-up approval (TSAT). Another cause can be the engine start-up procedure. Since these aircraft do often not make use of the pushback truck. Therefore, the engines are started before pushback. This procedure may take longer for these aircraft to start push-back. For the other WTCs the time spent in this subprocess is very low (around 02:00 min). This may indicate that the required pushback trucks are available at -5 min before TSAT, as advised by LVNL. However, in WTC M and H a higher time spent can be seen between 10:00 and 15:00 min. This may be caused by a later actual push-back approval or that aircraft need to wait since multiple aircraft in the vicinity start pushback as well. It may also be caused by the type of pushback truck, personnel and or company.

During *Taxi-Out* multiple factors influence the time spent. It was expected that overall WTC's H, J, and M will have small mean differences, since the frequently used runway combinations may be able to compensate the taxi-out distance from particular gate locations. However, since WTC J has restrictions when it comes to the use of taxiways and special procedures, it was expected that this category has the highest mean difference and time spent. The overall results show, however, that there is only a significant difference in combination H, M. WTC J might have special procedures and restrictions, however, the pushback area and surroundings are have traffic interference in contrast to the other piers. This may be the cause as to why the average time spent is only 12:25 min (evening) and 16:49 min (afternoon). Another possible cause is that in the evening (12:25 min) the assigned runway (36C) is closer in distance than in the afternoon. WTC H and M stand at piers/gates where an aircraft which is pushed back might cause interference with aircraft positioned at a gate nearby. It is seen that WTC L spent less time during Taxi-Out with a minimum mean difference of 06:53 min (less) with M. This is caused by the fact that L has a much shorter taxi distance. These aircraft are parked next to the runway (04-22), on Schiphol-East. For WTC L and H it is seen that the average time spent differs in the evening. This may be caused by the lower amount of active aircraft of that WTC during the evening compared to the other dayparts. Whereby it may be more challenging to fit WTC L into the sequence and WTC H may be able to push back sooner. Furthermore, for WTC L in the evening there is looked at the assigned runway. This since departing from 04 has a larger taxiing distance than 22. However, no relation can be seen. As final, it can be seen that WTC H spent on average the most time in the process.

This research is a complement to the current pre-departure and planning method. For each subprocess the operational impact of the WTC is different, the results of this research must be taken into account in the future. However, it should be noted that no external factors or CTOT's are taken into account. The reasons behind the results might be caused by external factors as well. To find out what caused the operational impact on each of the processes, follow-up research is required. It is also important to find the causes of the negative time spent and outliers. If operational impact (due to fleet mix) is not equalized in the future, available capacity may be affected. This is a bottleneck for the airport to grow in flight movements, and it increases delay. Also, the used data is from the final update of the time references, therefore activities beforehand are not taken into account.

9 Conclusion

This research was initiated to answer the main question: *'What is the operational impact of the fleet mix on the outbound capacity at Amsterdam Airport Schiphol under the A-CDM principles?'.* This is answered by performing quantitative research towards the time spent in defined (sub)processes. The Wake Turbulence Categories (WTC) are compared for the entire outbound phase and the (sub)processes individually. The two main processes are *Start-Up* and *Taxi-Out.* The Start-up can be divided into two subprocesses: 1 and 2. The data used is from the month of July 2019 and includes all flight movements, with exception of helicopters.

In the outbound phase, each combination of the group WTC shows a significant difference. It can be seen that a heavier WTC spent on average more time in the outbound phase. Besides, coincidence of the differences can be eliminated, or not, through statistical testing. Overall, the WTCs differ less significant in the evening than the other dayparts. This correlates with the less variety in fleet mix during the evening, despite the time spent is longer in this daypart. On a limited scale, this relation can be seen between the morning and afternoon as well. These relations can also be seen in the analysis towards the Realization vs the Declared capacity, where peak hours with less variety in fleet mix reach the capacity more often. Overall, it can be seen that there is an operational impact of the fleet mix on the outbound capacity. This can be defined as the wider the fleet mix variety during a peak hour, the more capacity is lost. This is caused by the significant differences in time spent between WTCs in (sub)processes, rather than the overall process time. This impact, however, is different for every (sub)process and WTC. Whilst J shows the most difference during the *Start-Up*, H and M show the biggest difference during *Taxi-Out*. Also, the variety of the time spent on the fleet mix is the biggest in *subprocess 1*, and *Taxi-Out*.

During the *Start-Up* process it can be seen that the time spent in the process differs for each WTC (exception of M and H). The largest differences are with J, with an average of 39:13 min. This difference is especially seen in the afternoon, where WTC J behaves more extreme (55:56 min) than the evening (05:47 min). Furthermore, the majority of the time spent in the outbound phase is spent in the *Start-Up* for L and J. Different than the outbound phase, WTC M and L spent on average more time in the *Start-Up* than H. However, this difference is minimal which range from 00:31 min until 04:00 min. During the morning and afternoon, WTC L spent more time than H and M (around 04:00 min). For the evening this is the other way around. This also applies to combination H, M, where H spent less time than M in the evening. The impact of the *Start-Up* process is mainly caused by WTC L (13:02 min average) and J (39:13 min average). This since they differ the most from M and H, which spent approximately the same time in the *Start-Up* process. However, it must be noted that M and H have excesses that spent way more time (maximum 127:00 min) than the average.

