

IMPACT OF RUNWAY CHANGES ON THE CAPACITY OF AMSTERDAM AIRPORT SCHIPHOL

INSIGHT IN THE DYNAMICS & EFFECTS OF RUNWAY CONFIGURATION CHANGES

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IMPACT OF RUNWAY CHANGES ON AIRPORT CAPACITY

This report, commissioned by the Knowledge Development Centre, provides insight in the impact of runway changes on airport capacity in terms of deviations and variations in daily operations and planning.

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PREFACE

This research report is proof of competence for obtaining the Bachelor of Science degree in Aviation Logistics from the University of Applied Sciences, located in Amsterdam, the Netherlands. The degree program is focused on aviation related logistic processes including organising flow of assets, managing logistic chains, optimising processes and planning of assets. This thesis provides insight in the competences with regard to capacity management.

The research project is part of the final thesis as a completion to the degree program commissioned by the stakeholders of the Knowledge Development Centre (KDC), placed at Air Traffic Control the Netherlands. The KDC Centre of Excellence is a collaboration between the Amsterdam University of Applied Sciences (AUAS), and the main stakeholders of the KDC, i.e. Amsterdam Airport Schiphol, KLM Royal Dutch Airline and Air Traffic Control the Netherlands. The KDC Centre of Excellence collaborated with the AUAS with the main objective to research capacity management.

This quantitative analysis indicates how the dynamic aviation industry operates with small margins of improvements and against its maximum capabilities, challenged by environmental and safety regulations.

During the writing of the research project, I had the luxury to obtain all operational data from the three involved stakeholders of the KDC. Amongst the available data, I could ask for the expertise of industry experts regarding my research and I am thankful for this.

Thereafter, I would like to thank Evert Westerveld for his effort in guiding me during the entire research project. His expertise, feedback and network brought extra value to the research and kept challenging me until the end. Without the support of Evert Westerveld, I would not have been able to provide a research project as it is now.

Secondly, my thanks are in place for Frenchez Pietersz his guidance during the writing of the research plan and project. Without the insights and feedback of Frenchez Pietersz, I would had more difficulties writing my research project. Accordingly, his expertise and enthusiasm provided me with frequent findings which were useful for my research.

Moreover, I would like to thank Alina Zelenevska for het weekly input during the SCRUM meetings. With her commitment, I was able to work effectively throughout the research. Also Ceriel Jansen and Eugene Leemans were involved during the research and I want to thank them as they were always approachable for any questions.

In addition, my research could not have been executed with the provided data by Stephan Galis. At the start he provided me with basic knowledge about my research topic, and later gave me data which was required for the research. Moreover, I would like to thank Ferdinand Dijkstra as he helped me with the analysis methods during my research. Without them I would not have been able to perform the research.

Last but not least I want to thank my fellow students Huib de Jong, Joep Boekhout and Niek Jacobsen for making every day at the office a pleasant time. And in addition, their help and tips were useful for me during the research. The weekly feedback sessions were from great value to me.

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ABSTRACT

This thesis provides insight into the dynamics and effects of runway changes on the airport capacity of Schiphol. This research was desired by the stakeholders of the Knowledge Development Centre (KDC) Mainport Schiphol, because there was no information on how the airport capacity was affected. The objective was to create clarity of the impact of runway changes and provide an advice on points of improvements for trajectories after 2020. Through quantitative analysis insight is created in the current situation and recommendations based upon conclusions are made. These recommendations are based upon new insights created throughout this research.

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LIST OF ABBREVIATIONS

AAS	Amsterdam Airport Schiphol (Group)
ACC	Area Control Centre
A-CDM	Airport-Collaborative Decision Making
AIBT	Actual In-Block Time
ALDT	Actual Landing Time
AMAN	Arrival Management
AOBT	Actual Off-Block Time
AOP	Airport Operations Plan
ATMAP	Air Traffic Management Airport Performance
ATOT	Actual Take-Off Time
AXIT	Actual Taxi-In Time
AXOT	Actual Taxi-Out Time
CCIS	Closed Circuit Information System
CPDSP	Collaborative Pre-Departure Sequence Planning
CRP	Capacity Requirement Planning
CTOT	Calculated Take-Off Time
CTR	Control Region
DDR	Demand Data Repository
EHAM	Amsterdam
ELDT	Estimated Landing Time
EOBT	Estimated Off-Block Times
ETOT	Estimated Taxi-Out Time
EUACA	European Union Airport Coordinators Association

EXIT	Estimated Taxi-In Time
EXOT	Estimated Taxi-Out Time
IATA	International Air Transportation Association
IenM	Ministerie Infrastructuur en Milieu
KDC	Knowledge Development Centre
KLM	KLM Royal Dutch Airlines
KPA	Key Performance Area
KPI	Key Performance Indicator
LIV	Landing Interval
LVNL	Luchtverkeersleiding Nederland
OM	Operating Manual
ORS	Omgevingsraad Schiphol
OVV	Onderzoeksraad voor Veiligheid
STIV	Start Interval
TMA	Terminal Manoeuvring Area
TWR	Tower
UDP	Uniform Daylight Period
VEMMIS	Safety, Efficiency & Environment Management Information System <i>Veiligheid, Efficiency & Milieu Management Informatie Systeem</i>

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CLARIFICATION OF CONCEPTS

Area Control Centre ACC

In air traffic control the Area Control Centre is a facility responsible for controlling aircraft en-route in a particular volume of air space at high altitudes between airport approaches and departures. The Area Control Centre or Area Control is located between the Terminal Manoeuvring Area (TMA) and higher airspaces.

Airport Collaborative Decision Making A-CDM

A-CDM is a joint venture which aims to improve the operational efficiency of all airport operators by reducing delays, increasing the predictability of events during the progress of a flight and optimizing the utilization of resources. In addition this will increase capacity at participating airports.

EUROCONTROL DDR-2 data DDR

The DDR-2 data of EUROCONTROL collects early available flight intentions, initial planned flights, from airlines and from coordinated airport through the European Union Airport Coordinators Association (EUACA). Moreover, the DDR data indicates the actual executed trajectories of all European flights.

Runway Preference Table

Due to noise pollution and other operative limitations Air Traffic Control the Netherlands constructed the Preferred Sequence Table. The table indicates ideal combinations of four runways of which two are the primary runways (Polderbaan & Kaagbaan).

Runway Change

Throughout this research the concept runway change is used. The term runway change is divided in two kinds of changes. The first type of runway change is identified as a runway configuration change, in which a change is made to the current configuration within a preference. For instance, going from the 1+1 concept to 2+1 concept within preference 1. The second type of runway change is a runway change, in which the preference changes. For instance, the runway preference 1 changes to preference 2.

Plan Stability

One of Schiphol's objective is to make the Airport Operations Planning (AOP) more stable. Meaning that Schiphol is aiming for plan stability. However, if the executed AOP changes throughout the day it is interpreted as plan instability. If the planning is changed frequently, it affects the capacity.

Terminal Manoeuvring Area TMA

In air traffic control the Terminal Manoeuvring Area (TMA) is a particular volume of airspace, smaller than ACC, in which aircraft are routed from or towards the airport. In this region separation standards are smaller because aircraft speed is lower than upper airspaces. The TMA is located between Area Control Centre (ACC) and the Control Tower Region (CTR).

Veiligheid, Efficiency & Milieu Management Information System VEMMIS

VEMMIS is an information system which stores operational data of Air Traffic Control the Netherlands and is used by experts for performance measurements. The data available varies from aggregated performance indicators to detailed flight information.

EXECUTIVE SUMMARY

This research is commissioned by the Knowledge Development Centre (KDC) Mainport Schiphol and provides insight in the impact of runway changes on airport capacity. The motivation for this research came from a report on safety of air traffic at Schiphol which concluded the airport works with an average of eighteen daily runway changes. As the runway changes gave some safety hazards, it did not conclude anything about effects on capacity. As Schiphol is reaching its maximum capacity, the KDC stakeholders desire insight in the impact of the runway changes on airport capacity.

This is done by quantitative analysis of the daily operations and the Airport Operations Planning (AOP). The outcome of this research is used for the future of Schiphol after 2020. As this research provides insight in the impact of runway changes on airport capacity, it will support one of the future trajectories of Schiphol. These trajectories are either sticking to the current trajectory or increase peak capacity. The current trajectory consists of extending the peak periods and thus less runway changes. The other trajectory increases peak period capacity, meaning more traffic in a peak although LVNL needs to operate with the same amount of runway changes per day.

As the research focusses on the daily operation and planning system of Schiphol, there are multiple findings and conclusions. The results of analysis on daily operations indicate that runway changes have no significant impact on the airport capacity.

In particular, the taxi-times, landing & starts interval and time spent in the Control Area/Area Control Centre (CTA/ACC) are not significantly affected. In short, the used dataset indicate a slight increase of the Actual Taxi-In Times (AXIT). The difference between the AXIT of a nominal situation in which no runway changes occurred and a situation in which a runway change occurred indicate no significant changes. However, the Actual Taxi-Out Time (AXOT) does not increase if its compared with a nominal situation. The reason is confirmed by a Tower-Supervisor: departures are either held at the gate or a buffer platform if continuous supply of departures to the runway cannot be guaranteed. The landing & starting interval of ten minutes indicates a slight increase, which means less flights landing or starting during a runway change. However, the hour capacity is not reduced if its compared to other days of the month because of the excellent work of the air traffic controllers. Before and after a runway change, air traffic controllers manage to realise maximum utilisation of the runways. Also, according to the database, there is no difference in the time an aircraft spends in the CTA/ACC. Of the abovementioned processes, the analysis determined that departures are affected the *most* by the runway change. The departures are held longer at the gate or buffer platform to maintain continuous flow of departures to the runway.

Although there is a minor impact of runway changes on daily operations, the planning system is affected more. The results of the analysis on the planning system of Schiphol indicate deviations caused by the runway changes.

Schiphol operates with Airport-Collaborative Decision Making (A-CDM) to effectively plan airside operations. The A-CDM system uses two variables which correspond with runway changes to plan operations at the airport. These two variables are the inbound flight information and runway capacity and directly affect the inbound and outbound sequence. The runway configuration changes influence the Target Off-Block Time (TOBT) during the inbound phase of the flight. As the TOBT is Actual In-Block Time (AIBT) + Minimum Turnaround Time (MTT), ground handlers will have to plan ad-hoc on the inbound flights. The Estimated In-Block Time (EIBT) is moved earlier in time on average with a runway configuration change. As the EIBT comes forward in time, all involved parties are forced to change their planning. For the outbound flights, the runway configuration changes are a factor which contributes to the inaccuracy of the TSAT. The change in runway capacity triggers a recalculation of the Collaborative Pre-Departure Sequence Planning (CPDSP), automatically changing the Target Start-Up Time (TSAT) if another earliest possible Target Take-Off Time (TTOT) is available. The analysis

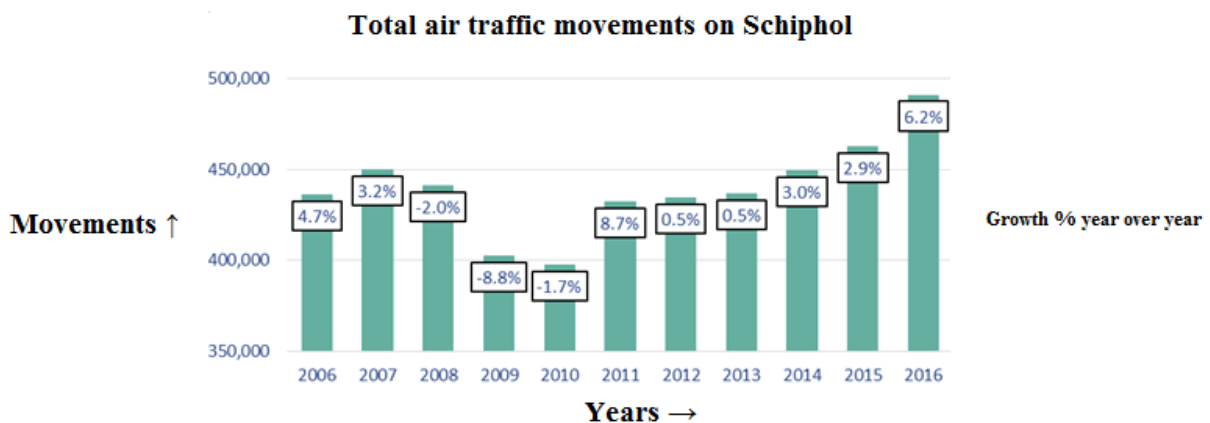
indicated that a runway change moves the TSAT later in time. Meaning a runway change will cause the A-CDM to calculate a later departure time on average.

The impact of runway changes on the planning system is bigger than on the daily operations. As the daily operations show no significant deviations or variations, the analysis indicated impact of the runway changes on the planning system as described above. However, there are still some questions unanswered after this research because it gave some new insights. The current trajectory in which all stakeholders are involved, is suitable for the current situation. This is mainly caused by the work of the air traffic controllers of the LVNL, which continue to perform safe and effective operations. Although questions concerning the current planning system and workload of the air traffic controllers raised. Therefore research on the follow topics is recommended:

- Research workload of air traffic controllers during runway change.
- Research predictability of the sequencer of A-CDM system during a runway change.
- Research the two trajectories for the future of Schiphol after 2020.

1. INTRODUCTION

In the previous years the air traffic movements have rapidly increased at Schiphol. The length of peak periods increase and the off-peak periods decrease which results in more or less continuous changing between inbound and outbound peak. LVNL concluded that Schiphol is currently operating at maximum capacity during the peak hours. The maximum capacity is reached due to several factors, in which safety and environmental regulations play an important role. The Alders agreement determined that until 2020 Schiphol is permitted to grow to a maximum of 500,000 air traffic movements per year. However, the growth numbers of 2016 already indicated 479,000 commercial air traffic movements which is a growth of 6% compared to 2015, shown in **Graph 1**. According to Sedee (2018), Schiphol handled almost 497,000 flight movements in 2017 which is just under the limitation.



Graph 2 - Growth of Schiphol indicated per year from 2006 to 2016 (Source: LVNL, 2017)

Schiphol rapidly became one of the busiest airports in Europe in the last decades. The safety standards at the airport are therefore strictly monitored by the Onderzoeksraad van Veiligheid (OVV), an authority solely focused on improving safety at government owned companies.

In April 2017 the OVV concluded in the report “*Veiligheid Vliegverkeer Schiphol*”, that there are several safety risks at Schiphol. One of the safety risks in the report is the continuous changing between runways, either to limit the noise pollution for the airport vicinity or because of weather conditions. The report of the OVV on safety of air traffic at Schiphol states that air traffic controllers approximately change runways sixteen times per day on average (Onderzoeksraad voor Veiligheid, 2017).

As the OVV report states different safety risks of the runway changes, the stakeholders of the KDC began to question how capacity is affected by runway changes. The stakeholders therefore desire an impact analysis of the runway changes, indicating how plan stability of ground and airspace capacity is affected.

1.1. BACKGROUND INFORMATION

In 1992 Schiphol handled 18.7 million passengers and approximately 239,000 air traffic movements. In the years after until 2016, total air traffic movements rapidly increased to almost 479,000, making Schiphol Europe its 3rd biggest airport in terms of market share (Schiphol, 2016). According to Skorupski & Wierzbicki (2016) important factor that contributes to the available capacity is the layout of an airport.

1.1.1. THE UNIQUE LAY-OUT OF SCHIPHOL

The runways are designed via a tangential runway concept by Jan Dellaert, meaning the runway system has different tangent points of wind directions and a centrally placed station area. Since the construction of the tangential runway system continuous expansion and improvements resulted an area of approximately 2,790 hectares covering 90 gates, 73 aprons, 25 cargo aprons, five main runways and one smaller runway as indicated in Appendix I – Layout Schiphol (Schiphol, 2017).

The current runway system of Schiphol has five main start- and landing runways of which the Kaagbaan (06-24) and Polderbaan (18R-36L) are the preferential runways. The five main runways are suitable for all aircraft types and vary in length from 3,300 to 3,800 meter. Notable is that the Oostbaan (04-22) is a shorter runway of 2,000 meters primarily used for General Aviation⁴ and is not considered as one of the five main runway, although the Oostbaan can be used for commercial air traffic if necessary. The usage of the runways are decisive for the operations at Schiphol, in terms of available capacity (Onderzoeksraad voor Veiligheid, 2017).

The unique layout of Schiphol determined by the tangential concept of Jan Dellaert nowadays brings adverse effects. There is constant interaction between the runways at Schiphol and safety limitations therefore affect the daily operations. The unique layout works with different wind directions and speeds but is certainly also a limiting factor for the airport capacity.

At Schiphol the runway usage, i.e. used runway combinations, is determined by weather conditions, safety regulations and environmental regulations. Firstly, **weather conditions** are decisive for which runways are available for operation. Secondly, runway allocation is based upon the **preference table**. And thirdly, the number of runways used from the preference table is based upon **environmental policies**, i.e. traffic supply, in the Alders Agreement (Alders, 2013). The number of runways used at the same time determine throughput of air traffic at the airport, which is decisive for the available capacity of the airport.

1.1.2. WEATHER CONDITIONS AND PREFERENCE TABLE

As safe operations need to be guaranteed, weather conditions determine which runways can be used. The tangential runway system of Schiphol has runways with different tangent points, meaning that with certain meteorological conditions specific runways are not allowed for operation.

The runways used during certain meteorological conditions are based upon the eight different combinations determined in preferred sequence table (hereafter preference table). This preference table was drawn at the Alders table between local residents, administrators, central government, Amsterdam Airport Schiphol (AAS), the airlines and LVNL in 2008. The preference table is part of the New Standards and Enforcement System which is part the Alders Agreement. The table is drawn upon noise performance per runway (Alders, 2013). The runways do not only differ in noise performance, each runway also has its own safety level in terms of required separation for possible go-arounds, throughput efficiency and operational availability. The preference table is designed within safety regulations, weather conditions and environmental rules. Within the regulations the preferred sequence is designed for optimised noise performance and maximum achievable capacity.

The preferred sequence is a combination of four runways of which two are a primary (L1) and secondary (L2) landing runways and two are primary (S1) and secondary (S2) starting runways, as indicated in **Table 1**. The primary and secondary runways are distinguished in terms of noise performance as usage of the primary runways have less noise nuisance for the vicinity of the airport than secondary runways. As implicated before, the primary runways are the Kaagbaan (06/24) and Polderbaan (18R/36L).

⁴ General Aviation conducts smaller air traffic with business intentions i.e. private jets and Royal aviation.

Runway Sequence Table. Valid 06-23 hours local time					
	Preference	Runway Combinations			
		L1	L2	S1	S2
Required visibility and day light conditions - Good visibility within UDP	1	6	36R	36L	36C
	2	18R	18C	24	18L
	3	6	36R	9	36L
	4	27	18R	24	18L
Good visibility	5a	36R	36C	36L	36C
	5b	18R	18C	18L	18C
Marginal visibility	6a	36R	36C	36L	9
	6b	18R	18C	18L	24

Table 1 - Runway Sequence Table of Schiphol per type of condition (Source: LVNL, 2017)

Of the aforementioned preferential runways, the primary runways are always used if available and weather permitting. If several runway combinations are suitable for operation within meteorological conditions⁵, the preference table determines which runway combination is actually used (LVNL, 2017a). The Alders Agreement determines that LVNL should handle commercial flights on the most preferred runway sequence according to the preference table. To visualise all preferences, Appendix II – Configuration Preferences can be used.

According to the Alders Agreement, the first combination of the sequence table available is used if:

- Tangent wind component on L1 and S1 \leq 15 knots.
- Tangent wind component on L2 and S2 \leq 20 knots.
- No tail wind component $>$ 0 knots.
- When visibility range and runway conditions permit preference usage.

The decision of which runways are used of the eight preferences varies and depends on four other variables:

1. If the period is within the Uniform Daylight Period (UDP).
2. The availability of runways, in terms of maintenance.
3. Anticipation on changing circumstances and the moment of changing to a more preferred runway combination.
4. Temporary runway usage of combinations to make a runway change possible.

In short, the Netherlands knows different kinds of winds. Theoretically, on specific moment on the day the wind can come from the South-East and three hours later from the North-West. As winds are strong and variable in the Netherlands, it requires the LVNL to change from runway usage. However, wind is not the only limiting factor. The visibility conditions are also from importance for the daily operations, shorter visibility range means less capacity.

The number of runways used at the same time from the preference table is determined by environmental policies, as noise nuancing agreements have been made in the Alders Agreement.

1.1.3. ENVIRONMENTAL POLICIES

The Appendix III of the Alders Agreement determined that 90% of runway combinations should be explicable according to set standards for runway usage. Explicability is based upon the operational handlings with the goal to limit noise pollution to the vicinity. According to the Alders Agreement

⁵ Good visibility within UDP = 5000 m. sight range and cloud base = 1000 ft. & Marginal visibility = $<$ 1500 m. sight range and cloud base = 300 ft.

(2013), Schiphol is always permitted to use a 1+1 runway configuration. This means one runway is used for landings and one runway is used for take-offs.

As the supply of air traffic increases LVNL will need more runway capacity to effectively handle the inbound and outbound traffic. In the Alders Agreement standards for handling more air traffic than a 1+1 configuration can effectively operate are determined. Implicating that the number of runways in operation are allowed to increase when traffic supply demands it. Schiphol is then allowed to use a 2+1 or 1+2 configuration during peak hours. The addition of the second runway is only permitted when the amount of landings respectively starts are more than six per ten minutes (Alders, 2013). All 1+1 and 2+1 or 1+2 configurations are preferably operated at the five main runways of Schiphol.

When there is a transition between peaks, an inbound peak alternates into outbound peak and vice versa, short usage of a fourth runway, i.e. 2+2, is permitted. The fourth runway is only allowed to prevent capacity loss during the transition for a maximum of twenty minutes, facilitating a maximum of 60 air traffic movements per day and a maximum of 14,600 air traffic movements per year.

Schiphol has four different options of runway usage during the day:

1. 1+1 off-peak: one runway for inbound traffic and one runway for outbound traffic.
2. 2+1 inbound peak: two runways for inbound traffic and one runway for outbound traffic.
3. 1+2 outbound peak: one runway for inbound traffic and two runways for outbound traffic.
4. 2+2 transition between the inbound and outbound peak: two runways for inbound traffic and two runways for outbound traffic.

Theoretically, if traffic supply is very irregular on a certain day LVNL is obligated to change runway combinations more often than on a day with a constant supply of air traffic. For Schiphol, the seven-peak system of KLM is an indication of the supply of air traffic indicated in **Figure 1**.



Figure 1 - Seven Peak System KLM (Source: Fact Sheet Network and Hub System KLM, 2011)

The first intercontinental flights (light grey arrows at 06:50) arrive early in the morning and transfer to connecting flights to European destinations (black arrows at 06:50). European flights then arrive, followed by intercontinental transfers. The inbound and outbound peaks of the seven-peak system spread across the day result in runway changes. This constant wave of different type of traffic, i.e. inbound and outbound, are at fixed times each day. These fixed times give the rough times of when runway changes planned, indicated at **Figure 2**.

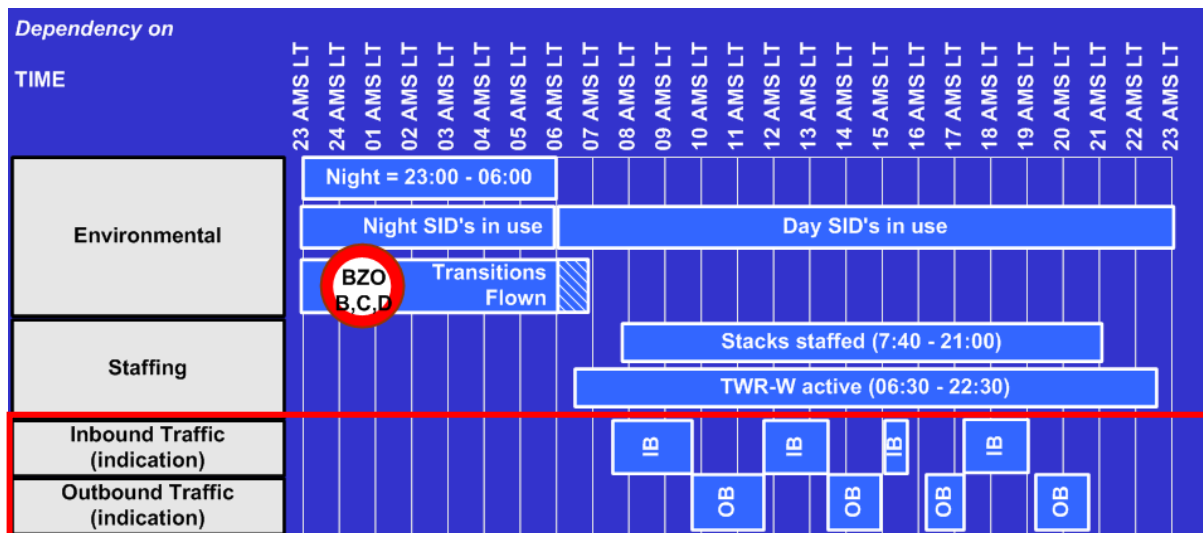


Figure 2 - Indication of inbound and outbound traffic at Schiphol (Source: LVNL ATM Ops View, 2005)⁶

To summarize the current situation, the procedure of determining the runways for operations depends on different variables. Firstly the meteorological conditions such as wind, visibility range and cloud base determine the runways available from the preference table. Secondly, the highest preferred runway combination from the preference table is chosen. Thirdly, the environmental policies are decisive for the number of runways used.

1.2. PROBLEM STATEMENT

Politically and environmentally LVNL is bound to the concept of the 2+1 runway usage, and the maximum utilisation of the preferential runways Kaagbaan (06/24) and Polderbaan (18R/36L). The operational concept drives the LVNL to frequent changes of runway combinations. If changing between runway combinations affects the airport capacity, and there is currently not known if it does, an undesired counterproductive concept is used.

As the air traffic is expected to keep growing, especially after 2020, there are two options to choose from when it comes to the future of Schiphol:

1. **The current trajectory:** there is no increase of the peak-hour capacity. Growth takes place in the shoulders of the peaks, which creates more overlap between inbound and outbound. This trajectory will eventually lead to 2+2 runway usage as it puts less pressure on changing runway combinations. This trajectory is most certainly chosen for if the runway changes affect capacity.
2. **Increasing peak-hour capacity:** there is an increase of the peak-hour capacity after 2020. This trajectory means that frequent runway changes do not affect the airport capacity. The changing between runway combinations remains part of the daily operation.

1.3. MOTIVATION

As Schiphol has an average of sixteen runway changes per day due to different variables, the motivation is to provide insight to what extent, direct and indirect, runway changes influence airport operations and the Airport Operations Planning (AOP). This is desired because stakeholders want to manage the operations effectively and efficiently in order to manage all available airport capacity.

The direct impact of a runway change will be indicated in the daily operations. Effects of a runway change could indicate delays or an increase of certain airside processes. Therefore, moments of runway changes should be compared with a nominal situation in which no runway changes occur.

⁶ As the ATM OPS View 2005 is slightly outdated, Figure 1 at page 4 indicates more recent overview of the current situation at Schiphol in terms of the inbound and outbound peaks.

An indirect effect is indicated in the AOP. However, this AOP is very important to provide the correct assets and services at the right time and place. Changes to this operational planning has a negative impact on the plan stability. Plan stability is based on the preservation of execution plans at a point in time where performance of statement is considered acceptable. Therefore direct and indirect effects are determined.

1.4. RESEARCH GOAL

For the stakeholders of the KDC, especially for LVNL and AAS, it is useful to have insight in how runway changes affect the airport system. Therefore the goal is to provide an impact analysis of the runway changes on airport capacity and plan stability.

1.5. RESEARCH QUESTIONS

In order to provide insight in the impact of runway changes, the following main research question is formulated:

What is the impact of runway changes on the capacity & plan stability of airspace- and ground capacity at Amsterdam Airport Schiphol?

Answering the research question provides insight and maps remarkable differences during runway changes at Schiphol. To answer the main research question it is important to identify the following objectives during the research:

- How Schiphol's plan stability is affected by runway changes.
- Which actual operational deviations and variations occur during runway changes.
- How airport capacity is affected by runway changes.
- How the stakeholders are affected by runway changes.

These objectives are translated into two sub-questions:

1. What are the deviations and variations in operations due to runway configuration changes?
2. How is Schiphol's plan stability affected by planned and unplanned runway changes?

Various research steps are executed to provide an answer to the sub-questions and thus the main research question. At first, literature study explores the current literature in regard to the relation between the runway system and airport capacity, and to identify possible operational consequences of runway changes. It gives an indication of which parameters are usable during the research. Then the quantitative research, i.e. data analysis, is executed to determine initial differences and actual deviations during runway changes.

1.6. SCOPE

The flights registered by the A-CDM system are researched as it gives a clear indication of the operations in terms of what was planned and how it is executed. The sample retrieved consists of six months from the summer period 2017. Airport Coordination Netherlands states that summer period is active from 26th of March until 28th of October, meaning the sample will consist of A-CDM data ranging between 1st of April until the 30th of September 2017.

1.7. RESEARCH STRUCTURE

The analysis of runway changes is performed via multiple steps. The objective of stating the research structure is to indicate how research is performed in a structure which is clear to the reader. Therefore the research starts with briefly introducing the current situation and motivation for the research. To provide an analysis on how runway changes influence airport capacity, a research method should be made, in terms of methodology and followed by identifying the current literature available. The

importance of this part is to frame the usable theory and identify what is already known about the research topic. The research design will also indicate how the research is performed and how the results per sub-question are formulated. The results are divided in different chapters followed by a conclusion, discussion and recommendation. Underneath, the research structure is indicated per chapter.

1. **Introduction** to the research topic.
2. **Research Design** which contains of the research methodology and literature review.
3. **Results of sub-question 1** concerning the operational deviations due to runway changes.
4. **Results of sub-question 2** concerning the impact of runway changes on plan stability.
5. **Conclusions** which will give an overall answer to the main research question.
6. **Discussion** about interesting findings during the research.
7. **Recommendation** for further research.

The results are written in different chapters and therefore make the most important part of the research alongside the research method.

2. RESEARCH DESIGN

The goal of the research is to provide an analysis on the impact of runway changes on the planned of airspace- and ground capacity of the airport system. This section represents the methodology of the research, in terms of sub-questions and what data is required. Before required data is determined per sub-question, the required dataset, dataset size, timeframe and identification of runway changes is determined. This is in order to delineate the research in a proper manner.

According to Baarda (2010), it is important to determine the size in advance, although the representativeness of the sample is more important than its size. Two types of data are analysed, which are also different in size. However, both datasets are from the summer period 2017, as these indicate enough runway configuration changes for the research to state differences. Airport Coordination Netherlands states that summer period is active from 26th of March until 28th of October. For this research April until September are chosen to be analysed.

The first type of data will consist of flight plans which are gathered from Eurocontrol, in the methodology confirmed what is included. This is in order to provide insight of how actual flight plans deviate from initially planned flight plans during a runway configuration change. Analysing this data will indicate result in an impact analysis of how daily operations are affected by a runway configuration change. The sample size of Eurocontrol data is two months, July 2017 and August 2017, with approximately 23,000 inbound and 23,000 outbound per month registered European flight movements. This data is analysed using Microsoft Excel.

The second type of data will consist of Airport-Collaborative Decision Making (A-CDM) data gathered directly from the A-CDM system and from the VEMMIS⁷. The A-CDM data will give more detailed information for each flight, and how the planning stability is affected by a runway configuration change. As this data is more detailed the sample size is bigger, and consists of the months April until September. This sample size is analysed using Microsoft Access and Excel.

2.1. RESEARCH METHODOLOGY

A literature review provides insight to earlier studies about runway configuration changes in relation with airport capacity. Also, the literature review shows relevant information, models and theories which are used throughout the research.

To provide quantitative research on both sub-questions defined before, two different databases are build. The sub-questions for this research are defined as:

1. What are the deviations and variations in operations due to runway configuration changes?
2. How is Schiphol's plan stability affected by planned and unplanned runway changes?

These two sub-questions will determine the impact on the current daily operations and airport operations planning.

2.2. DEVIATIONS AND VARIATIONS IN DAILY OPERATIONS

- *What are the deviations and variations in operations due to runway configuration changes?*
- Research method: quantitative desk research.
- Goal: provide insight of the deviations and variations in actual operations. The deviations respectively variations are determined by analysing how parameters differ from a nominal situation.

⁷ VEMMIS is the *Veiligheid, Efficiency & Milieu Management Informatie Systeem* of LVNL which registers all airport activities.

In order to determine how the daily operations are affected by runway configuration changes, a database is build up using three different datasets. Namely: Eurocontrol’s (initial) flight plans, VEMMIS’ additional operational information, e.g. runway usage, taxi-times and gate allocation, and from Tower Logging System the pre-calculated variable taxi-times. This data is specific per runway and gate combination. Microsoft Excel and Access make it possible to combine this data and are used throughout this research. The database used for this sub-question will consist of the following datasets:

- Eurocontrol’s Demand Data Repository-2 (DDR).
 - M-1 Initial Data.
 - M-2 Actual Data.
- VEMMIS realised taxi-times.
- VEMMIS gate allocation.
- VEMMIS runway usage.
- Tower Logging System pre-calculated variable taxi-times.

Eurocontrol DDR consists of information about arrivals and departures with different parameters. These parameters indicate initially planned operations and actual executed operations. DDR data is retrieved via NEST, an analytic program of Eurocontrol and is exported into a Excel sheet. The dataset consists of flight data from 1 July 2017 until 31 August 2017.

The DDR is filtered into flights with origin Amsterdam (EHAM) for departures and destination EHAM for arrivals in order to provide separated insight of the impact. For departures the (initial) flight plans from off-block time until entering the Control Area (CTA) is analysed, whilst for arrivals (initial) flight plans are analysed from entering the CTA until in-block time. The parameters indicated in **Table 2** are exported per flight by NEST. For an individual flight all parameters are given and indicate how the operations on a specific moment were executed.

Arrivals	Departures
Estimated/Actual In-Block Time (EIBT and AIBT)	Estimated/Actual Off-Block Time (EOBT and AOBT)
Estimated/Actual Landing Time (ELDT and ALDT)	Estimated/Actual Take-Off Time (ETOT and ATOT)
Estimated/Actual Terminal Manoeuvring Area Entry / Exit Time	Estimated/Actual Terminal Manoeuvring Area Entry / Exit Time
Estimated/Actual Area Control Centre Entry / Exit Time	

Table 2 - Parameters for Eurocontrol dataset.

The VEMMIS datasets consists of more specific airport operations data which are automatically registered on a database of the LVNL. Combining the VEMMIS data with Eurocontrol’s DDR will indicate per flight the parameters of the initially planned phase (DDR) and actual operated (VEMMIS). The two datasets are linked via a manually created primary key: call sign & date, e.g. EZY83UK on 14-08-2017 becomes “EZY83UK42968”.

This primary key is used to combine the above mentioned parameters of Eurocontrol’s DDR with VEMMIS its data concerning realised taxi-times, gate allocation, the used Initial Approach Fix (IAF) and runway usage per flight. The impact of runway configuration changes can now be analysed as the individual flight data will consist of information:

- **Departures:** primary key, date, callsign, origin, destination, gate, runway, pre-calculated taxi-times, realised taxi-times, EOBT, AOBT, ETOT, ATOT and initial and actual TMA entry and exit time.

- **Arrivals:** primary key, date, callsign, origin, destination, gate, runway, pre-calculated taxi-times, realised taxi-times, ELDT, ALDT, EIBT, AIBT, IAF and initial and actual ACC entry and exit time.

Calculated times are written via the following format throughout the research as hh:mm:ss, e.g. 21 minutes and 36 seconds is hereafter 00:21:36.

Identification of the runway configuration changes are done via a separate Excel sheet generated by VEMMIS. This is generated as a preference sheet roughly indicating the configurations used per timeframe. Appendix III – Preference Usage July and Appendix IV – Preference Usage August indicate the preference usage during July and August. The sheets do not indicate other changes to the configurations for instance changes within the preference.

To find the exact moment of when runway configuration changed VEMMIS data, indicating per 10 minutes which runways were active, is used. An example indicated in **Table 3**, indicates the timeframe in which a runway change took place within an preference.

#STEPS	LANDING_1	LANDING_2	TAKEOFF_1	TAKEOFF_2
14-8-2017 8:00	18R	0	24	18L
14-8-2017 8:10	18R	0	24	18L
14-8-2017 8:20	18R	0	24	18L
14-8-2017 8:30	18R	0	24	18L
14-8-2017 8:40	18R	18C	24	18L
14-8-2017 8:50	18R	18C	24	18L
14-8-2017 9:00	18R	18C	24	18L

Table 3 - Runway configuration changes identification.

From here the flight data of all concerned flights are provided in a database. Using the preference sheet or the VEMMIS data which indicates the timeframe of what runways are used amongst the build database, makes it possible to compare the daily operations with a runway configuration change and a nominal situation in which no runway configuration changes take place.

To provide insight in how daily operations are influenced by a runway configuration change, three undesired effects are analysed which have direct impact on airport capacity. In terms of ground capacity, the data can indicate if there is an increase of taxi-time. In terms of runway throughput, the data can indicate the differences in the landing and starts interval. And in terms of airspace capacity, the time spent by flights in the CTA is analysed. The following operations are analysed:

- Taxi-times.
- Landing and starting interval.
- Stack usage.

2.2.1. TAXI-TIMES

Taxi-times are analysed as an increase of taxi-times will lead to a reduction of capacity . By other means aircraft will occupy the taxiways longer, which could lead to congestion. Taxi-times during a runway change interval of 20 minutes are compared with taxi-times during the nominal situation. Actual Taxi-Out Time (AXOT) and Actual Taxi-In Time (AXIT) are relevant in this phase of the research as these indicate the operational parameters. The AXOT and AXIT are extracted from the database.