Subprocess 1, which is part of the *Start-Up*, looks similar to the overall view of the *Start-Up* based on the time spent. This subprocess is from the target off-block time until the target pushback approval time is issued. It can be seen that the majority of the time spent during the *Start-Up* happens in this subprocess. Here, the averages range from 01:00 until 03:00 min. Just like the *Start-Up,* M (08:17 min) and L (12:35 min) spent on average more time than H (06:56 min). Again, the biggest differences are caused by WTCs L (average of 12:35) and J (average of 36:58 min). As seen in the Outbound phase and the *Start-Up,* the excessive values under M and H happen during this subprocess. However, no relation is seen with the active runway combinations. For L the average time spent in the evening is higher than the morning and afternoon. This may be caused by the low amount of aircraft, so the planning is more difficult. In this subprocess, the impact of the fleet mix can be seen by the variety of time spent within WTC M and H, and the differences of time spent between the WTCs involving L (12:35 min) and J (36:58 min). This process will be most important for Schiphol airport, due to the occupation of the gates/stands.

Subprocess 2 which is also part of the *Start-Up*, shows a different behaviour than *subprocess 1*. This subprocess is from the target approval time of the pushback until actual pushback. More difference in mean is observed for combination H, M. However, this is only 01:12 min. In general, the time spent of the WTCs are more similar than the other processes. The biggest differences are seen in combinations involving WTC L (06:44 min). Besides, WTC J has significantly less impact on this process than it could be seen in *subprocess 1*. Different than the other subprocess is that H (02:26 min) now spent more time than M (01:14 min). The impact of the fleet mix less in this subprocess, as the WTCs show less significant difference. Here, WTC L has the biggest impact with the largest difference in time spent. However, there is still some variety of the time spent in M and H.

As final, during the *Taxi-Out* process, a different operational impact is seen than during the *Start-Up* process. Bigger differences are seen between the WTCs. Here, combination H, M shows more difference in mean than the other combinations (difference in mean 05:26 min). During *Start-Up,* the least difference can be seen in combination H, M. Besides, combinations H, J and J, M show no significant difference. Furthermore, it can be seen that J behaves more similar to the other WTCs during *Taxi-Out* than during the *Start-Up*. No further research is required since no random behaviour is seen. Besides LVNL is already working on improving the variable taxi times.

10 Recommendations

Derived from the discussion and the conclusions, the following recommendations are made:

- Create situational awareness
  In the results, it is seen that for each (sub)process the operational impact of the fleet mix differs. Also, throughout the day differences are seen. To eliminate this impact, it is recommended that the results of this research regarding the outbound phase is transferred to the staff that is working in the pre-departure planning, and other outbound planning purposes. More awareness of the differences in time spent (determined by WTC), may help to further improve the operation.

- Reliability of Time references output
  During this research the time difference between the time references under the A-CDM are calculated. It is seen that some flights have a negative time difference, which mostly can be seen in the *Start-Up* and the related subprocesses. Also, during *Taxi-Out* small time differences of 01:00 min or below are seen. Since between the time references several activities occur, these results should not be possible. Therefore, there should be looked at the accuracy and reliability of these time references in the outbound phase.

- Causes of impact
  This research is mainly focused on the question of 'What' is the operational impact of the fleet mix. Hereby it is seen that indeed there is an operational impact of the fleet mix on the outbound capacity. However, to eliminate the differences between the WTC, an even more important question needs to be asked, as to why these differences occur. When this question is answered, a better picture is sketched, and more situational awareness is created. Also within the WTC large differences are seen, regarding the spread of the data. Here the same question needs to be asked, as to why these differences are so extensive.

  The main focus of the further research lays in the Start-Up. This since LVNL (2020) is already working on improvement of the *Taxi-Out* process. In *subprocess 1* it is seen that in WTC M and H there is more variability of the time spent. To establish the why these variety occurs, there need to be looked at the activities of these flights. This can be done by asking the controllers, and observing the operation.

  For *subprocess 2* there must be looked at why WTC L differs in time spent with the other categories. This can also be done by observing the operation and interviews.

- Used vocabulary
  During this research, several definitions and their interpretation were required. However, it was noted that the needed vocabulary was not stated clearly. Besides, the definition and interpretation was not known by people, or at least not clear. Therefore, to make sure this is clear, also for further investigations, it is recommended that a clear overview of the meaning and interpretation behind the definitions is made.

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Appendix I Reflection

To finish my bachelor's Aviation with a specialization in logistics I conducted a graduation internship in the period of February till July of 2020 at the Knowledge and Development Centre – Centre of Excellence, located at Air Traffic control the Netherlands. I applied for this internship to improve my communication and analytics skills, create new connections, and be more confident. Especially communication and being more confident suited the required competence in the application form.

When I look back at this period, there are a couple of things that I would do differently. This mostly regards taking actions earlier in some situations. At the beginning of the internship, the assignment that I was given was not very clear to me. Or better said I thought I understood it correctly, well did was not the case. Besides after three weeks, I found out that my current assignment is already been performed by someone else. At first, this was not a problem, but since it took a couple of weeks to have a clear assignment, that was also clear to me, it was rather frustrating. Looking back I would have put more pressure on the fact that a clear and scoped assignment is required at the beginning of the internship, and therefore the outcome might be earlier, and the support base of the assignment was bigger.