The physical usage of taxiways after a runway change may be challenging as taxi routes will be different. As there are prescribed taxi routes (Smit, van den Bos, & Dubbeldam, 2007), controllers are occasionally enforced to use alternatives routes shortly before or after a runway change.

Deviations between the realised and expected taxi-times, e.g. AXOT and EXOT, are compared with a nominal situation in which no runway changes are made in order to provide insight of how taxi-times deviate during a runway change.

In order to provide a conclusion on the differences, statistical validation is used. As SPSS is a statistics program with multiple kinds of tests, beforehand there is determined an independent parametric u-test is executed, also known as a Mann-Whitney U-Test. This type of test is used as there is not known if the taxi-times are normal or ordinal distributed.

2.2.2. LANDING AND STARTING INTERVAL

For comparison there are two situations determined as flights affected by a runway change and flights not affected. The flights affected by a runway configuration change are analysed in an interval which consist of five minutes before and five minutes after the runway configuration change. The nominal situation, in which flights are not affected, will consist of flight which were not affected by a runway change.

The reason of why this is researched is because the runways are a key element to the airport capacity. According to Sama, D'Ariano, Corman & Pacciarelli (2017) the actions performed at the runways have an impact on the overall capacity of the airport. Meaning that if the number of flights reduces per hour due to a runway configuration change, the capacity is affected. Another finding could be that it does not reduce the hour capacity, although it could affect the workload for air traffic controllers. This could be indicated by a reduction of number of flights during the interval of ten minutes around a change, nevertheless having no effect on the hour capacity compared to other days meaning that more flights are controlled before or after a runway change.

To calculate the effect on the LIV and STIV, the realised landings and starts per hour are gathered via VEMMIS. This is generated in a sheet and indicates the total flight movements on a specific day per hour. The number of flights in ten minutes around a runway configuration change are determined by analysing the database with Eurocontrol DDR data. An initial hour capacity is calculated based upon the amount of flights in the interval of ten minutes around a runway change via **Formula 1**.

$$\text{Initial Hour Capacity} = \text{number of starts in 10 minutes} * 6$$

Formula 1 - Runway configuration changes identification.

The initial hour capacity stands for the theoretical capacity if the number of starts per ten minutes are equal throughout the hour. This is compared with the landing and starts realisation of the same hour of a different day to provide insight in how throughput deviates in that given situation. If the runway configuration change deviates from a nominal situation, the same independent parametric significance test is used.

2.2.3. STACK USAGE

For arrivals the airspace capacity is analysed in terms of the time an inbound flight is active in one of the CTA sectors. This is to determine if traffic bunching occurs during a runway configuration change. The consequence of traffic bunching during a runway configuration change are mainly environmental but can also increase workload as more coordination is required during this period.

In the European ATM Masterplan of 2015, the airport capacity will increase if enhancements are made to traffic sequencing, and more predictable runway occupancy time (SESAR, 2015). The usage of stacks, identified as ARTIP, RIVER and SUGOL, might have an impact on the traffic sequencing during unpredictable runway usage.

The stack usage is analysed by calculating the amount of time an aircraft have spent in the CTA. The database with Eurocontrol's DDR indicate the executed and initial planned flight trajectories in which the time spend in the CTA is also generated. Firstly the moments of when a runway configuration change

took place are identified. Then the actual time is compared with the initial flight plan, meaning that if actual times are higher, it suggests there was a slight delay. The data gathered from the runway configuration change interval are compared with a nominal situation. If the deviation of the initial flight plan is higher than average during a nominal situation, an independent parametric significance test is used. Also per stack, or IAF, the initial flight plans are analysed to make an estimation of which sector is burdened the most with delays.

2.3. PLANNING STABILITY AT AMSTERDAM SCHIPHOL AIRPORT

- How is Schiphol's plan stability affected by planned and unplanned runway changes?
- Research method: qualitative and quantitative desk research.
- Goal: provide insight of how a runway change has an influence on the planning stability of Schiphol

At Schiphol, all air traffic and process handlings are coordinated and planned to secure efficient and effective airport operations. Each year the Dutch airspace is used more in terms of flight movements, which requires more communication and better planned operations. A-CDM is a system which contributes to efficiency by relevant data sharing in order to create relative more capacity than without a planning system (Schiphol, 2017). To analyse how the Airport Operation Planning (AOP) is affected, the influence of the runway configuration changes on the A-CDM system is determined. The following sources are used to determine how the A-CDM system is affected by a runway configuration change:

- OPS Manual CDM@AMS (Schiphol, 2015).
- Airport CDM Implementation the Manual (Eurocontrol, 2017).

If the runway configuration changes influence parts of the A-CDM system, the concerned parameters are analysed. In order to analyse how the planning of Schiphol is affected by runway configuration changes, a database is built up from A-CDM data. The A-CDM data is very specific and states all available planning parameters concerning planning stability. As the inbound and outbound A-CDM log files are very detailed and large in storage size, Excel cannot be used. For this section Access is used to import, analyse and calculate with all data gathered. This historical A-CDM data is retrieved via the Performance Department of LVNL. Because Access is more suitable for large data, more months are analysed during this sub-question.

The A-CDM log file, indicates all planning and executed A-CDM milestones which are explained during the analysis. Per change in parameter of the A-CDM milestones a new data line is made. This means that each change in estimates or runway/gate allocation are registered in the A-CDM log file. However, as determined before Access is more suitable for large databases, and therefore a bigger data set is used. The inbound dataset is retrieved from 26 March 2017 until 31 August 2017. For the outbound dataset a smaller dataset is used. This is the cause of the file size of outbound flight information, the data size is four times bigger and not accessible for Access as it can only work with import files smaller than 2 gigabyte. Therefore the outbound dataset contains all flight information from 26 March 2017 until 31 May 2017. The A-CDM log files are retrieved from CISS in a .txt file. Access has the compatibility to import different file types such as Excel, .txt- and .csn files.

The following parameters are indicated in the A-CDM logfiles:

- **Departures:** primary key, date, callsign, clock, destination, type of aircraft, gate, runway, EOBT, Target Off-Block Time (TOBT), AOBT, ETOT, Target Take-Off Time (TTOT), ATOT, Target Start-Up Time (TSAT), Actual Start-Up Request Time (ASRT).
- **Arrivals:** primary key, date, callsign, type of aircraft, origin, destination, gate, pre-calculated taxi-times, realised taxi-times, ELDT, ALDT, EIBT, AIBT, IAF.

As A-CDM data registers all changes to the above mentioned parameters, the runway changes are identified easily. The change between runways are analysed in terms of the impact on the airport planning. An example of how the runway change affects the planning is indicated in **Table 4**.

CLOCK	CSN	TYPE	ARR_GATE	LRWY	STACK	ELDT	EIBT
4-4-2017 11:20:32	KLM52Y	B737	C11	18R	RIVER	4-4-2017 11:28:31	4-4-2017 11:40:43
4-4-2017 11:20:48	KLM52Y	B737	C11	18C	RIVER	4-4-2017 11:28:31	4-4-2017 11:35:13
4-4-2017 11:20:48	KLM52Y	B737	C11	18C	RIVER	4-4-2017 11:27:03	4-4-2017 11:33:45

Table 4 - Runway change paired with other ELDT and EIBT.

For each analysis step in Access a query is build. During the building of the database with query’s the help of an expert is used. Moreover, a manual for basic Access skills is used throughout.

- The Missing Manual (MacDonald, 2013)

A-CDM data indicates all changes to the AOP and is therefore very complex. The usage of queries in the database filters the data which is used for this analysis. The queries are used throughout the research and therefore it is important to identify what a query is and how these are used.

“Using a query makes it easier to view, add, delete or change data in the Access database. Some of the reasons for using queries stated by Microsoft are:

- *Find specific quickly data by filtering on specific criteria or conditions.*
- *Calculate or summarize data.*
- *Automate data management tasks, such as reviewing the most current data on a recurring basis.”* (Microsoft, 2018)

From all inbound and outbound data, only the flights which have a registered runway change are from importance. These flights are filtered by making a query and using the function “Totals” in Access, making a selection of only inbound respectively outbound flights which have more than one runway in the A-CDM data. This query is made into a table, available for all types of researches. The more than one runway table is still very complex as each flight have at least ten-fifteen data lines. To calculate the average deviation and standard deviation from how the parameters change during a runway change, the last parameters of the old assigned runway is determined. This is done with a “Totals” query, filtering only the last data line of the old runway. The same procedure is done for selecting the first parameters of the last assigned runway. If there are changes in the parameters, this will indicate how the planning is affected.

The parameters which are analysed during this section of the research depends on the first part where qualitative research determines which parts of the A-CDM are affected by the runway change. The parameters which are influenced are then analysed using the abovementioned steps in making a query.

The query which is used to filter flight data with a runway change, consist of all call signs and data of which there is more than one unique runway. This query is used for further analysis as this will contain of data which indicate how parameters are affected with a runway change.

3. LITERATURE REVIEW

The relevance of the research topic, i.e. impact of runway changes on airport capacity, is identified during the research of Jacquillat and Odoni (2017). As airport operations are enabled by physical and technological infrastructure, the maximum capacity of infrastructure affects the throughput the airport. The key drivers for airport throughput are identified during the research as the number of runways, runway configuration, separation standards, weather and other operating conditions, mix of arrivals and departures and fleet mix. The actions performed at the runways are decisive for the overall airport capacity⁸ and performance (Jacquillat & Odoni, 2017).

According to Sama, D'Ariano, Corman & Pacciarelli (2017) these coordinated actions at runway have a great impact on the overall airport performance since it is the initial point of departing and arriving air traffic movements. Several factors, such as weather conditions (i.e. wind and visibility), traffic demand, air traffic controller (from here defined as controller) workload and the coordination of flows with neighbouring airports influence the selection of runways. Certain changes in runway combinations require more coordination relative to others. Planning the operative runways, and thus required runway changes, is an important process for the airport, Air Traffic Control (ATC) and airline. When usage of runways is forecasted 3 hours in advance, the research indicated runway forecast was with an accuracy of 81%. (Avery & Balakrishnan, 2015). To operate with the highest available capacity within limiting factors, Schiphol has set a preferred runway configuration table. The runway system has five main runways with different tangent and incursions points limiting continuous usage, requiring runway changes and alternations (LVNL, 2017a).

Runway changes at Schiphol are based upon firstly safety regulations. The regulations conduct the operating limits for air traffic in terms of tailwind, crosswind components and adverse weather conditions at an airport (ICAO, 2007). Secondly, environmental regulations/policies to disburden the vicinity of the airport are stated in the Alders Agreement. According to the Alders Agreement Appendix III (2013) he used runways are determined upon weather conditions, preferred sequence and traffic supply. The tangential runway system and variables demand ATC of Schiphol to change runways relatively more than other European hub airports such as London Heathrow Airport.

Changing between runway combinations has an impact on the operation (Kamgarpour, Zhang, & Tomlin, 2011). The impact of the process of changing at Schiphol is to be researched, because Schiphol executes, on average, eighteen runway configuration changes on daily basis (Onderzoeksraad voor Veiligheid, 2017). Meaning that if the process of runway alternation leads to unnecessary loss of capacity or reduction of efficiency, this occurs averagely eighteen times per day.

Each runway has its own runway performance in terms of throughput per hour (LVNL, 2017b). According to Guépet, Briant, Gayon and Acuna-Agost (2017) runway operations and ground operations are integrated in different programs, e.g. Airport-Collaborative Decision Making (A-CDM) from EUROCONTROL, making the runway system an important factor that determines airport capacity. The process of integrating runway usage and ground operations with A-CDM is sequentially done in three steps. First, an earliest time at the runway is estimated for every aircraft through an estimation of taxi-times after request for start-up. Resulting in a calculation of the optimal take-off sequence, which is determined as the second step. Finally the ground operation is scheduled to match with the predicted take-off sequence. Changing runways will require the process to be restarted, meaning taxi-times and take-off sequences are changed. The objective of integrative programs such as A-CDM is to increase runway efficiency and reduce unnecessary waiting and taxi-times at the airport its infrastructure (Guépet, Briant, Gayon, & Acuna-Agost, 2017).

⁸ Airside capacity restricted airports such as Schiphol.

To clarify how and if the total airport performance and capacity are affected at Schiphol, specific airport areas in which runway usage play a role should be determined and analysed. To measure airport performance of the airside and adjacent airspace EUROCONTROL developed an Air Traffic Management Airport Performance (ATMAP) framework in 2009. This framework is used to indicate the effect of runway usage on overall airport performance since ATMAP divides the airport performance between airside and landside. For the impact of runway changes only airside (and adjacent airspace) Key Performance Indicators (KPIs) are relevant which are divided in five Key Performance Areas (KPA) of which two are relevant: efficiency and punctuality. Each performance area has its own defined KPIs, of which *five* are able to define how runway alternation influences the overall airport performance (Helm, Classen, Rudolph, Werner, & Urban, 2014):

- **KPA Capacity** conducts *pre-departure delays & taxi-out additional time* which are used to analyse how runway changes affect capacity which is part of overall airport performance.
- **KPA Punctuality** conducts *on-time performance, early arrivals & departure delay causes* which are used to analyse how runway changes affect the punctuality which is part of the overall airport performance.

The five KPIs above are declared as rather general and should be more detailed in their respective application and exact dimension as it vary of importance between airports (Helm, Classen, Rudolph, Werner, & Urban, 2014).

Previous research on timing of runway alternation of Kamgarpour, Zhang & Tomlin (2011) indicate that moments of alternation between runway combinations have an impact on the overall airport capacity. Each controller has another alternation time as different variables play a role in runway alternation. The optimisation of alternation will minimise delays resulting from the transitional periods of the configuration changes. Because changing runway configurations result in different flying paths and taxi routes at the airport, there is a probability that previous paths and routes may intervene with the old situation. In this case the minimal separation requirements delay the air traffic both arriving and departing. The areas in which constraints occur are identified in a case study at John F. Kennedy International Airport (JFK). The case study identified how the TRACON⁹ is affected, in terms of constrains by the timeframe in which alternation takes place. Certain moments in an hour have less costs when switching between runways. These costs are defined as the total difference between the expected landing time and actual landing time, meaning delay. The result of the case study showed how benefits are gained in the delays by optimising aircraft arrival during transitional periods of configuration switching (Kamgarpour, Zhang, & Tomlin, 2011).

Research of Oseguera-Lohr, Phojanamongkolkij, Lohr & Fenbert (2013) indicated that runway configuration changes are accompanied by increased workload for controllers and managers, particularly when a change in direction of flow occurs (e.g. from a North flow to South flow). The research indicated three types of runway changes.

1. Direction in flow.
2. Change in arrival runway.
3. Change in departure runway.

The first type of alternation, change in direction of flow, can result in a loss of efficiency, increase the workload for controllers and require additional coordination between the airport and TRACON. Oseguera-Lohr, Phojanamongkolkij, Lohr, & Fenbert (2013) indicate that the main reason of reduction in efficiency is caused by the way in which arrivals are routed into the terminal area. This means that there must be enough airspace to allow published routes to be flown within safety standards. The impact of the two remaining types of runway changes (i.e. change in arrival and departure runway configuration) result in less to no loss of efficiency. The conclusion of the research indicates that

⁹ TRACON is equal to Terminal Manoeuvring Area (TMA).

managing runway alternations increases the capacity. This is the result of better selection of runway use and timing of configuration changes. Another benefit of effective runway management is an increase in efficiency as ground and airborne operations are better balanced leading to reduced delays (Oseguera-Lohr, Phojanamongkolkij, Lohr, & Fenbert, 2013).

The three types of runway changes are identifiable for Schiphol as:

1. Change in direction, alternating between preferences.
2. Change in arrival runway, alternating within the preference.
3. Change in departure runway, alternating within the preference.

Runway changes are divided in planned and unplanned changes. However, the unplanned runway changes are exceptional it remains considered as an unstable approach for inbound traffic by International Aviation Transport Association (IATA). The unplanned runway change represents an undesirable deviation as a result from an action that increases risks. The unstable approach, and thus unplanned runway change, may have any number of contributing factors of which weather, workload, poor planning, procedures and approach design play a role. In the undesired circumstances, the unplanned runway change will lead to a go-around, affecting airport capacity (IATA, 2016).

In 2014 Suwa & Morita published a research providing a new method for short-term Capacity Requirement Planning (CRP). The objective of CRP is to determine a stable allocation of given resources with the main aim to minimize the probability of each operation to exceed the capacity. This new method was to create more planning stability in logistics as exceeding the available capacity is highly undesired. The term “stability” means the higher predictability of a released capacity plan, if a planning is unstable it will result in a loss of productivity and an absorption of delays caused by disruptions (Suwa & Morita, 2014)

To determine how runway changes affect airport capacity, an impact analysis should indicate the differences (i.e. impact) between a nominal situation and during runway changes (i.e. 10 minutes before and after, an interval of 20 minutes). According to Drago and Gallo (2017) multiple channels and variables should be analysed to create a funded impact analysis. To prove a significant impact between two groups, i.e. nominal situation and during runway changes, statistical significant difference is determined. If a statistical significance is proven, this means that a result from testing or experimenting is not likely to occur randomly or by chance but it is likely to be attributable to a specific cause (Investopedia, 2017).

To conclude, previous researches indicate that runways are a key driver for airport capacity, which is divided during the research in ground and airspace. According to Jacquillat & Odoni (2017) airport capacity is based upon airport operations enabled by physical infrastructure, of which runways and taxiways are identified as important elements. As the actions which are performed at physical infrastructure have an influence on airport capacity, there are three elements which are researched during this project. This are actions performed at the runways, taxi-ways and at the gate. The physical infrastructure, i.e. runways, taxiways and gates, and operations are integrated in A-CDM to reduce airport congestion and increase efficiency (Guépet, Briant, Gayon, & Acuna-Agost, 2017). And knowing that Schiphol uses A-CDM it is necessary to at least focus on some elements in the A-CDM system which are influenced with runway configuration changes.

Airports provide forecasts of the expected runway combinations for a given period (Avery & Balakrishnan, 2015). Changes to the runway system have an impact on the operation. The moment of when runway changes are made, are important to maintain operative effectiveness as bad timing of transitional periods result in delays and congestion (Kamgarpour, Zhang, & Tomlin, 2011). Knowing this, the operations with runway changes are compared with a operation without runway changes to identify to what extend the LVNL has its runway changes under control.

4. ANALYSIS: PART ONE

IDENTIFY HOW THE DAILY AIRPORT OPERATIONS ARE AFFECTED BY RUNWAY CONFIGURATION CHANGES.