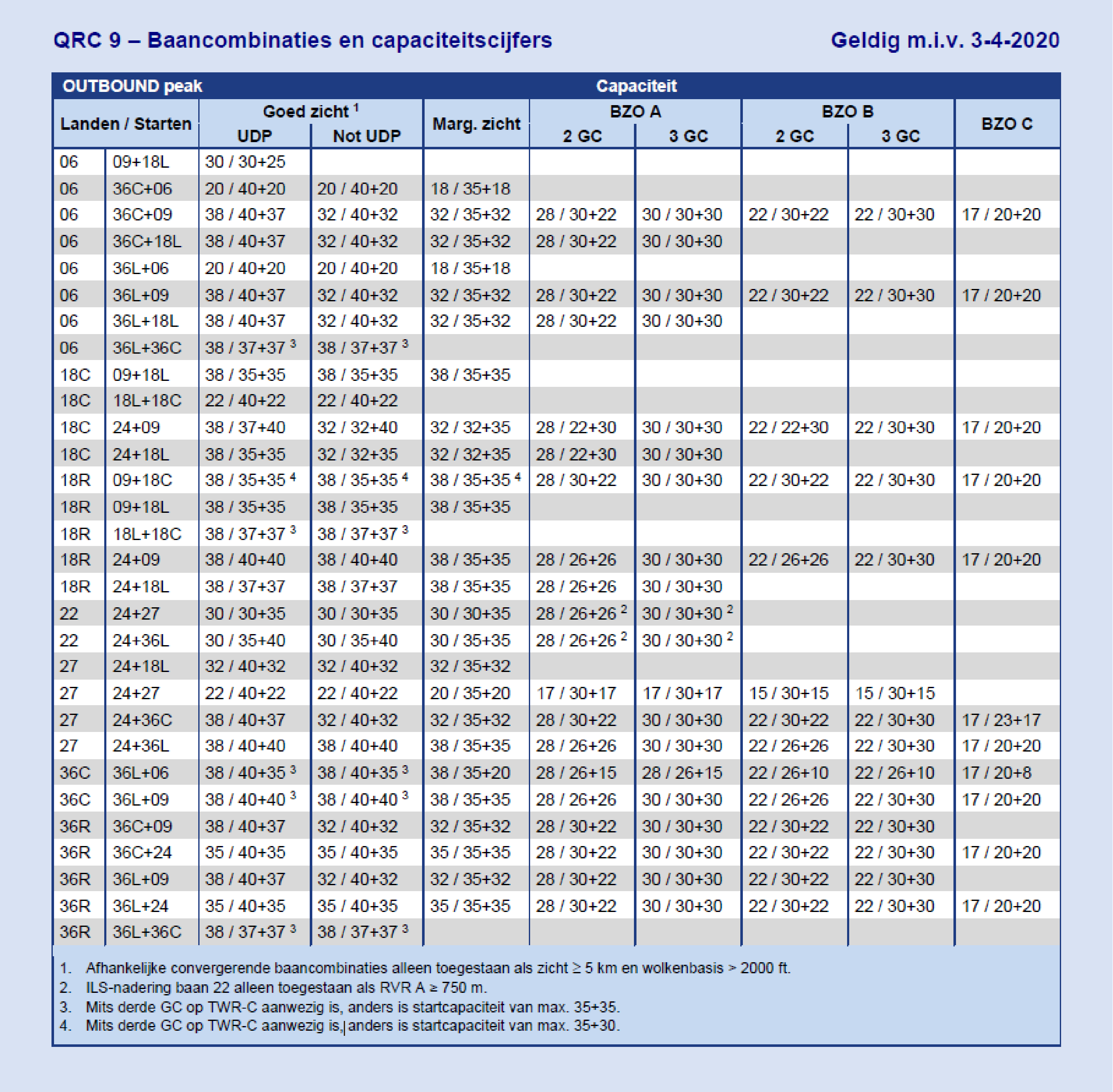
Another thing that I would change during this period, is to be more confident in the actions I take, even when people might get annoyed by those actions. In the first couple of weeks, I experienced it as chaotic based on the administrative side of the internship. One of the problems was that sometimes entering the building was a challenge since I had no guidance or company pass. In the beginning, I was told that it is not appreciated to ask people things or go to the coherent department ourselves. Therefore, when I was told that the problem was taken care of, I just waited, since I did not want to cause any problems. However, since there was a possibility that entering the building was not possible for two whole weeks, I took action into my own hands, whatever what people might think. To my surprise, they were very kind and helpful and after 30 minutes later I received my company pas. Maybe if I conducted this step sooner, I would have gotten the pas earlier. However since I was not really ‘allowed’ to take action ourselves, I did not want to cause any problems if we did take action. Here I learned that sometimes you just have to let go of what other people think to eventually achieve your goal.

Before this internship started amongst others the improvement of my communication skills was my main goal. I learned during my third-year internship that when you present everything calm and confident, you already have a great start. I often struggle to make a clear and short story. During this time I often have everything that is required in my head, but I struggle to transfer this to others. I notice that a lot of times when I struggle with this is when I don’t feel very comfortable in the situation and/or around the people I present to. During the internship, I found myself in this situation very often, at a stage I did not experienced earlier in my life. As of today I still try to figure out why this happened. Perhaps since I needed to work from home, and comments, feedback, and situation are harder to handle in the comfort of your own home, and without the visual of the people talking to you. In a way, I felt disconnected. I also notice that I can present more clearer when I have more confidence, which mainly happened when I tried not to care what the other was thinking since this is also not always right. During the internship, a lot of comments or situations felt very negative towards me personally, while this perhaps is not the intention. When such situations occurred, I had a very hard time to coop with this and to find the strength to just shake it off and continue. Since this internship was not a normal situation, I talked with the management of my school about my situation. From this talk, it was clear to me that I handled the situation right, and that I just had to take in all the things I had learned and not take their comments personally. Looking back I would have done this sooner, to gain more confidence in the whole situation.