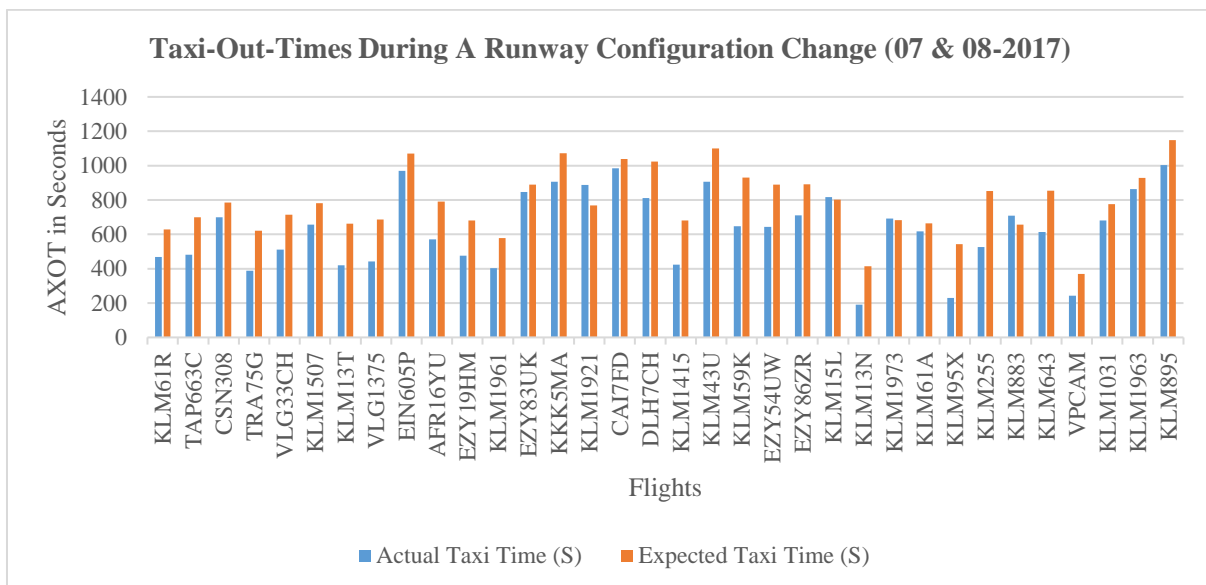
In the following chapter, results of the analysis of the daily operations are concluded. As determined before in the methodology, three different airside processes are analysed. Firstly, the impact on taxi-times is determined (4.1). Secondly, the impact of runway changes on the landing and start interval is analysed (4.2) and thirdly the time spent in the Control Area (CTA) is determined (4.3).

4.1. IMPACT ON TAXI-TIMES

Schiphol uses A-CDM to create an ideal sequence of aircraft departing, explained more elaborate in Chapter 4. The planned taxi-times from gate to runway are taken into consideration in building the sequence. However, the estimated taxi-times provided by A-CDM used in the building of the sequence are inaccurate because it uses a standard taxi-times. This time is a rough estimation of the amount of minutes an aircraft takes to taxi towards the runway. If initially planned times are compared to the actual taxi-times of VEMMIS, it will always deviate.

Therefore to compare the initial planned taxi-times, data from the LVNL's Tower Log System is used. The data provides insight in estimated taxi-time per aircraft type, per gate to each runway and vice versa. As VEMMIS data indicates the exact amount of time an aircraft taxied and which configuration was in use at that given time, the estimated planned taxi-times are compared with the actual operation.

Comparing the actual time taxi-times with the calculated/expected taxi-times per aircraft type, per gate and per runway will give an indication of how taxi-times are influenced by a runway configuration change. A sample of Taxi Out Times (AXOT), indicated in **Graph 2**, show the taxi times during a runway configuration change.

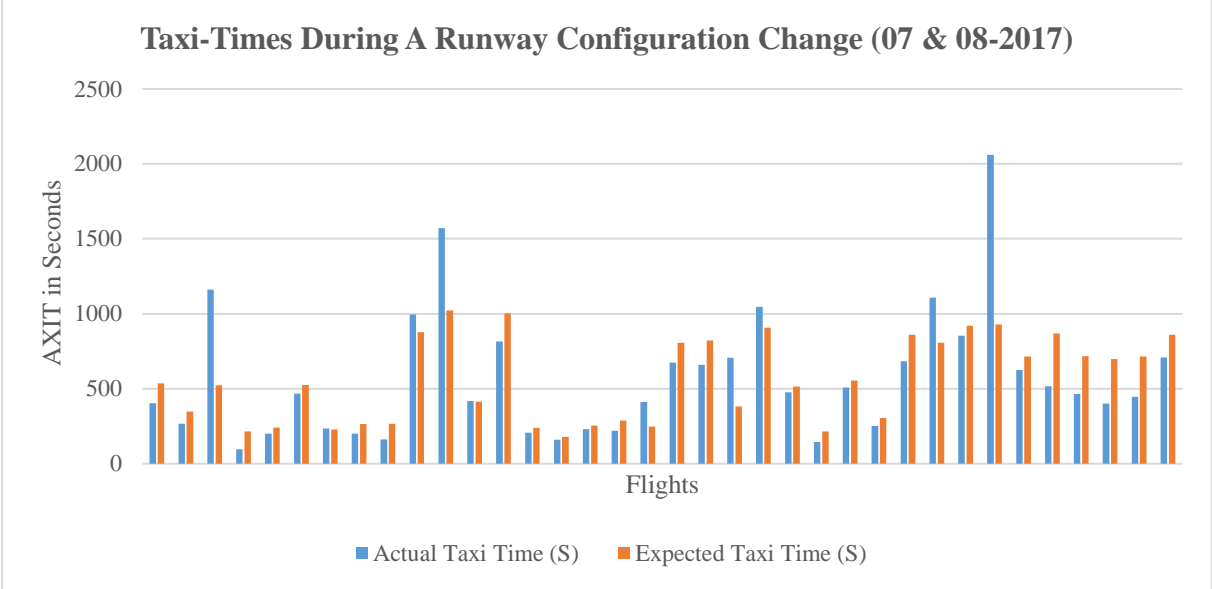


Graph 2 - Taxi Out Times during a 20 minute interval around a runway configuration change in the months 07-2017 and 08-2017.

The explanation for this is found at the Tower Supervisor (TWR-SUP). The ground controllers of Schiphol are determined to keep airside operations as efficient as possible, meaning waiting aircraft at taxi-ways are not desired. If taxi-times are estimated to increase, ground controllers are inclined to keep

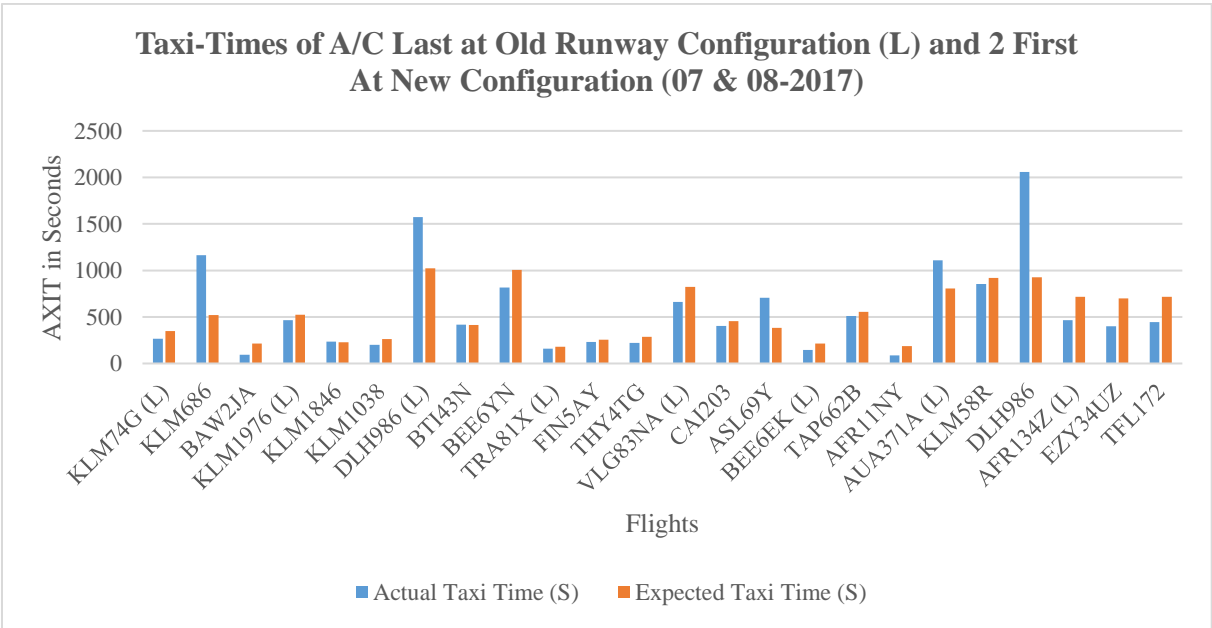
aircraft at the gate or move the aircraft to a buffer points at the airport, e.g. P-platform. This is to provide a constant flow without excessive supply of aircraft to the runway.

For arrivals, the taxi times defined as Taxi In Time (AXIT), show different results. The comparison of AXIT with the expected taxi-times from the Tower Log System indicate somewhat higher AXIT as indicated in **Graph 3**.



Graph 3 – Taxi In Times during a 20 minute interval around a runway configuration change in the months 07-2017 and 08-2017.

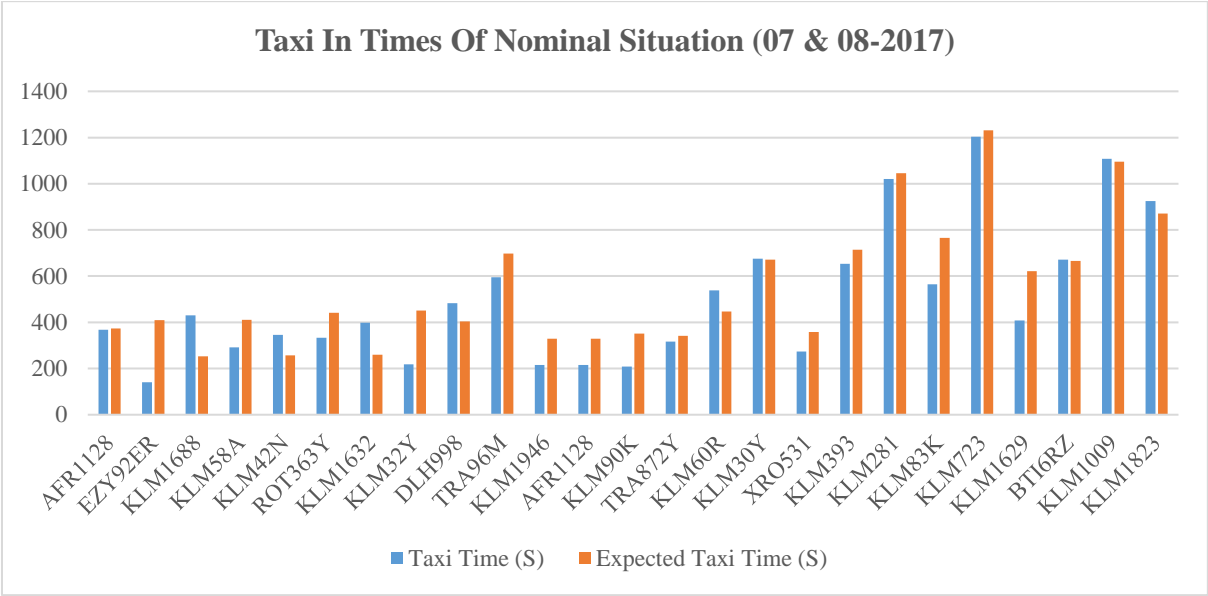
As not all the AXIT are increased the sample is analysed more towards the moment of the actual runway change. The taxi-times of the last flight landing on the “old” runway configuration and the two first on the “new” runway configuration are indicated at **Graph 4**. Each last flight on the old runway is indicated with a L after the call sign.



Graph 4 - Taxi In Times of last aircraft at old runway configuration and two first aircraft at new configuration.

For arrivals the taxi-time is slightly higher than calculated. This is different compared to the AXOT, in that case none of the departing aircraft had a longer taxi-time. Thus to analyse whether this happens

during a runway configuration change, a nominal situation in which no runway configuration changes are made is compared. **Graph 5** indicates the nominal AXIT during a nominal situation.



Graph 5 - Taxi In Times of Nominal Situation.

The graph indicating the taxi-times after a runway change shows some aircraft which have a higher taxi-time than expected and the nominal situation indicates less differences. To statistically prove if the differences between expected and actual taxi-times are higher during a runway change, an Independent-Samples Mann-Whitney U Test is used. The choice for this test is because there is no information of how the taxi-times are divided and the number of $n1$ and $n2^{10}$ variables are <30 (van Geloven, 2015).

- The null hypothesis is: the runway changes have no effect on differences between actual and expected taxi-in-times.
- The h1 hypothesis is: the runway changes have an effect on differences between actual and expected taxi-in-times.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Runways is the same across categories of Groups.	Independent-Samples Mann-Whitney U Test	,362	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

Figure 3 - Output of SPSS/Mann-Whitney U-Test.

For the sample test, the differences between expected and actual are used. These are marked as category “Runway” and divided in two “Groups” in which group 1 represents runway change and group 2 a nominal situation, indicated in **Figure 3**. From this sample the data indicates that there is no significant difference according to the performed statistic test, and the null hypothesis is retained. The 0.05 significance level indicates a 5% risk of concluding that a difference exists when there is no actual difference (Frost, 2015). As the significance level is 0.362 it means that there is a risk of 36.2% of

¹⁰ $N1$ and $N2$ represent the amount of variables of the groups “taxi-time after runway change” and “taxi-times nominal situation”.

concluding that a difference exists when there is no actual difference. This chance is relatively high and therefore the null hypothesis is retained.

4.2. LANDING/STARTS INTERVAL

In order to provide insight of how the starts and landings are influenced by the runway changes the Start Interval (STIV) and Landing Interval (LIV) are analysed. As Sama, D'Ariano, Corman & Pacciarelli (2017) concluded in previous research, actions performed at the runway have a great impact on the airport its capacity.

Therefore if throughput of the runway is reduced, which is an increase of the LIV/STIV, it means airport capacity is influenced. At LVNL, the Quick Reference Chart 09 – Runway Combinations & Capacity Figures is used to determine, per runway and per flight movements per hour, the LIV/STIV. **Table 5** indicates the amount of aircraft which make use of a runway per hour and which LIV is connected to it.

Capacity	LIV/STIV	Capacity	LIV/STIV	Capacity	LIV/STIV
45	1,3	34	1,8	25	2,4
42	1,4	33	1,8	24	2,5
40	1,5	32	1,9	22	2,7
38	1,6	29	2,1	20	3,0
37	1,6	28	2,1	18	3,3
35	1,7	26	2,3	<17	3,5>

Table 5 - Starts and Landing Interval (Source: LVNL 2017b)

For the determination of the LIV/STIV the moment of runway configuration change is determined. The runway change is identified by VEMMIS data which indicates actual runway usage and the Main Runway Indicator (MRI) runway status. To determine if the capacity is influenced during a runway configuration change, the starts and landing realisation are analysed of two months. The hour capacity is not influenced according to the analysis of realisation per hour, the LIV and STIV are mostly determined by weather conditions such as strong winds or poor visibility. The changing between runways, in terms of changing the flow gives some deviation in the LIV and STIV but are not directly negative for the rest of the hour capacity. Appendix V – Hour Capacity July and Appendix VI – Hour Capacity August indicate the runway usage per hour in terms of landings and starts during a sample with runway configuration changes (**Table 6**).

Date	Used Capacity (Landing/Starts)	Total Flight Movements
10-07-2017 07:00	32/53	75
26-07-2017 06:00	65/34	99
12-08-2017 16:00	44/15	59
14-08-2017 12:00	37/55	92
15-08-2017 08:00	39/67	106
15-08-2017 15:00	30/52	82
17-08-2017 07:00	41/46	87
20-08-2017 12:00	34/44	78
21-08-2017 14:00	32/41	73
22-08-2017 07:00	38/53	91
22-08-2017 10:00	44/60	104
22-08-2017 14:00	29/42	71
23-08-2017 07:00	34/51	85
25-08-2017 15:00	37/43	80

Table 6 - Used Hourly Capacity During Runway Configuration Changes (Source: VEMMIS, 2018).

The table above gives an indication of how the hour capacity was affected during a runway change. As there is noticed, the total flight movements are not lower than the average hourly landing and starts of the same month, indicated in Appendix V and Appendix VI. The LIV and STIV also depends on type of peak, i.e. inbound or outbound. This clarifies why some landings respectively starts are lower, Figure 1 at page 4 supports this.

To determine if workload for ATC increases after a runway configuration change, the LIV/STIV per 10 minutes around the concerned runway configuration change is calculated. Accordingly the runway configuration changes are identified via VEMMIS data which indicates actual runway usage. This data indicates the time of the runway configuration change and if the flights 5 minutes before and 5 minutes after the specific time are analysed. The outcome of this analysis is that during a runway change, the LIV respectively STIV are affected. As there was determined under the paragraph Taxi-Times at page x, the departures are kept at the gate or buffer platforms if taxiing will cause congestion or unnecessary waiting times at the taxiways. Therefore there is expected that during a runway change the STIV is more affected than landings. An example, indicated in **Table 7**, of the same two months as mentioned before indicate the amount of landings respectively starts five minutes before and five minutes after the given time.

Direction of flow change	Landings	Starts	Initial Hour Capacity Landings	Initial Hour Capacity Starts
10-7-2017 7:12	4	7	24	42
26-7-2017 6:54	11	6	66	36
14-8-2017 11:56	4	2	24	12
21-8-2017 14:05	10	1	60	6
22-8-2017 7:32	4	3	24	18
22-8-2017 15:37	4	3	24	18
23-8-2017 7:12	7	2	42	12
25-8-2017 15:37	6	4	36	24
Addition or removal runway				
12-8-2017 16:16	8	1	48	6
15-8-2017 15:50	7	3	42	18
17-8-2017 7:33	7	10	42	60
18-8-2017 10:35	8	10	48	60
20-8-2017 12:08	6	4	36	24
22-8-2017 10:37	8	11	24	66

Table 7 - LIV and STIV per runway configuration change.

An example from Table 7, on 14-8-2017 on 11:56 the runway configuration changed. This configuration change was paired with a change in direction of air traffic flow. In five minutes before and five minutes after the change, four landings were made and two starts. Theoretically it means that in an hour 24 landings and 12 starts could be made.

In general the LIV during the same runway configuration change is higher than the STIV. The table above indicates the total flight movements which theoretically could have taken place if the 10 minute interval was the same all hour. The table indicates that runway configuration changes of which the flow of direction changes, have more impact on the theoretical capacity. This could mean that shortly before or after an runway configuration change the workload increases for an air traffic controller.

4.3. TIME IN CONTROL AREA/AREA CONTROL CENTRE

Flights with destination Amsterdam (EHAM) will make use of the Control Area (CTA) /Area Control Centre (ACC), the Terminal Manoeuvring Area (TMA) and Control Region (CTR) en-route to a runway of Schiphol. If suddenly the traffic supply is higher than expected air traffic controllers may use holding points at ARTIP, RIVER or SUGOL (LVNL, 2018a). The moment excessive traffic supply occurs is known as traffic bunching. As the alternation between runway configuration takes some effort, and especially with direction of flow changes, the usage of holding points are researched at this given moment. However, there is expected that the moment of alternation is chosen carefully with underlying thoughts.

The flights coming into the Dutch airspace already have an assigned runway in the A-CDM system (Derogee, 2015), but this can change in the path to the airport. There are essentially three type of runway changes as given in the paragraph before and likely identified by Oseguera-Lohr, Phojanamongkolkij, Lohr & Fenbert in 2013, of which type 2 and type 3 are combined during this research:

- Type 1: Change of direction of flow, due to weather conditions.
- Type 2: Additional or removal of runway, due to traffic supply and regulations.

Type 1 runway configuration changes mostly occur due to a changing wind in terms of direction and speed. In the Alders Agreement (2013) there are different rules which declare runway usage with certain crosswind and tailwind actors (*page 3*). When these limitations for usage are almost exceeded, a representative of the KNMI will give a precise forecast of when the wind will exceed the limitations. Amongst with the air traffic controllers the window of when a runway configuration change is required is then determined in order to use the best moment for alternation. Via this way the air traffic controller tries to minimize the effect of a runway change on the inbound flights.

To quantify this, the initial flight plans of Eurocontrol are used. The initial flight plans are established in the pre-flight phase¹¹. These flight plans indicate the initial time an aircraft should spend in the CTA, compared with the actual flight plans which are realised. The month August is analysed in this section. **Figure 4** indicates the areas which are controlled by the LVNL. Area Control Centre (ACC) controls the designated CTA.

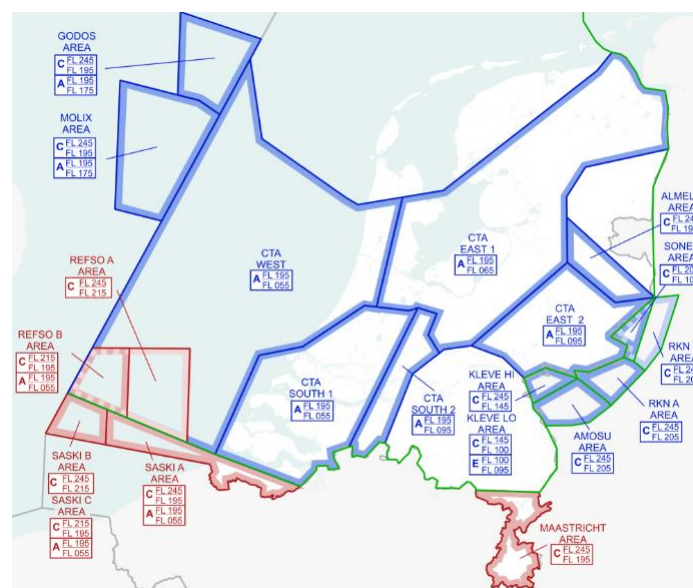


Figure 4 - Control Area (CTA) of Dutch airspace (Source: LVNL, 2018)

¹¹ The pre-flight phase is the period from the first submission of a flight plan until the first delivery of an ATC clearance.

The controlled areas by the Amsterdam ACC are identified as five different sectors: CTA East 1 and 2, CTA South 1 and 2 and CTA West. As concluded before, if traffic supply is higher than expected air traffic controllers may use holding points at ARTIP located in CTA East 1, RIVER located in CTA South 1 or SUGOL located in CTA West.

For August 2017, there are 68 flights analysed which were involved with a runway configuration change type 1. Type 2 runway changes are not taken into consideration as these type of configuration changes have less to no impact on the throughput (Oseguera-Lohr, Phojanamongkolkij, Lohr & Fenbert, 2013). The sample is compared with a nominal situation without runway configuration changes with a same sample size, randomly picked. A sample of approximately 10 flights around the runway change is analysed and give the following outcomes indicated in **Table 8**. The nominal situation is indicated in **Table 9**.

Stack	Number of flights	Average deviation from initial flight plan during runway configuration change
ARTIP	37	00:01:48
RIVER	13	00:00:05
SUGOL	18	00:01:56
Total/Average	68	00:01:28

Table 8 - Runway configuration change deviations from flightplan in CTA.

Stack	Number of flights	Average deviation from initial flight plan during a nominal situation
ARTIP	37	00:02:07
RIVER	17	-00:00:02
SUGOL	14	00:02:10
Total/Average	68	00:01:25

Table 9 - Nominal situation deviations from flightplan in CTA.

As there is analysed, there are minor deviations during a runway configuration change compared to a nominal situation. However the analysis indicate that either the deviation from the flight plan via SUGOL is the highest either due to delays which occur or inaccurate flight plans.

To conclude, the daily operations are affected in a minor way according to the used database. The taxi-out-times do not increase and taxi-in-times do not significantly increase due to runway changes. The taxi-out times do not increase due to a generated departure delay to maintain a constant flow of taxiing flights towards the runway. This is also indicated in the STIV, it shows a slight decrease of starts in ten minutes around a runway configuration change with a direction of flow change. The LIV and hour capacity is not affected by a change. This could indicate an increase of workload for air traffic controllers before and after a runway configuration change. The airspace is not affected as the nominal situation has the same average deviation of the initial flight plan. Moreover, a Tower-Supervisor confirmed the minor effects. This is elaborated in the next chapter.

5. ANALYSIS: PART TWO

IDENTIFY HOW THE AIRPORT PLANNING IS AFFECTED BY RUNWAY CONFIGURATION CHANGES.

In the following chapter, results of the analysis on the planning stability are concluded.. Firstly, the current planning system of Schiphol is analysed (5.1). Secondly, the impact of inbound flight information on the planning stability is determined (5.2) and thirdly the impact of Collaborative Pre-Departure Sequence Planning (CPDSP) recalculations due to runway capacity changes are determined (5.3).

5.1. PLANNING SYSTEM OF SCHIPHOL

The current flights at Schiphol are coordinated by the Dutch Air Traffic Control (ATC). All ground operations between touch-down and take-off are coordinated by Schiphol Tower, ground handling not taken into account. At the airside of Schiphol, the infrastructural capacity is limited and needs to be utilised in the most efficient way. Therefore these ground operations are planned beforehand to avoid excessive congestion and long delays. However, knowing many variables play a role in airport processes, planning by hand is no success.

Schiphol has its current airside processes planned via A-CDM system. The existing airport Central Information System Schiphol (CISS) is used for realizing the A-CDM system, meaning that the A-CDM system gathers all available information for flights during the inbound, turnaround and outbound flight phase. It uses a number of criteria in determining the best available time for certain phases of the airport processes. The A-CDM system has the following functions:

- Collect all relevant data from involved sector parties.
- Calculate estimations of new events or establish an event.
- Make new data available to involved sector parties for situational awareness.

The A-CDM system automatically provides a planning, in which ATC can change criteria such as available capacity.

“Airport CDM (A-CDM) aims at improving the overall efficiency of airport operations by optimising the use of resources and improving the predictability of events. It focuses especially on aircraft turnaround and pre-departure sequencing processes.” (Eurocontrol, 2017)

The planning via A-CDM goes via the milestone approach, which indicates different significant events during the planning of a flight. Whenever a milestone is successfully completed, it will trigger the decision making processes for downstream events. A-CDM knows sixteen milestones per flight, indicated in **Figure 5**. The more downstream milestones events are, the more accurate the planning will be (Derogee, 2015).

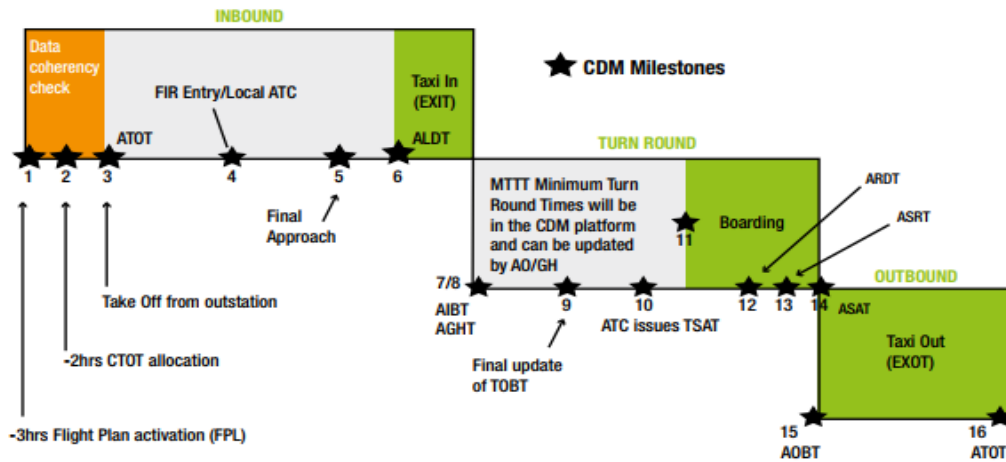


Figure 5 - A-CDM Milestones (Source: Airport CDM Implementation Manual, Eurocontrol, 2012)

The most important elements of the A-CDM milestones for Schiphol are Estimated Landing Time (ELDT), the Estimated In-Block Time (EIBT), the Target Off-Block Time (TOBT), Target Start-Up Approval Time (TSAT) and the Target Take-Off Time (TTOT) as these determine the pre-departure sequence.

Initially planned TOBT for flights are retrieved from the Scheduled Off-Block Time (SOBT) provided beforehand by the airline. The initial TOBT/SOBT is based upon schedule information of the airline for incoming flights which have no connected flight defined yet, meaning the flight plan is not activated in Schiphol's A-CDM system. When the flight connects to the A-CDM data, the first milestone, the TOBT will automatically be generated based upon EIBT and Minimum Turnaround Time (MTT). Changes in the ELDT and EIBT will result in an updated TOBT. This process will continue until the aircraft is Actual In-Block (AIBT). From here the ground handler is the only source for updating the TOBT during the turnaround.

If the flight just arrived AIBT, the departure is already planned via A-CDM via an ideal way in which the congestion at the airside is reduced the most. This is done by the Collaborative Pre-Departure Sequence Planning (CPDSP) system which uses the TOBT to calculate the earliest possible TTOT for each flight. The earliest possible TTOT is used in order to calculate the optimal the take-off sequence, not to be confused with pre-departure sequence. The earliest possible TTOT is calculated by using TOBT plus Estimated Taxi-Out Time (EXOT). The TTOT is used to determine the TSAT for a flight, namely TTOT minus EXOT is the ideal TSAT indicated in **Figure 6**.

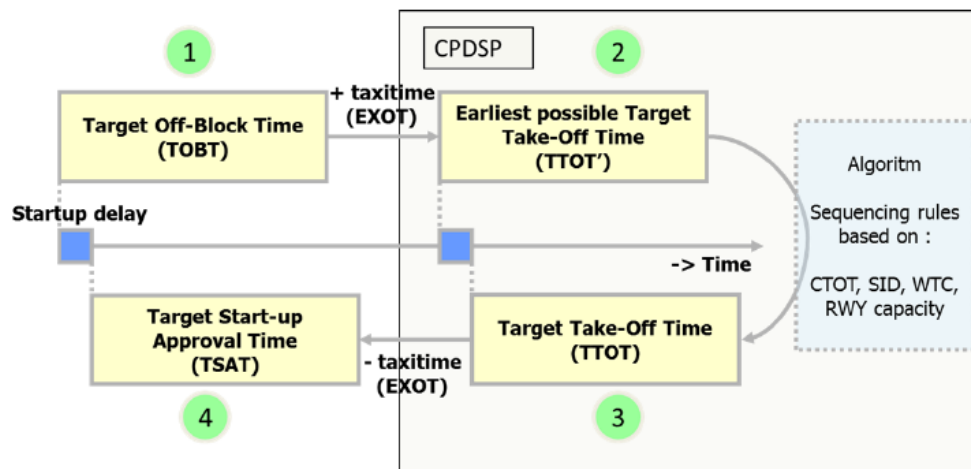


Figure 6 - CPDSP pre-departure sequence planning (Source: Operation Manual A-CDM@AMS, Derogee et al., 2015)

The CPDSP calculation is triggered by several events within A-CDM. TOBT updates, changes in runway usage and/or capacity and Calculated Take-Off Time (CTOT) changes will trigger a recalculation of the pre-departure sequence. If recalculation takes place, the earlier calculated sequence will change. In fact, flights with a CTOT are planned to take-off earlier than non-CTOT flights, meaning that these will be placed behind the CTOT flights. Then again the earliest possible TTOT is used as a key for the optimal sequence.

Figure 7 indicates how the pre-departure sequence is calculated in the form of a flow diagram. In the flow diagram there are two points given, which are analysed more of how these two points affect plan stability:

1. Change to ELDT/EIBT.
2. Change due to recalculation of CPDSP.

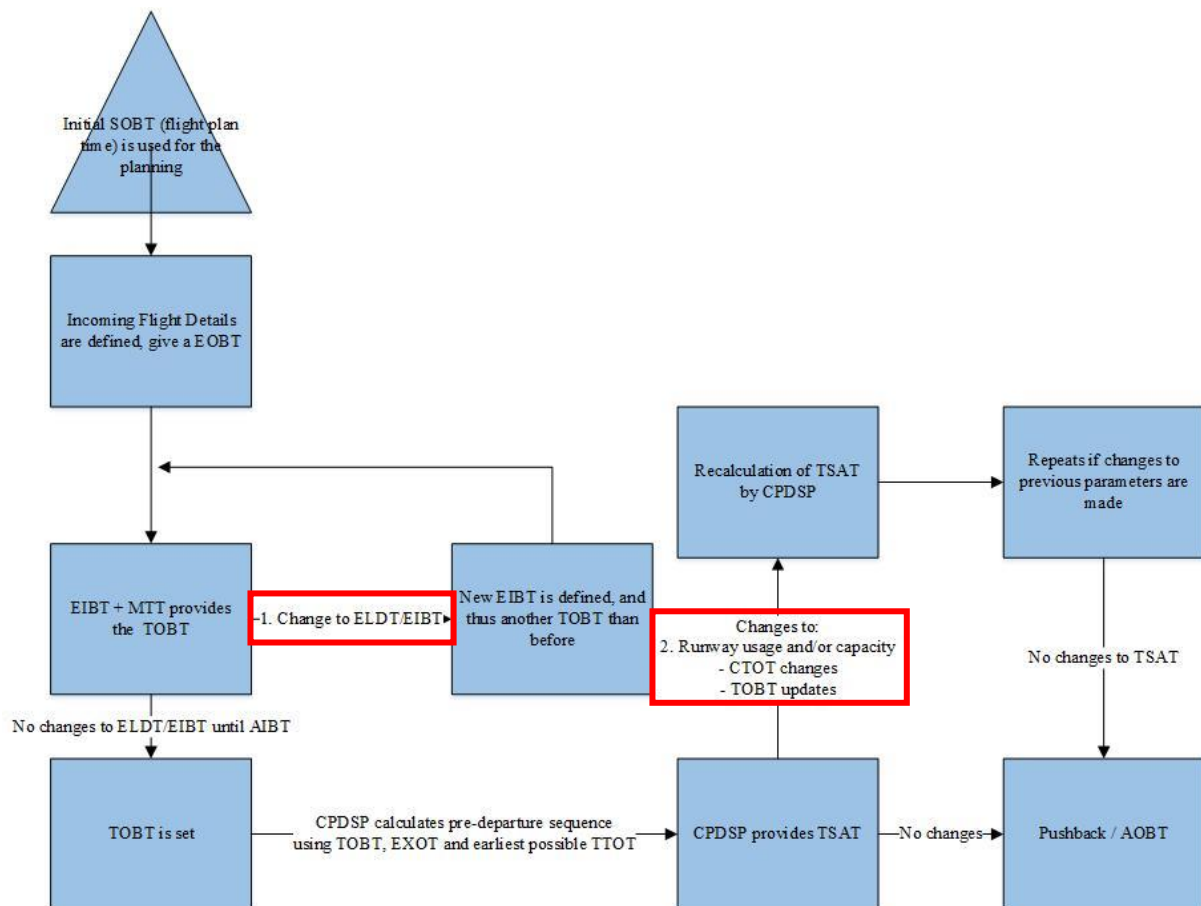


Figure 7 - Flowchart re-calculation pre-departure sequence.

5.2. CHANGES TO ELDT/EIBT

During the inbound phase of a flight, the ELDT and EIBT are already used for determining the optimised departure sequence in the future. However, a lot can happen in two hours after the incoming flight details which were defined until the landing. During the trip towards Schiphol different aspects play a role in changing the ELDT and EIBT, which can be connected to runway changes.

If a flight enters the Dutch airspace, ATC will know approximately 20 minutes before it passes the Dutch Flight Information Region (FIR) where the flight is located. An initial runway is assigned to the flight in this phase, which can still be changed due to different variables. However, the assigned runway should be stable 20 minutes before landing. If a new runway is assigned to the flight, it will come with another ELDT/EIBT as trip time and taxi-time will vary from the situation before a runway change.

To analyse how the ELDT/EIBT fluctuates by a runway change, an analysis of difference between the EIBT before a runway change and EIBT after a runway change is made. Meaning that all inbound flights with more than one runway are filtered from A-CDM data. There is analysed if the dispersion and standard deviation are higher in comparison to a nominal situation in which no runway changes are made in the process of approaching.

The current pre-departure sequence planner is part of the A-CDM system and calculates, based upon the inbound flight information, a departure sequence for the future. As flights are connected 3-hours in advance to Schiphol’s A-CDM system, the ELDT and EIBT at this moment already form a defined departure sequence with an calculated TSAT as indicated in **Figure 8**.