As final, the thing that I needed to apply at the beginning, is to take more free time or make a clearer distinction between work and my personal life. When starting working from home in March to the situation around COVID-19, I found it hard to motivate and concentrate. Mainly because I live in a very small space, and since there is no one around. Also, I know from myself, that I work better on location, and when I have easy access to other people to discuss things or just talk to. In the last few weeks of the assignment, I found myself in a place where I just wanted to close this period and move on. Mainly because of the problems that occurred during this period, but also since I was mentally exhausted. At this moment I worked long days, which also extended in the weekend besides my side-job, which also changed due to COVID-19. After a while, the situation only got worse, which people close to me also noted. However since I really want to prove myself, I found it hard to follow their advice in taking things slower. After a while, I followed their advice and took some more time off, and separate work and personal life again. Then I quickly found rest in my head and had my focus, motivation, and confidence back. I wish I did this sooner, so my head was more at peace. The main message I learned is that taking some rest translates in better results than working when you are mentally exhausted.

Appendix II *Outbound peak runway capacity*

In this appendix the maximum available runway capacity for each combination is stated.



QRC 9 – Baancombinaties en capaciteitscijfers **Geldig m.i.v. 3-4-2020**

OUTBOUND peak		Capaciteit							
Landen / Starten		Goed zicht [1]		Marg. zicht	BZO A		BZO B		BZO C
		UDP	Not UDP		2 GC	3 GC	2 GC	3 GC	
06	09+18L	30 / 30+25							
06	36C+06	20 / 40+20	20 / 40+20	18 / 35+18					
06	36C+09	38 / 40+37	32 / 40+32	32 / 35+32	28 / 30+22	30 / 30+30	22 / 30+22	22 / 30+30	17 / 20+20
06	36C+18L	38 / 40+37	32 / 40+32	32 / 35+32	28 / 30+22	30 / 30+30			
06	36L+06	20 / 40+20	20 / 40+20	18 / 35+18					
06	36L+09	38 / 40+37	32 / 40+32	32 / 35+32	28 / 30+22	30 / 30+30	22 / 30+22	22 / 30+30	17 / 20+20
06	36L+18L	38 / 40+37	32 / 40+32	32 / 35+32	28 / 30+22	30 / 30+30			
06	36L+36C	38 / 37+37 [3]	38 / 37+37 [3]						
18C	09+18L	38 / 35+35	38 / 35+35	38 / 35+35					
18C	18L+18C	22 / 40+22	22 / 40+22						
18C	24+09	38 / 37+40	32 / 32+40	32 / 32+35	28 / 22+30	30 / 30+30	22 / 22+30	22 / 30+30	17 / 20+20
18C	24+18L	38 / 35+35	32 / 32+35	32 / 32+35	28 / 22+30	30 / 30+30			
18R	09+18C	38 / 35+35 [4]	38 / 35+35 [4]	38 / 35+35 [4]	28 / 30+22	30 / 30+30	22 / 30+22	22 / 30+30	17 / 20+20
18R	09+18L	38 / 35+35	38 / 35+35	38 / 35+35					
18R	18L+18C	38 / 37+37 [3]	38 / 37+37 [3]						
18R	24+09	38 / 40+40	38 / 40+40	38 / 35+35	28 / 26+26	30 / 30+30	22 / 26+26	22 / 30+30	17 / 20+20
18R	24+18L	38 / 37+37	38 / 37+37	38 / 35+35	28 / 26+26	30 / 30+30			
22	24+27	30 / 30+35	30 / 30+35	30 / 30+35	28 / 26+26 [2]	30 / 30+30 [2]			
22	24+36L	30 / 35+40	30 / 35+40	30 / 35+35	28 / 26+26 [2]	30 / 30+30 [2]			
27	24+18L	32 / 40+32	32 / 40+32	32 / 35+32					
27	24+27	22 / 40+22	22 / 40+22	20 / 35+20	17 / 30+17	17 / 30+17	15 / 30+15	15 / 30+15	
27	24+36C	38 / 40+37	32 / 40+32	32 / 35+32	28 / 30+22	30 / 30+30	22 / 30+22	22 / 30+30	17 / 23+17
27	24+36L	38 / 40+40	38 / 40+40	38 / 35+35	28 / 26+26	30 / 30+30	22 / 26+26	22 / 30+30	17 / 20+20
36C	36L+06	38 / 40+35 [3]	38 / 40+35 [3]	38 / 35+20	28 / 26+15	28 / 26+15	22 / 26+10	22 / 26+10	17 / 20+8
36C	36L+09	38 / 40+40 [3]	38 / 40+40 [3]	38 / 35+35	28 / 26+26	30 / 30+30	22 / 26+26	22 / 30+30	17 / 20+20
36R	36C+09	38 / 40+37	32 / 40+32	32 / 35+32	28 / 30+22	30 / 30+30	22 / 30+22	22 / 30+30	
36R	36C+24	35 / 40+35	35 / 40+35	35 / 35+35	28 / 30+22	30 / 30+30	22 / 30+22	22 / 30+30	17 / 20+20
36R	36L+09	38 / 40+37	32 / 40+32	32 / 35+32	28 / 30+22	30 / 30+30	22 / 30+22	22 / 30+30	
36R	36L+24	35 / 40+35	35 / 40+35	35 / 35+35	28 / 30+22	30 / 30+30	22 / 30+22	22 / 30+30	17 / 20+20
36R	36L+36C	38 / 37+37 [3]	38 / 37+37 [3]						

1. Afhankelijke convergerende baancombinaties alleen toegestaan als zicht ≥ 5 km en wolkenbasis > 2000 ft.
2. ILS-nadering baan 22 alleen toegestaan als RVR A ≥ 750 m.
3. Mits derde GC op TWR-C aanwezig is, anders is startcapaciteit van max. 35+35.
4. Mits derde GC op TWR-C aanwezig is, anders is startcapaciteit van max. 35+30.