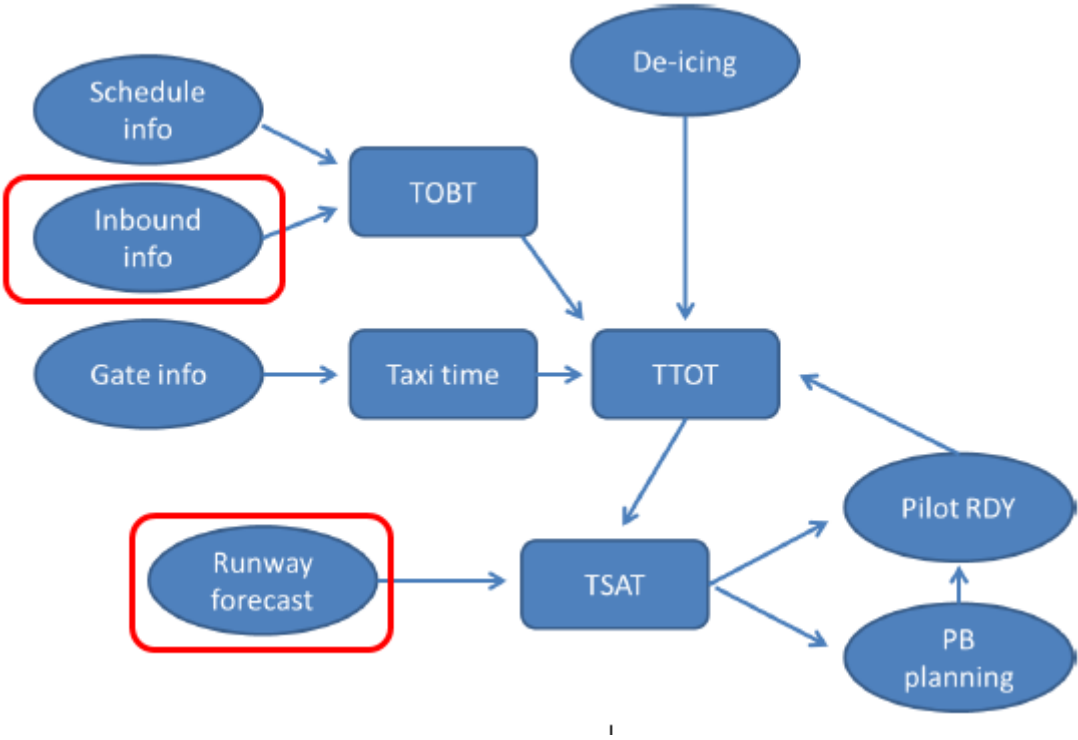


Figure 8 - Runway configuration change (direct) impact on TSAT (Source: OPS Manual CDM@AMS, Derogee et al., 2015)

At first the inbound information gives a TOBT based upon EIBT and ELDT. The inbound information is retrieved by the A-CDM system as soon as it is connected to the system, calculating the departure-sequence already and as concluded before the ELDT and EIBT are used for this. Changes to the ELDT and EIBT are triggered by two variables namely deviating trip time and runway changes. This is verified by the data as indicated in the example **Table 10**.

CLOCK	CSN	TYPE	ARR_GATE	LRWY	STACK	ELDT	EIBT
4-4-2017 11:20:32	KLM52Y	B737	C11	18R	RIVER	4-4-2017 11:28:31	4-4-2017 11:40:43
4-4-2017 11:20:48	KLM52Y	B737	C11	18C	RIVER	4-4-2017 11:28:31	4-4-2017 11:35:13
4-4-2017 11:20:48	KLM52Y	B737	C11	18C	RIVER	4-4-2017 11:27:03	4-4-2017 11:33:45

Table 10 - Recalculation of ELDT and EIBT due to a runway change.

The A-CDM system assigns a runway approximately 40 minutes before the then expected ELDT to a flight. This can change until 20 minutes before landing, after this moment the assigned runway becomes stable in the A-CDM system. To solely focus on the impact of a runway change on the planning, the average ELDT and EIBT change are determined which are paired with a runway changes as concluded above in example Table 10. The average deviation from ELDT and EIBT from the previous assigned

runway are calculated. Also the net deviation which are paired with a runway change are determined in **Table 11**.

	Average deviation	Standard deviation
EIBT difference between first and second runway.	-00:02:19	00:05:21
ELDT difference between first and second runway.	-00:02:23	00:11:30

Table 11 - Average and standard deviation of differences between ELDT and EIBT of first and second runway.

This analysis indicates that with a runway change the planned ELDT and EIBT of a flight are earlier than firstly calculated. And as this process of recalculating new ELDT and EIBT occurs frequently, it also has an impact on the planning stability of the A-CDM system. As the ELDT and EIBT are earlier than expected, the ground handlers will probably need to adjust their planning ad-hoc and at late stages as well as an increase of workload compared with a situation in which the planning is stable.

The reason for this unstable ELDT and EIBT is made by the current A-CDM planning system. In the current A-CDM system, the ELDT and EIBT are determined based upon the then active runway. The inbound and outbound peaks are therefore a disturbance in the planning for the future. As the inbound and outbound peaks will change each time, so will the available runway capacity as indicated in **Figure 9**, as an inbound peak has more inbound capacity than during an outbound peak.

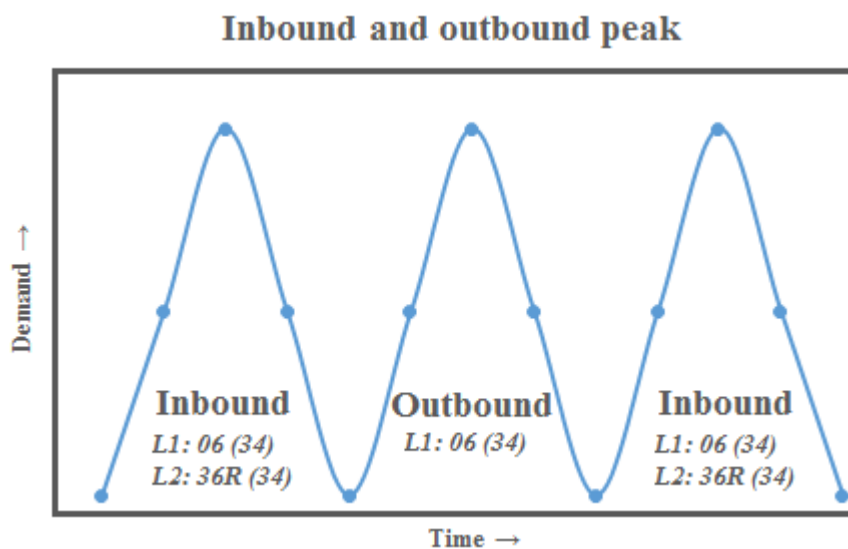


Figure 9 - Change in runway capacity due to a runway configuration change.

Flights which are connected during the latest phase of the inbound peak will have an ELDT and EIBT based upon two runways available. However, if this inbound peak alternates to an off-peak or outbound peak, a new ELDT and EIBT is planned which automatically update the pre-departure sequence planner. The A-CDM milestones are very unstable at the beginning of this phase, also indicated in **Table 12**. To indicate how unstable the inbound information and the sequence is due to runway changes, an example will show what happens.

Moment	Time	Runway configuration
A.	08:00 – 09:50 (inbound peak)	L: 06 and 36R S: 36L
B.	09:50 – 10:00 (2+2 transition)	L: 06 and 36R S: 36L and 36C
C.	10:00 – 11:30 (outbound peak)	L: 06 S: 36L and 36C

Table 12 - Example of recalculations of the sequence due to runway configuration changes.

- A.** At this moment inbound flights are connected to the A-CDM system and a sequence of arrival flights is established. As an example, the flight is sequenced to land at 10:30. An ELDT and EIBT are calculated. Moreover, these parameters are also used for the PDSP.
- B.** As there is a transition between inbound to outbound, other runway capacities are entered in the CISS system. As more capacity is available according to what is entered in the CISS system, the A-CDM system triggers a recalculation. As more runway capacity is available for a short amount of time, the EIBT is calculated to be earlier. A new optimised sequence is calculated for the same flight.
- C.** As the transition peak is only allowed for a certain amount of time, the runway capacities are adjusted again for the outbound peak. Meaning that the arrival runway capacity is reduced, and Arrival Management (AMAN) recalculates a new arrivals sequence. Not only are the ELDT and EIBT very inaccurate at the beginning of the connection to the system. It is also unpredictable how inbound flights are planned for the runway capacities.

The data used for this section indicates that the average deviation between ELDT and EIBT during runway configuration changes are earlier in time. The explanation for this is that most of the flights land during the inbound peak. As the runway capacity increases during the inbound peak, it will change the ELDT and EIBT. The standard deviation is however higher, and the ELDT and EIBT are dispersed 00:11:30 (ELDT) and 00:05:21 (EIBT) from the average. This is mainly the cause of the unstable sequence planner as the sequence and the estimated runways and landing times are calculated far before relevant, in terms of determining the sequence. Also, in theory, the departure sequence is recalculated as the TOBT and TSAT are based upon EIBT+MTT. However, this cannot be verified with the used database because there is no link in the data between inbound flight information and outbound flight information of the same aircraft in the given A-CDM log files. Meaning that there cannot be analysed how fluctuation of ELDT and EIBT, caused by a runway configuration change, influence the departure sequence.

In 2017 the Onderzoeksraad voor Veiligheid (OVV) report on “*Veiligheid Vliegverkeer Schiphol*” concluded there are approximately eighteen runway configuration changes per day. This means that the runway capacity also changes eighteen times per day, forcing the A-CDM system to recalculate sequences multiple times per day due to changes in ELDT and EIBT caused by runway configuration changes. The outcome is probably individual flights having unnecessary delays.

5.3. CHANGE DUE TO RECALCULATIONS CPDSP

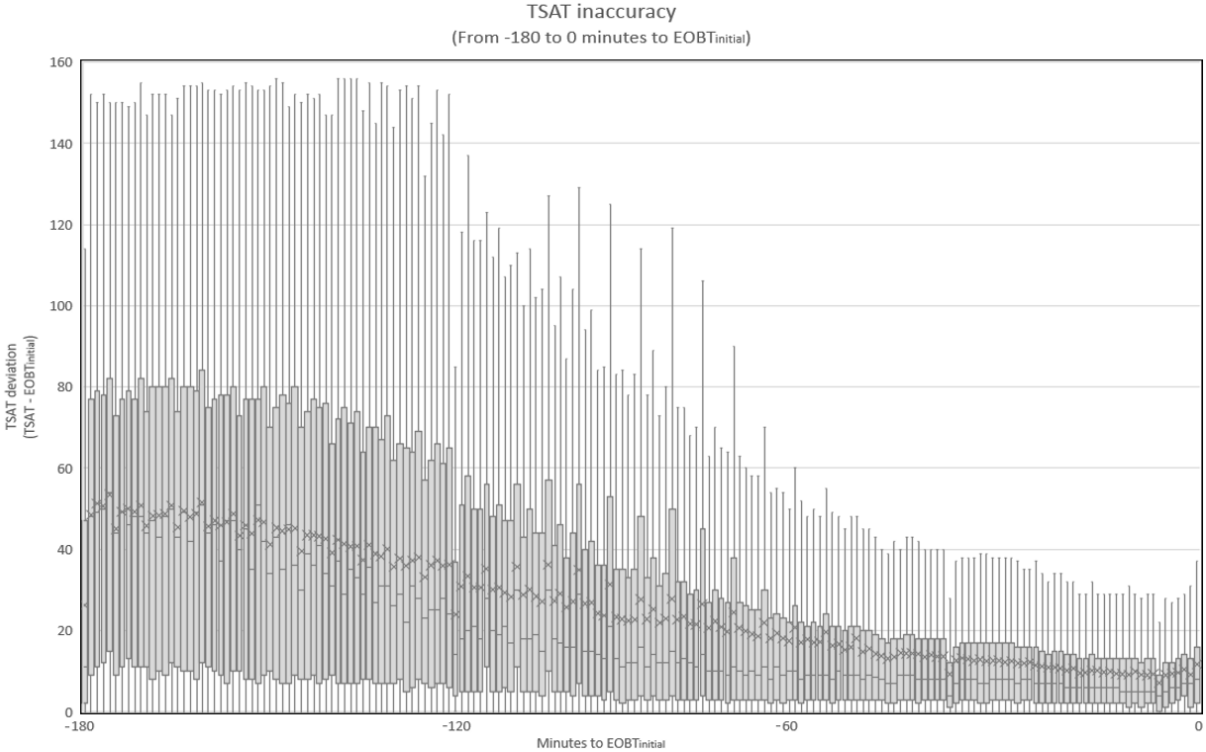
Schiphol plans its capacity using a capacity forecast sheet. This forecast is discussed four times a day between representatives of ATC, KLM and KNMI. The outcome is a forecast sheet indicating the coming four hours in detail and the rest of the day. This sheet is released by either the Tower-Supervisor (TWR-SUP) or Approach-Supervisor (APP-SUP). On this sheet, the expected runway combinations of a configuration are forecasted based upon availability, demand, wind and visibility. During this capacity forecast meeting the runway configuration is planned with an alternative configuration depending on the wind conditions. The planned runways have an estimated inbound and outbound capacity, which is entered in the CISS system of Schiphol at moment of use and is used for future planning. In this way, the determined capacity and runway configuration influence the A-CDM planning of Schiphol.

As outbound A-CDM data indicates the TSAT and TTOT, the planning stability of the departure sequence is analysed in this section. This is done by analysing how a change to runway usage and/or capacity influence the TSAT and TTOT. The question is how flights react to this change and what the consequence will be for the concerned flights.

The runways planning are entered in the CISS system, indicating which runways are active and which other runways are used at given times at Schiphol. This is discussed during the capacity forecast meetings. Furthermore, the TWR-SUP and APP-SUP can choose to change the runway configuration at any time if circumstances demand configuration changes. If change is demanded, by for instance a changing wind direction, the TWR-SUP and APP-SUP will have close phone contact about the runway configuration change. In this case, the supervisors will designate and calculate which flight will make use of the “old” runway and which flight will be the first at the “new” runway. This will also be communicated with the ACC and ground controllers because it will determine their handling strategy (Operation Manual SPL GND, 2018).

The runway forecast is used for calculating the pre-departure sequence planner, if changes are made to the runway usage and/or capacity it will trigger a recalculation of the earliest possible TTOT on the new configuration. If the earliest possible TTOT changes, the TSAT will also be recalculated. Appendix VII – Capacity Forecast Sheet indicates a capacity forecast sheet, highlighting the forecasted runway and capacity.

If runway configuration changes are registered in the A-CDM system, it means that flights with an alternation in departure runway get another A-CDM expected taxi-time. This is one of the reasons why the TSAT will change. Moreover, due to different runway configuration changes in the preamble to the initial TSAT it gives some instabilities of the accuracy as indicated in example **Graph 6**. This figure indicates the inaccuracy of the TSAT from 180 minutes before the initial EOBT. The initial EOBT is the on-the-day corrected Scheduled Off-Block Time (SOBT).



Graph 6 - TSAT instability before EOBT initial (Source: KDC, 2018).

The TSAT accuracy from -180 minutes until the initial EOBT is very unstable. As there is indicated in **Graph 6**, the deviations are higher at the beginning of the planning sequence. One of the reasons for changing TSAT before off-block is the changing runway capacity.

For outbound flights all flights with a runway change are filtered and analysed how TSAT changes after a runway change. The TSAT is expected to become earlier as the last runway configuration change from inbound to outbound create more capacity. Meaning an inbound- or off-peak changes into an outbound peak, moving from one starting runway to two starting runways. However, the database indicates a different outcome in **Table 13**.

	Average deviation	Standard deviation
TSAT difference between first and second runway.	00:08:44	00:31:23

Table 13 - TSAT differences paired with a runway change.

The average deviation between the old and the new runway TSAT indicates that the TSAT is moved 00:08:44 later. Also the standard deviation indicates a high dispersion of the TSAT after a runway change meaning the predictability of the TSAT is low. There are some consequences of the TSAT fluctuation, which are not necessarily all caused by runway configuration changes, affecting operators, ground handlers and airline crew.

Fluctuations of the TSAT have an impact on the departure sequence. As the start-up times are based upon the earliest possible TTOT, the runway configuration change also has an impact on this A-CDM milestone as indicated in **Table 14**.

	Average deviation	Standard deviation
TTOT difference between first and second runway.	00:13:57	00:32:51

Table 14 - TTOT differences paired with a runway change.

The data indicates that a runway configuration change exhibits with an average deviation in TTOT of 00:13:57. This data implicates that most of the outbound flights get a later place in the departure sequence. However, the standard deviation is again very high, meaning the dispersion of TTOT is very unpredictable after a runway configuration change. The standard deviation of TSAT and TTOT are relatively high compared to EIBT and ELDT in **Table 15**.

	Average deviation	Standard deviation
Inbound		
EIBT difference between first and second runway.	-00:02:19	00:05:21
ELDT difference between first and second runway.	-00:02:23	00:11:30
Outbound		
TSAT difference between first and second runway.	00:08:44	00:31:23
TTOT difference between first and second runway.	00:13:57	00:32:51

Table 15 - A-CDM deviations due to runway configuration change.

To conclude, the runway configuration changes influence the TOBT during the inbound phase of the flight. The TOBT is AIBT + MTT, thus ground handlers will have to plan ad-hoc on the inbound flights. The EIBT is moved earlier in time on average with a runway configuration change. As the EIBT and ELDT comes forward in time, all involved parties are forced to change their planning. For the outbound flights, the runway configuration changes are a factor which contributes to the inaccuracy of the TSAT.

6. CONCLUSIONS

To conclude the overall research project, the structure has the similar approach used for the results. This means that all conclusions from the beginning until the end are in chronologic order. The main research question: **“What is the impact of runway changes on the capacity & plan stability of airspace- and ground capacity at Amsterdam Airport Schiphol?”** is answered in this section of the research. The conclusion to this research question came from answering the following sub-questions:

1. What are the deviations and variations in operations due to runway configuration changes?
2. How is Schiphol’s plan stability affected by planned and unplanned runway changes?

The motivation for this research came from the report *“Veiligheid Vliegverkeer Schiphol”* (Safety Air Traffic Schiphol) published by the Onderzoeksraad voor Veiligheid (OVV). With daily eighteen runway changes on average, the OVV report concluded some safety hazards and nothing about impact on capacity. This research report mainly concludes the impact on capacity. Also the problem statement of which trajectory should be followed after 2020, is answered in this section. The two trajectories which are determined beforehand are:

1. Increase peak periods.
2. Increase peak capacity.

Before the actual analysis which answers the sub-questions, a literature review was performed to provide insight of what is already known about runway changes. There were some interesting findings and some conclusions which indicated that the actions performed at the runway have a great impact on overall airport capacity. Also the moment of alternation between runway combinations or configurations are very decisive for the costs in terms of reduced efficiency. Therefore to provide insight of how runway changes influence daily operations multiple interval moments in which runway configuration changes are made, are identified in with sub-question 1 within this research.

6.1. SUB-QUESTION ONE CONCLUSIONS:

As previous research indicated that the physical infrastructure is decisive for the airport capacity, there are three key actions analysed during the first sub-question in regard with ground capacity. These key actions include determination of impact on taxi-times, landings interval and starting interval. As the main research question also includes airspace capacity stack usage is also taken into account for the airspace.

The analysis of the taxi-times, landing respectively starts interval and stack usage indicated unexpected outcomes. As there was expected that a runway change respectively configuration change had an impact on airport capacity, research indicates there is no significant difference between a runway change and a nominal situation.

In terms of taxi-times, the actual taxi-out time does not variate from a nominal situation. Research have indicated that this is possible the outcome of keeping outbound flights longer at the gate or at designated buffer areas. The actual-taxi in time is a little higher than nominal and was therefore statistically tested if significant. According to the Man-Whitney U-Test, the taxi-in time was not significantly higher during runway changes.

The landing and starts interval are also analysed in order to provide insight of how actions at the runways are involved. This sections goal was to provide insight in the loss of capacity 10 minutes around a

registered runway change. In terms of arrivals, the landing interval did not increase during a runway change. However, the interval of a runway change had less starts compared to a situation in which no runway changes were made meaning the starts interval increased. The surprising outcome was that the hour capacity was not influenced as the total starts per hour were not lower. A consequence of this could possibly be increased workload for air traffic controllers before and after a runway change.

Moreover, the stack usage was also determined within the answering of this sub-question. The initial flight plans of Eurocontrol were used and compared with the actual flight plans. The research have indicated that there were no differences compared to a nominal situation in terms of longer occupation of the ACC during a runway change. An interesting finding using this database indicated that deviations from initial flight plans were higher when aircraft flew via ARTIP and SUGOL. The average deviation was lower on flights coming via RIVER, coming from the busiest airspace sector of the Netherlands.

In short, the daily operations are not directly influenced according to the research. However, there are some new insights for new research such as the possible increased workload for air traffic controllers during a runway change.

The literature review is also used to indicate how research for the second sub-question is executed. As previous research have indicated that the A-CDM system is the foundation for the airport operation planning at airports, it will be researched to determine the influence of a runway change on the planning stability of Schiphol. The objective of A-CDM is to increase runway efficiency, although this section will represents how the planning system reacts to an individual change in runway on the overall stability.

6.2. SUB-QUESTION TWO CONCLUSIONS:

This sub-question was answered with two types of research. Firstly, qualitative research determined that the A-CDM is influenced by runway changes in two ways. For inbound flights the changes in runway gives other estimated landing and in-block times, which is obvious as flight times to the head of the runway and taxi-times will variate with a change. For the outbound flights the changes in runway trigger a recalculation for a new departure sequence.

These findings are used for the quantitative research to determine how the runway changes influence the planning stability of the airport operations plan of Schiphol. From all inbound flights, which had more than 1 runway assigned, the historic data is gathered and analysed. The findings indicate two kind of outcomes per traffic type, i.e. inbound and outbound.

The inbound flights are affected by the runway changes in the planning as it generates a new prediction of the estimated landing and in-block time come earlier in time. Meaning the inbounds flights are calculated to be earlier on the physical infrastructure of airport. As the standard deviation is not very high, it indicates that the average deviation is relatively stable. However, the runway changes have a negative effect on the planning stability of Schiphol, because each change triggers a recalculation which adjusts the planning on which airport users plan their capacity. For inbound flights 20 minutes before entering the Dutch airspace a runway has been selected. However from the Dutch airspace border until Schiphol is still approximately 20 minutes travelling. This means that when an old runway configuration is about to change, the sequence is still build with the old configuration until it is changed in the CISS. Usually the sequence is made during an outbound- or off-peak moment which has less arrival capacity. The new configuration, causing the recalculation of estimated landing and in-block times, have more capacity meaning that these parameters are earlier in time.

The qualitative research also indicated that the outbound planning departure sequence is also influenced by a runway configuration change. This is already during the inbound sequence as the estimated in-

block time and minimum turnaround time calculate a target off-block time. The target off-block time is used for the pre-departure sequence later on in the chain. The change which is triggered by a runway change already influences the departure sequence in an early stage. However, this does not have a significant impact on the airport planning as there are a lot of other processes which can lead to a recalculation of the departure sequence.

When there is a change in runway usage and/or capacity, the target off-block time will not be changed. This can only be done manually by ground handlers. The change in runway usage and/or capacity will trigger a recalculation of the earliest possible target take-off time. This is the target start-up time plus the estimated taxi-out time which are determined per runway and gate combination (not to be confused with variable taxi-time). If the earliest possible target take-off time is changed, a new target start-up time will also be calculated. For the researched months, there is analysed and perceived that the target start-up time and earliest target take-off time move further in time on average. This means that the recalculation due to the runway change provide a sequence in which outbound flights are delayed more than before the runway change. The standard deviation of the target start-up time and earliest possible target take-off time are higher than the standard deviation of estimated landing and in-block time. Meaning that during the outbound sequencing, a runway configuration change gives an less predictable departure sequence.

In short, the airport operations planning of Schiphol is unstable because of different factors. One of the factors contributing to the planning instability are the runway changes as it triggers two different recalculations of the arrival sequence and departure sequence. Schiphol uses A-CDM as operation planning system, which is good as it provides more runway efficiency than without such system. However, due to an unstable sequencer runway configuration changes have a negative impact on the planned operations.

6.3. OVERALL CONCLUSIONS:

The research indicated two different answers to the sub-questions which answer the main question. Sub-question one indicated that there are no significant differences in operations during a runway configuration change. Sub-question two provided an answer which indicates that the planning system at Schiphol is influenced by a runway configuration change.

What is the impact of runway changes on the capacity & plan stability of airspace- and ground capacity at Amsterdam Airport Schiphol?

As the OVV report concluded that runway changes are paired with minimal safety hazards. However, nothing was stated on how the airport capacity was influenced. For this research the impact on capacity was researched in two segments, namely the impact on daily operations and on the Airport Operations Planning (AOP).

The impact of runway changes is not seen in the daily operations. Reasons of why the database did not indicated any significant differences in daily operations are confirmed by a Tower-Supervisor. The runway changes are entered in the system at the moment the operations actually change. However, the Tower-Supervisor and Approach-Supervisor have had close contact about the runway configuration change. The supervisors determine which flight makes use of the old runway as last and which flight is the first user of the new runway. One of the results indicated that there was a slight difference in starting interval, caused by a runway change. This is the result of a departure delay manually applied by an air traffic controller if necessary. The outbound flight will be held at the gate or alternative buffer platform if seamless throughput to the departure runway cannot be guaranteed. One of the advantages of the continuous throughput to and from the runway, is the minimisation of congestions at the taxiways.

The disadvantages are congestion which might occur on longer term at the gates and buffer platforms. Certainly if air traffic will increase after 2020, the limitation of infrastructural capacity of the gates and platforms are an issue.

However, planning stability of Schiphol's AOP is influenced by a change in runway usage and/or capacity. The runway changes make the airport operations planning more complex than needed. The A-CDM arrival sequence which is provided already three hours in advance is very unstable, and thereby only ad-hoc made planning is followed by ground handlers, airlines and air traffic controllers. The air traffic controllers work with the first-come-first-serve principle, relating back to a non-executable plan. The A-CDM departure sequence is also changed throughout the day due to changes made to runway capacity. The change which is registered in the A-CDM system indicates that the outbound flights are moved further in time.

Overall the answer to the main question is that nowadays daily operations are not affected and planning wise only minor delays are caused at the airport. If the prospect of an increase in air traffic movements on Schiphol is correct, it will mean that runway changes have more impact on the planning stability of the airport and presumably on daily operations. The recommendation implies what next research steps should be taken.

7. DISCUSSION

Each research analysis and conclusion provides new insights in new research possibilities. During the research, certain decisions have been made which provided the research conclusions as it is now. However, the research method is discussed in this section representing the points of improvements for the research.

At first, Eurocontrol DDR data was used for the research. The idea of using this dataset was that it provided initial planned and actual executed operations. However, after building the database from DDR the lack of useable data, such as runway usage and taxi-times, for the research was mentioned. The lack of specific data of DDR required other datasets, Tower Logging and VEMMIS, to be combined. This steps in building the database increased the workload and affected the overall planning. Later on during the research when A-CDM data was used it gave a moment of realization that another dataset should have been used from the beginning. Therefore, a small part of data should be analysed beforehand in order to conclude whether the data is valuable for the research. This additional step will make sure no extra work is done in the preliminary phase of the research.

Additionally, the usage of Excel was also a limiting program during the research. For the first sub-question a smaller dataset could be used. In order to provide an analysis which is executed on a bigger dataset, other methods such as SQL are recommended. The SQL method is a powerful database analysis method in which bigger datasets are analysed without interruptions of errors. This was a method which could have been from great value. Instead of the limitations of Excel only accessible with one month of A-CDM data and Access with four months of A-CDM, SQL could have analysed a year.

However, the produced dataset with DDR used for the first sub-question indicated a clear overview of how daily operations are affected by a runway configuration change. The only point of improvement for the validation of the research could be a bigger dataset used. The small sample size is not reliable enough to indicate if the analysed situation is always like that with runway configuration changes. It could possibly mean that it was a “lucky” pick in which the situations did not deviate very much. Moreover, a lot of variables have influence on the airport capacity, and for instance the increase of taxi-times could have been the consequence of another disruptive factor. Simulation of specific situations and more data in which runway configuration changes take place could be a solution for getting a more funded analysis.

As daily operations are not affected significantly according to this research, the future should be analysed. This should be done in order to provide an analysis of how an increase in air traffic movements will be affected by runway changes. Especially for the impact on the current sequence planning system.

The used database for the second sub-question consist of A-CDM data. This database could have been used for the first sub-question as well. However, the A-CDM data was mostly used to provide insight in the planning milestones of the inbound and outbound flights. This data states very accurate how the airport operation planning and actual executed operations are changed throughout the day. As the dataset is very specific and big, a filter has been applied on flights with more than one runway. However only the last change of runway has been used for this research, when in fact there could have been three changes in runway. Each registered runway change could be analysed and determined between which change, for instance from 36L to 36C, give the most deviation. This research step could have given a recommendation in which the most disruptive changes were given.

Moreover the second sub-question, the net impact of a runway change could have been researched. However, the goal of indicating the impact of runway configuration changes on the planning stability of Schiphol is proven. This could be done by comparing the first estimated parameters with the last and realised parameters of the last registered runway.

8. RECOMMENDATION

As determined in the analysis of the current situation at the beginning, Schiphol has approximately eighteen runway changes per day. According to the OVV (2017), this is paired with some safety hazards. These safety hazards are minimised by the LVNL and the data analysis of the first sub-question partly indicates this. To prevent congestions at the taxi-ways, aircraft are held at the gate or buffer platforms which is an (unconscious) procedure to mitigate hazards at the airside. As concluded that hour capacity is not affected, the analysis indicates a higher interval of landings and starts. This is mostly caused by the separation standards, to maintain safe operations.

Concerning capacity, the daily operations are not affected yet because of the professionalism of air traffic controllers. However, there is a correlation between the safety and capacity. Therefore new research needs to be performed concerning the workload of the air traffic controllers, because of the possible increased workload. This is in order to research the future increase of air traffic in correspondence with bigger safety hazards and higher workload during a runway change.

Another recommendation for further research is to stabilise the airport operations planning. Currently the planning is very unstable and the runway changes are one of the reasons that the sequencer makes new calculations. The runway change already has an impact when the flight is connected to the A-CDM system. This part in which the runway plays a role in the sequence could be later in the process. The ideal moment should be determined but instead of hours in advance, 40 minutes before take-off or landing the initial runway should be actual. Also the planning sequencer calculates with the old configuration while a new runway capacity will be in the near future. As the supervisors of Tower and Approach already know this, the planning system does not. It is therefore recommended to optimise or change functionalities of the sequencer in terms of “future runway configurations”. This is a valid option in order to provide a more predictable system in which capacity is used more efficient.

To relate back to the problem statement which gave two different trajectories after 2020, this research contributes to the trajectory in which peak-hour capacity needs to increase. Current analysis indicated no big deviations in the daily operations if compared to a nominal situation. However, if traffic increases it will mean that the runway changes have more impact on the planning system and departure delays will increase. More research concerning these trajectories is needed to conclude how Schiphol will react to choosing one of these trajectories. This research mainly supports the trajectory in which less runway changes should be made, in order to have efficient usage of capacity.

The last recommendation is to increase the dataset size and research further on the actual impact of the planning stability caused by a runway configuration change. Increasing the dataset its size for the sub-question could possibly give slightly different outcomes which will indicate that the runway changes have a significant impact. Further analysis of the A-CDM data which is used for sub-question two, could be analysed more in order to get more insight in the impact of runway changes on the daily operations.

In short, three recommendations are concluded at the end of this research:

- Research workload of air traffic controllers during runway change.
- Research predictability of the sequencer of A-CDM system during a runway change.
- Research the two trajectories for the future of Schiphol.
- Increase dataset size and validate current findings.

9. REFERENCES

- Alders, H. (a2013). *Alders Advies - Bijlage III Nieuwe Normen en Handhavingstelsel voor Schiphol*. Amsterdam.
- Avery, J., & Balakrishnan, H. (2015). *Predicting Airport Runway Configuration*. Cambridge, Massachusetts, USA.
- Baarda, B. (2010). Research. This is it! In B. Baarda, *Research. This is it!* (pp. 59-60). Groningen: Noordhoff Uitgevers.
- Derogee et al. (2015). *Ops Manual: CDM@AMS*. Schiphol, the Netherlands.
- Eurocontrol (2012). *Airport CDM Implementation Manual*. (pp 3-17) Retrieved from: <https://www.eurocontrol.int/sites/default/files/publication/files/2012-airport-cdm-manual-v4.pdf>
- Eurocontrol (2017). *Airport CDM Implementation the Manual*. Brussels, Belgium.
- Frost, J. (2015). *Understanding Hypothesis Tests: Significance Levels (Alpha) and P values in Statistics*. Retrieved from: <http://blog.minitab.com/blog/adventures-in-statistics-2/understanding-hypothesis-tests%3A-significance-levels-alpha-and-p-values-in-statistics>
- Guépet, J., Briant, O., Gayon, J.-P., & Acuna-Agost, R. (2017, June). *Integration of aircraft ground movements and runway operations*. Grenoble, France.
- Helm, S., Classen, A. B., Rudolph, F., Werner, C., & Urban, B. (2014). *Integration of landside processes into the concept of total airport management*. Braunschweig, Germany.
- IATA. (2016). *Unstable approaches*. Montreal, Canada.
- ICAO. (2007). *Annex 3 - Meteorological Service for International Air Navigation*. Montréal, Canada.
- Investopedia. (2017). *Statistical Significance*. Retrieved from Investopedia: <https://www.investopedia.com/terms/s/statistical-significance.asp>
- Jacquillat, A., & Odoni, A. R. (2017). *A roadmap toward airport demand and capacity management*. Pittsburgh, USA.
- Kamgarpour, M., Zhang, W., & Tomlin, C. J. (2011). *Modeling and optimization of terminal airspace and aircraft arrival subject to weather uncertainties*. Berkley, California, USA.
- KDC (2018). *Implementation of an Airport Operations Center (APOC) at Schiphol Airport: Improving capacity management?* Schiphol, the Netherlands.
- KLM (2011). *Fact Sheet Network and Hub Systems*. (pp: 2). Retrieved from: https://www.klm.com/corporate/en/images/008372%20Factsheet%20network_tcm729-342204.pdf
- LVNL (2005). *ATM Ops View 2005*. Schiphol, the Netherlands
- LVNL. (2017a). *Runway Use at Schiphol*. Retrieved from Luchtverkeersleiding Nederland: <https://www.lvnl.nl/en/environment/runway-use.html>
- LVNL. (2017b). *Quick Reference Chart 09 - Baancombinaties*. Schiphol, Nederland.
- LVNL (2018a). *Operation Manual Manual SPL ACC*. Schiphol, the Netherlands.
- LVNL (2018b). *Operation Manual SPL GND*. Schiphol, the Netherlands.

- MacDonald (2013). *Access 2013: The Missing Manual*. Retrieved from: http://dbmanagement.info/Microsoft/Access_2013_The_Missing_Manual_MS_Access.pdf
- Microsoft (2018). *Introduction to queries*. Retrieved from: <https://support.office.com/en-us/article/introduction-to-queries-a9739a09-d3ff-4f36-8ac3-5760249fb65c>
- Onderzoeksraad voor Veiligheid. (2017). *Veiligheid vliegverkeer luchthaven Schiphol*. Den Haag, the Netherlands.
- Oseguera-Lohr, R., Phojanamongkolkij, N., Lohr, G., & Fenbert, J. W. (2013). *Benefits assessment for tactical runway configuration management tool*. Hampton, USA.
- Sama, M., D'Ariano, A., Corman, F., & Pacciarelli, D. (2017). *Coordination of scheduling decisions in the management of airport airspace and taxiway operations*. Rome, Italy.
- Schiphol (2016). *Royal Schiphol Group: Annual Report 2016*. (pp 46). Schiphol, the Netherlands.
- Schiphol. (2017). *Route Development and Airport Sheets*. Retrieved from Schiphol: <https://www.schiphol.nl/en/route-development/page/amsterdam-airport-schiphol-airport-facts/>
- Sedee, M. (2018). *Schiphol net onder maximum aantal vliegbewegingen*. Retrieved from: <https://www.nrc.nl/nieuws/2018/01/08/schiphol-net-onder-maximum-aantal-vliegbewegingen-a1587513>
- SESAR (2015). *European ATM Master Plan: The roadmap for delivering high performing aviation for Europe*. Brussels, Belgium.
- Skorupski, J. & Wierzbicki, H. (2016). *Airport capacity increase via the use of braking profiles*. Warszawa, Poland.
- Skybrary. (2014, November). *Unstabilised approach: late runway or approach type change*. Retrieved from: https://www.skybrary.aero/index.php/Unstabilised_Approach:_Late_Runway_or_Approach_Type_Change
- Smit, L., van den Bos, H., & Dubbeldam, R. (2007). *CONOPS Verhoging van de grondafhandelingscapaciteit op basis van het huidige banenstelsel*. Schiphol: LVNL.
- Suwa, H. & Morita, D. (2014). *Stability-based short-term capacity requirement planning under uncertainty*. Osaka, Japan.
- Swaen (2017). *Doel en structuur van een reflectieve verslag*. Retrieved from: <https://www.scribbr.nl/stage/reflectieverslag-en-procesverslag/>
- van Geloven (2015). *Mann-Whitney U-Toets*. Retrieved from: https://wikistatistiek.amc.nl/index.php/Mann-Whitney_U_toets