Appendix III *Measures of Central Tendency and spread*

This appendix shows the Measures of Central Tendency and spread for each process. The results are divided in general, for each daypart, and Reaching the Declared capacity or not. The title of each table indicates the coherent process.

Table 15 Measures of Central Tendency and spread difference from Declared capacity peak hours for each daypart

	Morning	Afternoon	Evening
Count	30	31	30
Mean	-7.83	-8.55	-0.50
Std	3.12	2.80	5.00
Min	-14.00	-14.00	-13.00
25%	-9.75	-11.00	-4.00
50%	-7.75	-8.00	0.00
75%	-6.00	-6.00	3.75
Max	0.00	-3.00	8.00
Q1-Q3	3.75	5.00	7.75

Table 16 Measures of Central Tendency and spread runway combination 36L-36C and 18L-24 for each daypart

	36L-36C			18L-24		
	Morning	Afternoon	Evening	Morning	Afternoon	Evening
Count	12	14	11	9	13	10
Mean	-6.58	-7.29	0.27	-8.67	-9.23	-1.50
Std	3.53	2.58	4.78	2.83	2.59	4.99
Min	-14.00	-12.00	-9.00	-14.00	-14.00	-13.00
25%	-8.00	-8.75	-1.50	-10.00	-11.00	-4.00
50%	-7.00	-7.00	0.00	-8.00	-9.00	0.00
75%	-5.00	-6.00	4.50	-7.00	-7.00	1.75
Max	0.00	-3.00	6.00	-5.00	-6.00	4.00
Q1-Q3	3.00	2.75	6.00	3.00	3.00	5.75

Table 17 Measures of Central Tendency and spread Outbound phase per WTC

	L: Time spent in min	M: Time spent in min	H: Time spent in min	J: Time spent in min
Count	85	5198	929	3
Mean	16:30	21:02	26:12	54:34
Std	15:59	09:52	09:26	34:08
Min	-17:00	-03:30	06:55	18:12
25%	05:00	14:29	20:09	38:53
50%	15:30	19:14	24:59	59:34
75%	23:07	25:11	30:32	72:45
Max	82:00	127:39	100:07	85:56
Q1-Q3	18:07	10:42	10:23	33:52

Table 18 Measures of Central Tendency and spread outbound phase per WTC for each daypart

	L: Time spent in min			M: Time spent in min			H: Time spent in min			J: Time spent in min		
	Morning	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**
Count	42	34	9	1575	1669	1954	367	323	239	NaN	2	1
Mean	13:29	17:46	25:46	19:15	21:11	22:21	24:43	27:39	26:32	NaN	72:45	18:12

Std	13:56	15:30	23:22	08:13	11:04	09:48	06:35	12:19	08:18	NaN	18:38	NaN
Min	-17:00	-05:00	05:00	-03:30	02:10	02:14	10:22	07:35	06:55	NaN	59:34	18:12
25%	04:11	08:23	09:10	13:50	13:59	15:33	19:48	20:06	20:50	NaN	66:10	18:12
50%	14:53	14:35	17:55	17:47	18:56	20:54	24:05	25:13	26:14	NaN	72:45	18:12
75%	21:30	23:55	30:00	23:03	23:54	26:55	29:23	31:17	31:26	NaN	79:20	18:12
max	56:37	59:42	82:00	90:03	127:39	106:06	50:00	100:07	54:35	NaN	85:56	18:12
Q1-Q3	17:19	15:32	20:50	09:12	9:55	11:22	09:34	11:11	10:36	NaN	13:11	NaN

Table 19 Measures of Central Tendency and spread Start-Up per WTC

	L: Time spent in min	M: Time spent in min	H: Time spent in min	J: Time spent in min
Count	34	5081	907	3
Mean	13:02	09:31	09:18	39:13
Std	14:05	09:26	08:57	32:11
Min	-05:36	-11:22	-07:43	05:47
25%	03:59	03:51	03:47	23:51
50%	09:32	06:59	07:01	41:55
75%	17:58	12:19	11:55	55:56
Max	54:30	117:36	84:55	69:57
Q1-Q3	13:58	08:41	08:08	32:05

Table 20 Measures of Central Tendency and spread Start-Up per WTC for each daypart

	L: Time spent in min			**M: Time spent in min**			**H: Time spent in min**			**J: Time spent in min**		
	Morning	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**
Count	14	17	3	1547	1631	1903	360	315	232	NaN	2	1
Mean	11:55	14:39	09:03	07:31	09:53	10:50	07:37	10:22	10:29	NaN	55:56	05:47
Std	14:39	14:55	06:40	07:39	10:27	09:34	05:31	12:13	07:30	NaN	19:49	NaN
Min	-05:36	01:43	02:06	-11:22	-04:36	-04:38	-02:12	-02:12	-07:43	NaN	41:55	05:47
25%	02:49	05:53	05:53	02:57	03:38	04:28	03:36	03:13	05:21	NaN	48:56	05:47
50%	09:47	08:43	09:40	05:40	06:57	08:28	06:30	06:18	08:59	NaN	55:56	05:47
75%	17:17	18:49	12.32	10:07	12:05	14:56	10:13	11:27	15:15	NaN	62:56	05:47
max	50:57	54:30	15:23	81:16	117:36	95:20	28:18	84:55	43:09	NaN	69:57	05:47
Q1-Q3	14:28	12:56	09:30	07:10	08:27	10:27	06:37	08:14	09:54	NaN	14:01	NaN

Table 21 Measures of Central Tendency and spread subprocess 1 per WTC

	L: Time spent in min	M: Time spent in min	H: Time spent in min in min	J: Time spent in min
Count	83	5195	928	3
Mean	12:35	08:17	06:56	36:58
Std	16:18	09:29	08:56	34:03
Min	-15:00	-19:00	-12:00	-02:54
25%	00:00	02:00	01:00	19:57
50%	08:00	06:00	05:00	37:00
75%	20:00	11:00	10:00	54:00
max	82:00	119:00	86:00	71:00
Q1-Q3	20:00	09:00	09:00	34:03

Table 22 Measures of Central Tendency and spread subprocess 1 per WTC for each daypart

	L: Time spent in min			**M:** Time spent in min			**H:** Time spent in min			**J:** Time spent in min		
	Morning	Afternoon	Evening	Morning	Afternoon	Evening	Morning	Afternoon	Evening	Morning	Afternoon	Evening
Count	42	33	8	1573	1668	1954	367	323	238	NaN	2	1
Mean	10:40	12:13	24:15	05:56	08:35	09:54	05:25	07:47	08:09	NaN	54:00	02:54
Std	13:11	15:59	27:18	07:46	10:24	09:33	05:34	12:00	07:55	NaN	24:02	NaN
Min	-15:00	-03:00	-02:00	-19:00	-11:00	-07:13	-06:00	-07:00	-12:00	NaN	37:00	02:54
25%	00:00	-00:00	06:45	01:00	02:00	03:00	01:00	01:00	02:00	NaN	45:30	02:54
50%	07:30	04:00	20:30	04:00	06:00	08:00	05:00	04:00	07:00	NaN	54:00	02:54
75%	19:45	18:00	31:30	09:00	11:00	14:00	08:00	09:00	12:00	NaN	62:30	02:54
max	43:00	52:00	82:00	79:00	119:00	94:00	27:00	86:00	42:00	NaN	71:00	02:54
Q1-Q3	19:45	18:00	24:45	08:00	09:00	11:00	07:00	08:00	10:00	NaN	25:30	NaN

Table 23 Measures of Central Tendency and spread subprocess 2 per WTC

	L: Time spent in min	**M: Time spent in min**	**H: Time spent in min**	**J: Time spent in min**
Count	34	5081	907	3
Mean	06:44	01:14	02:26	02:15
Std	02:36	02:39	02:44	03:02
Min	00:52	-09:09	-05:46	-01:03
25%	04:44	-00:27	00:42	00:55
50%	07:08	01:06	02:07	02:53
75%	08:48	02:39	03:45	03:54
max	10:24	18:00	18:32	04:55
Q1-Q3	04:04	03:06	03:03	02:59

Table 24 Measures of Central Tendency and spread subprocess 2 per WTC for each daypart

	L: Time spent in min			**M: Time spent in min**			**H: Time spent in min**			**J: Time spent in min**		
	Morning	Afternoon	Evening	Morning	Afternoon	Evening	Morning	Afternoon	Evening	Morning	Afternoon	Evening
Count	14	17	3	1547	1631	1903	360	315	232	NaN	2	1
Mean	06:51	06:42	06:23	01:34	01:18	00:54	02:17	02:36	02:27	NaN	01:56	02:53
Std	02:57	02:25	02:55	02:34	02:50	02:31	02:45	02:49	02:36	NaN	04:13	NaN
Min	00:52	02:15	04:06	-06:42	-09:09	-06:52	-05:46	-04:24	-03:43	NaN	-01:03	02:53
25%	04:25	05:51	04:44	-00:03	-00:25	-00:42	00:29	00:54	01:02	NaN	00:26	02:53
50%	08:04	06:56	05:23	01:26	01:12	00:48	02:00	02:20	02:05	NaN	01:56	02:53
75%	09:14	08:43	07:31	02:59	02:50	02:20	03:40	03:57	03:27	NaN	03:26	02:53
max	10:24	10:17	09:40	16:08	18:00	12:28	18:32	15:06	12:50	NaN	04:55	02:53
Q1-Q3	04:49	02:52	02:47	03:03	03:15	03:02	03:12	03:03	02:25	NaN	02:59	NaN

Table 25 Measures of Central Tendency and spread of Taxi-Out per WTC

	L: Time spent in min	**M: Time spent in min**	**H: Time spent in min**	**J: Time spent in min**
Count	34	5084	907	3
Mean	04:38	11:31	16:51	15:21
Std	02:08	04:13	05:04	02:40
Min	00:38	00:20	02:36	12:25
25%	02:44	08:34	12:59	14:12
50%	05:05	10:51	15:47	15:59
75%	06:05	13:55	20:24	16:49
max	09:08	40:54	44:52	17:39
Q1-Q3	03:20	05:21	07:25	02:37

Table 26 Measures of Central Tendency and spread of Taxi-Out per WTC for each daypart

	L: Time spent in min			**M: Time spent in min**			**H: Time spent in min**			**J: Time spent in min**		
	Morning	Afternoon	Evening	Morning	Afternoon	Evening	Morning	Afternoon	Evening	Morning	Afternoon	Evening
Count	14	17	3	1548	1632	1904	360	315	232	NaN	2	1
Mean	04:42	04:25	05:36	11:44	11:18	11:32	17:03	17:19	15:53	NaN	16:49	12:25
Std	02:06	02:11	02:40	04:21	04:12	04:05	05:00	05:26	04:29	NaN	01:11	NaN
Min	01:30	00:38	02:32	01:04	00:20	00:31	02:36	03:02	04:39	NaN	15:59	12:25
25%	02:50	02:36	04:48	08:50	08:25	08:28	13:16	13:05	12:44	NaN	16:24	12:25
50%	05:17	04:18	07:04	10:58	10:41	10:54	16:33	16:12	15:13	NaN	16:49	12:25
75%	05:57	05:39	07:08	13:54	13:50	14:00	20:35	21:09	18:02	NaN	17:14	12:25
max	09:08	07:31	07:12	40:54	30:43	28:13	34:00	44:52	29:57	NaN	17:39	12:25
Q1-Q3	02:58	03:03	02:20	05:05	05:25	05:32	07:19	08:04	05:18	NaN	00:50	NaN

Appendix IV *Fleet mix overview*

In this appendix the distribution of the fleet mix as an overall, in the morning, afternoon and evening are displayed.

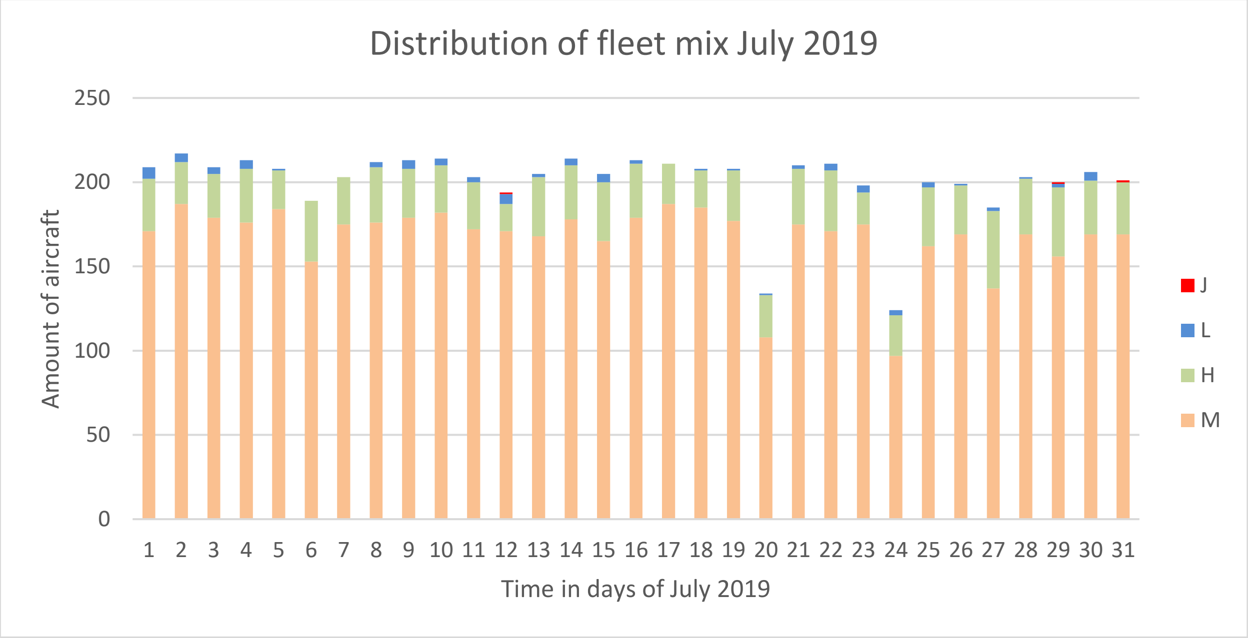


Figure 30 Distribution of fleet mix July 2019

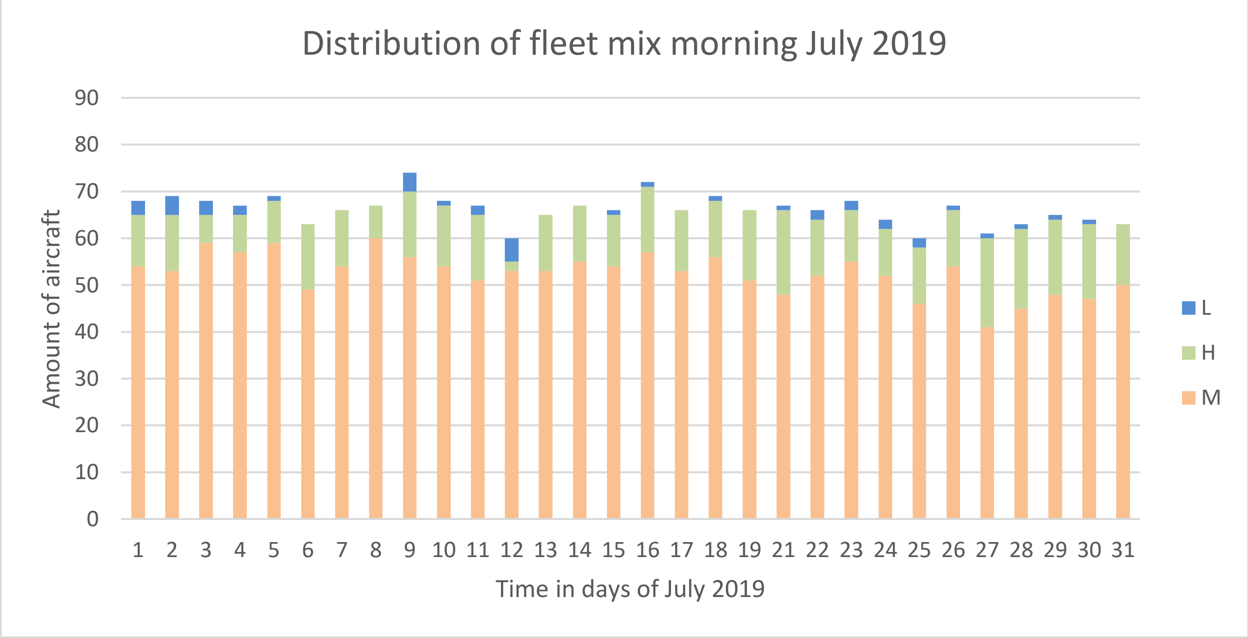


Figure 31 Distribution of fleet mix morning July 2019

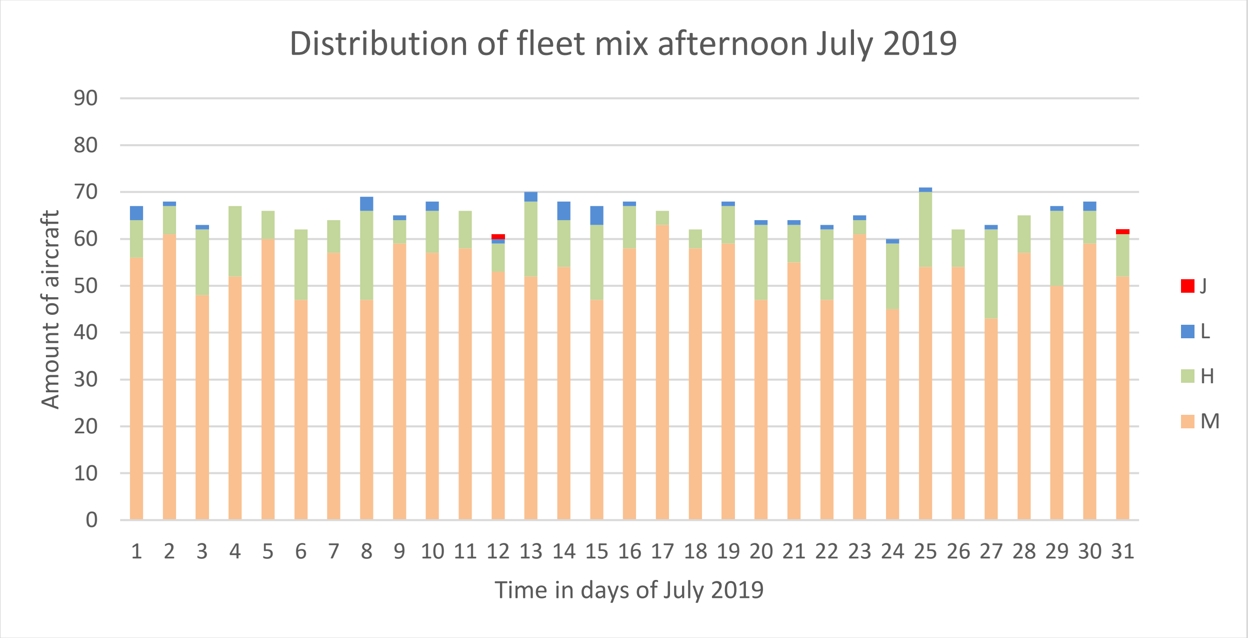


Figure 32 Distribution of fleet mix afternoon July 2019

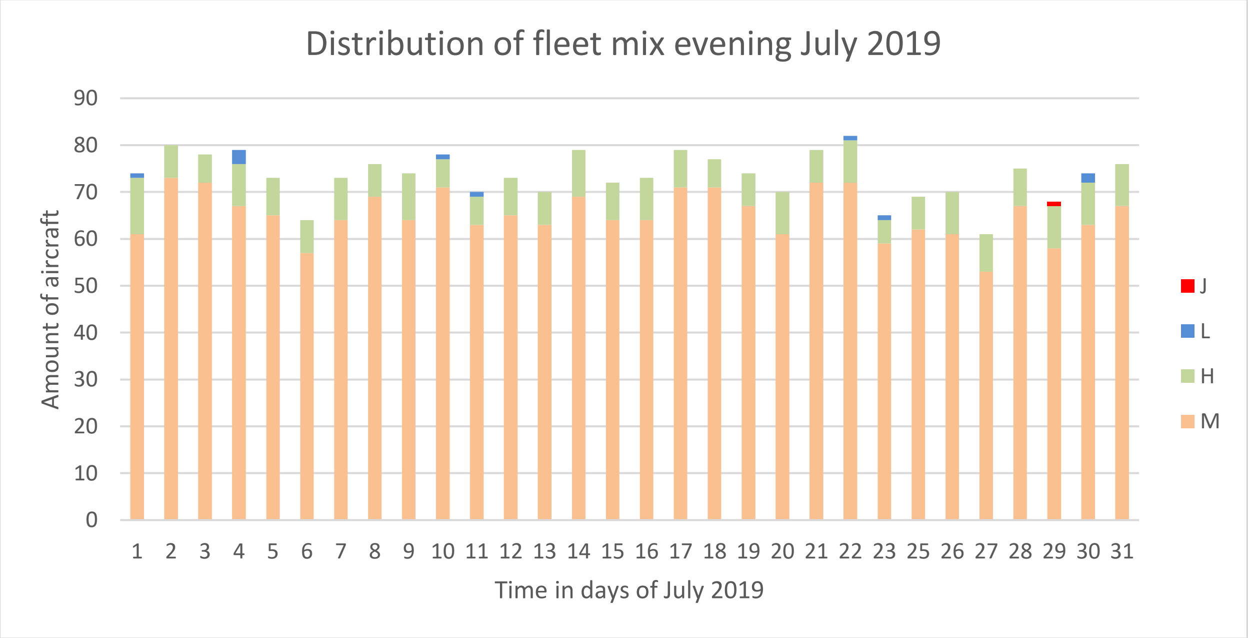


Figure 33 Distribution of fleet mix evening July 2019