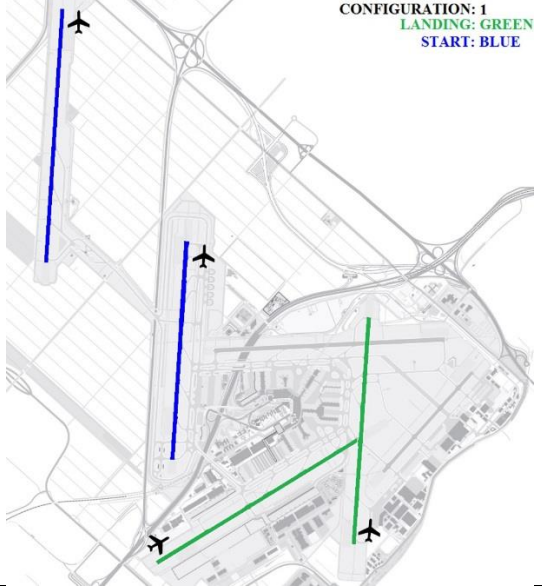
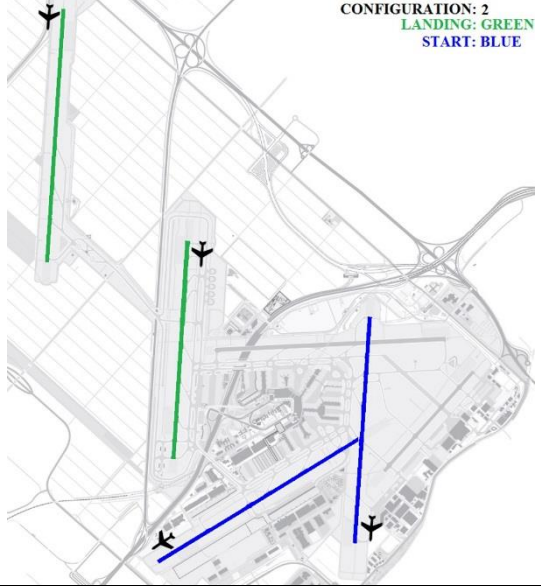
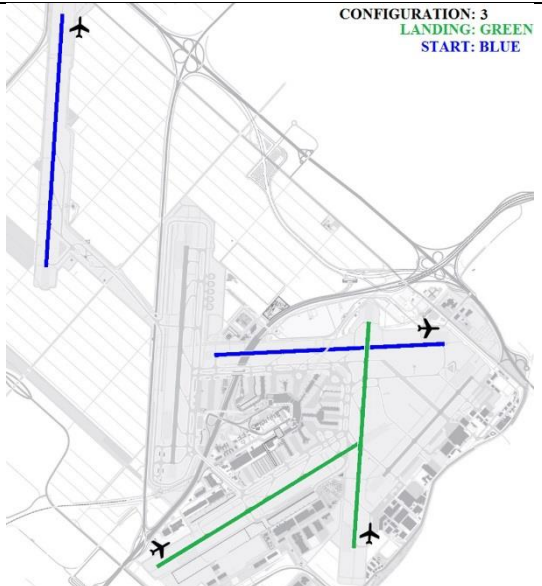
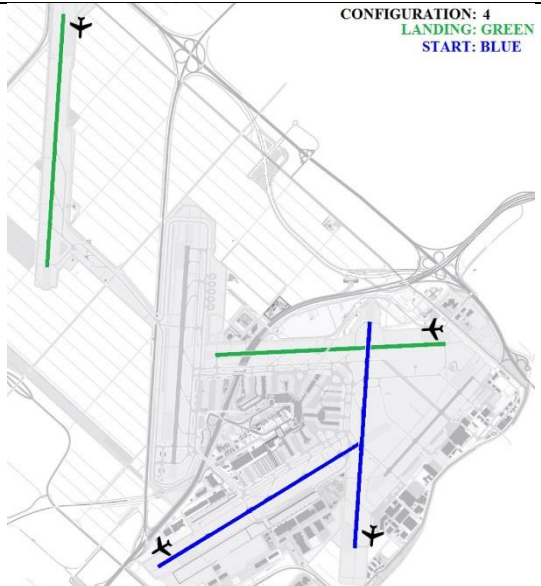
APPENDICES

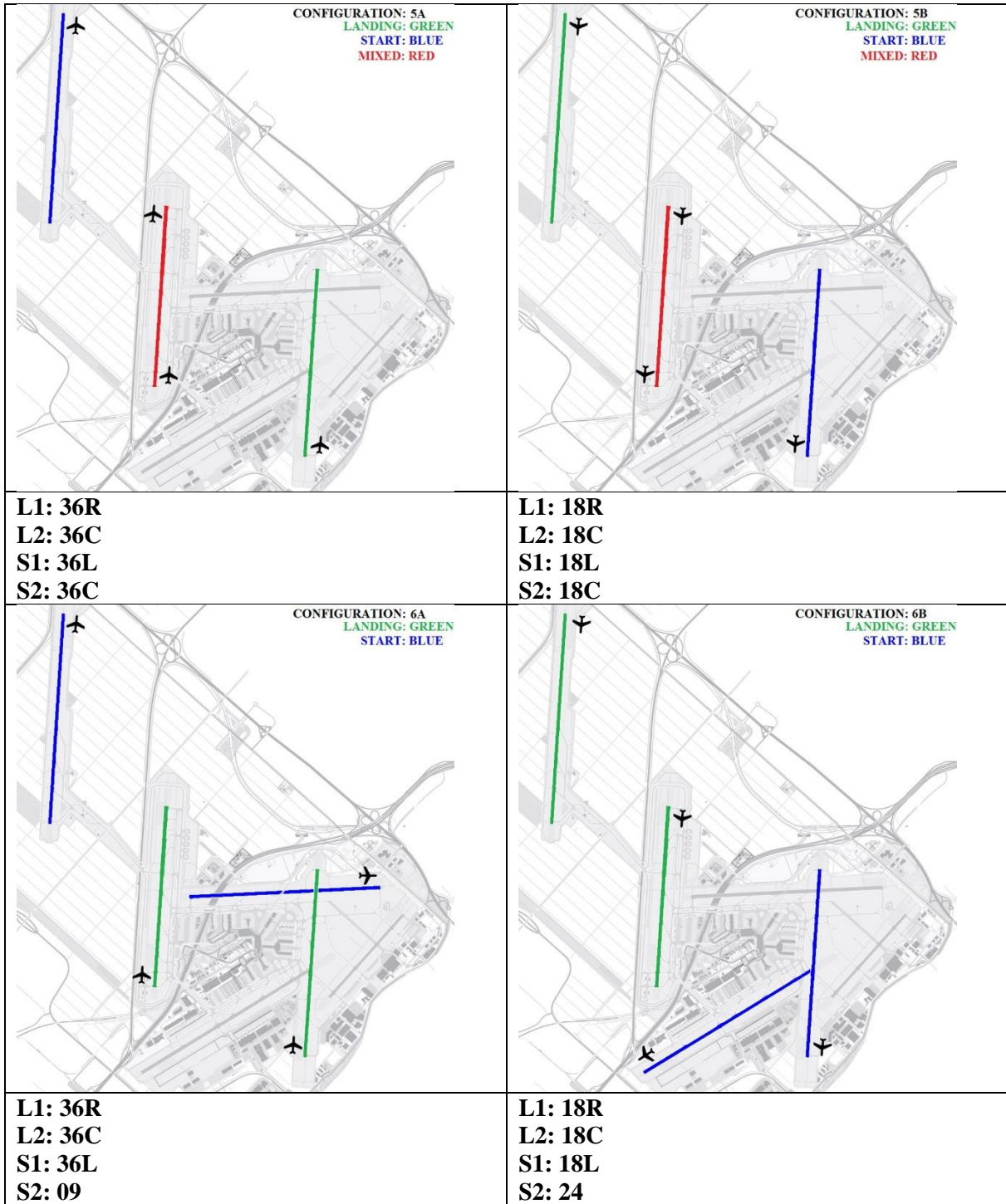
Appendix I – Layout Schiphol (Schiphol, 2017)	A
Appendix II – Configuration Preferences.....	B
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APPENDIX I – LAYOUT SCHIPHOL (SCHIPHOL, 2017)

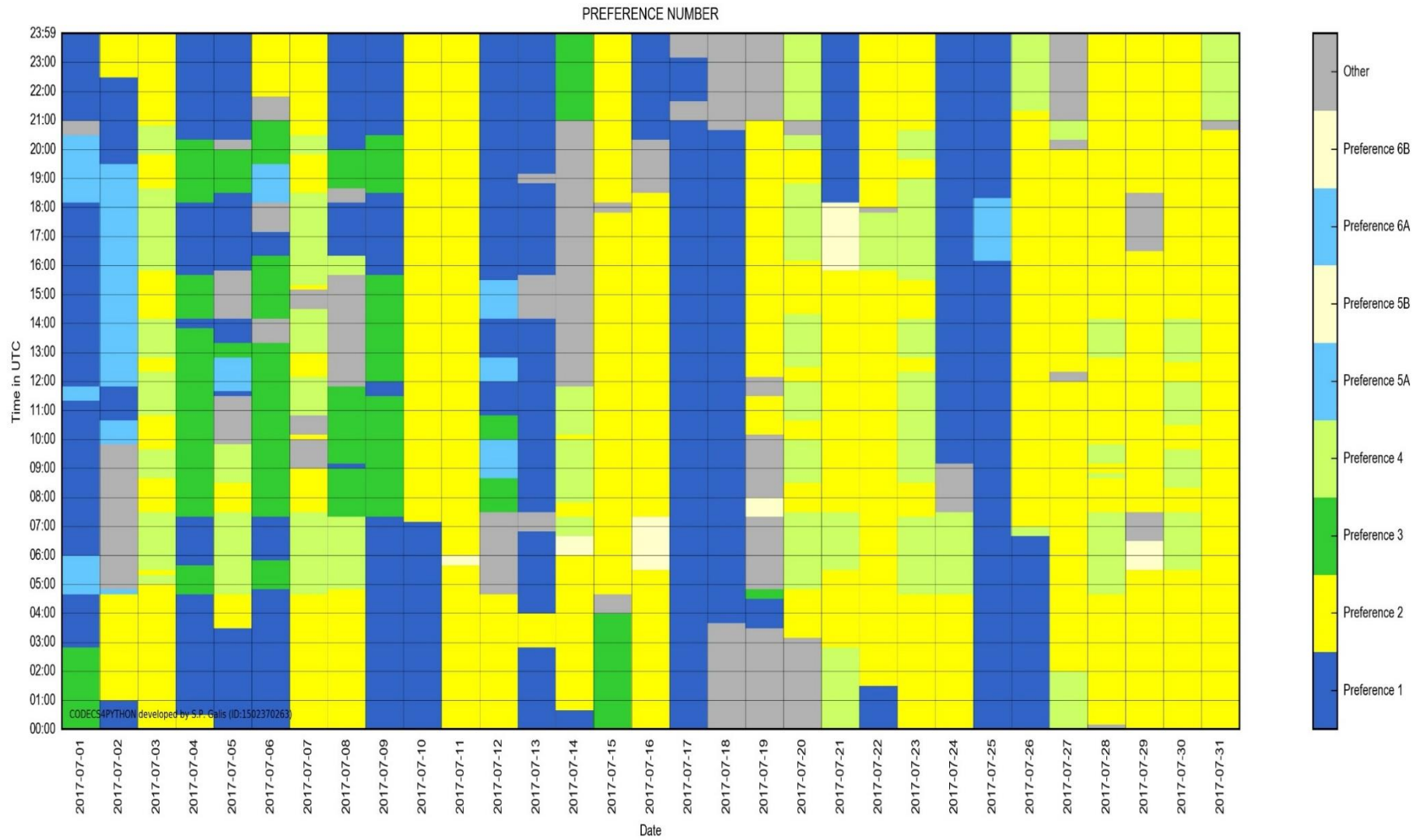


APPENDIX II – CONFIGURATION PREFERENCES

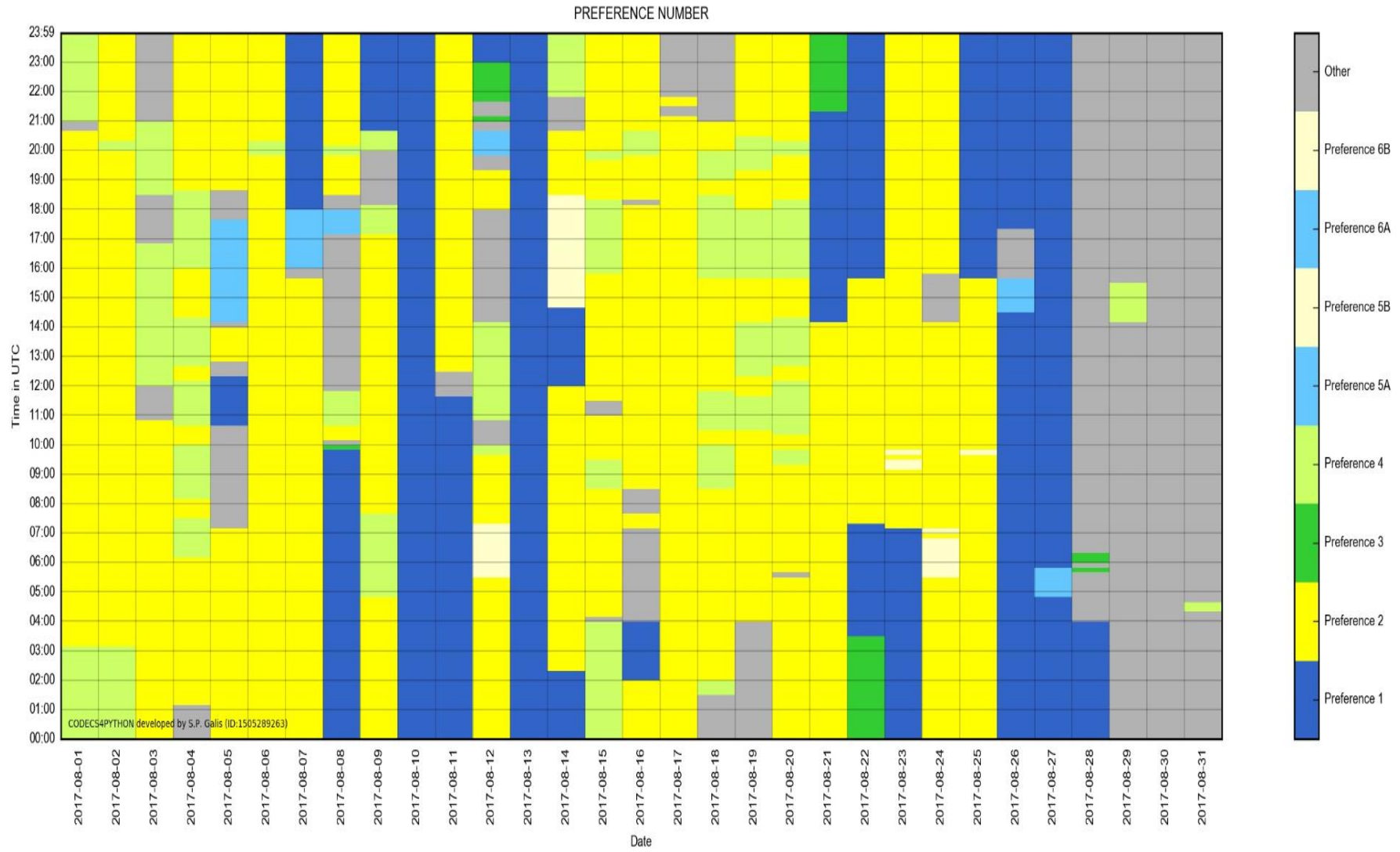
 <p style="text-align: center; color: green; font-weight: bold;">CONFIGURATION: 1 LANDING: GREEN START: BLUE</p>	 <p style="text-align: center; color: green; font-weight: bold;">CONFIGURATION: 2 LANDING: GREEN START: BLUE</p>
<p>L1: 06 L2: 36R S1: 36L S2: 36C</p>	<p>L1: 18R L2: 18C S1: 24 S2: 18L</p>
 <p style="text-align: center; color: green; font-weight: bold;">CONFIGURATION: 3 LANDING: GREEN START: BLUE</p>	 <p style="text-align: center; color: green; font-weight: bold;">CONFIGURATION: 4 LANDING: GREEN START: BLUE</p>
<p>L1: 06 L2: 36R S1: 09 S2: 36L</p>	<p>L1: 27 L2: 18R S1: 24 S2: 18L</p>



APPENDIX III – PREFERENCE USAGE JULY



APPENDIX IV – PREFERENCE USAGE AUGUST



APPENDIX V- HOUR CAPACITY JULY

ATA	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	Day
2017-07-01	47	68	34	35	60	37	48	30	52	22	22	41	63	17	25	25	11	15	5	704
2017-07-02	46	65	22	36	57	36	56	33	53	30	29	51	67	38	33	30	9	12	5	745
2017-07-03	49	66	38	41	55	32	58	38	57	36	29	50	72	39	32	32	8	15	3	790
2017-07-04	53	71	33	40	58	37	61	29	55	28	35	48	68	31	33	22	12	8	5	761
2017-07-05	50	71	37	43	52	33	58	30	64	18	36	44	65	37	29	30	22	5	5	770
2017-07-06	51	67	35	43	53	34	52	34	58	28	34	46	58	41	32	32	12	15	11	775
2017-07-07	52	70	35	38	61	38	57	26	59	32	31	47	66	37	35	30	6	18	9	790
2017-07-08	49	65	35	40	54	37	43	36	48	33	26	36	67	22	22	23	9	7	15	708
2017-07-09	48	65	29	37	48	32	57	35	56	25	31	44	69	40	30	32	12	15	12	764
2017-07-10	59	67	32	37	54	42	45	37	57	32	30	41	71	41	34	30	8	9	13	781
2017-07-11	48	67	36	41	56	34	56	35	60	27	27	51	70	37	35	24	12	13	7	781
2017-07-12	50	62	43	39	54	47	49	30	56	33	32	45	70	40	32	25	8	13	13	777
2017-07-13	49	68	40	42	51	40	49	36	61	33	38	50	69	32	36	25	8	13	15	792
2017-07-14	51	71	36	39	55	42	46	31	52	38	35	40	61	48	35	27	11	13	9	774
2017-07-15	52	67	35	42	56	34	49	27	50	31	26	39	53	30	25	23	10	9	16	716
2017-07-16	44	65	31	43	42	34	57	33	62	28	31	51	64	35	33	30	14	16	6	767
2017-07-17	54	67	38	41	49	43	52	31	66	27	30	47	70	40	32	25	13	10	8	784
2017-07-18	50	71	32	43	48	43	53	33	62	26	29	49	70	31	37	20	6	18	10	771
2017-07-19	49	65	33	34	57	36	53	38	54	37	32	36	55	50	35	29	11	13	12	770
2017-07-20	44	62	39	44	56	36	49	36	59	31	31	44	64	48	32	28	10	14	11	784
2017-07-21	46	71	37	41	58	38	54	36	52	35	37	46	71	36	35	23	13	12	10	796
2017-07-22	47	68	39	41	57	33	46	35	48	30	31	34	60	21	19	27	7	11	13	712
2017-07-23	43	62	28	39	49	39	49	36	52	28	38	52	69	36	36	29	9	15	15	775
2017-07-24	55	60	38	33	57	37	52	38	62	35	26	48	68	44	33	28	9	13	10	786
2017-07-25	52	69	29	45	54	40	50	39	61	20	38	42	67	40	33	25	6	20	9	789
2017-07-26	49	65	33	45	52	40	50	34	56	30	32	45	72	43	37	31	5	10	15	787
2017-07-27	45	70	37	44	50	32	50	42	60	27	34	40	71	33	29	33	12	19	12	787
2017-07-28	49	67	42	36	57	36	51	35	59	36	39	44	73	40	32	24	11	18	7	796
2017-07-29	42	67	38	38	58	36	47	34	46	31	24	36	66	20	25	25	8	12	12	710
2017-07-30	43	63	31	39	51	37	55	34	56	31	31	47	65	42	28	31	10	20	10	771
2017-07-31	50	67	40	39	50	42	52	39	57	32	34	45	67	46	34	29	4	13	9	789
Total	1516	2069	1085	1238	1669	1157	1604	1060	1750	930	978	1379	2061	1135	978	847	306	414	312	
Average	49	67	35	40	54	37	52	34	56	30	32	44	66	37	32	27	10	13	10	

Landings 07-2017.

Green indicates more than daily average landings.

Yellow indicates less than daily average landing.

APPENDIX V – HOUR CAPACITY JULY

ATD	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	Day
2017-07-01	42	28	51	64	35	57	54	42	46	38	48	17	25	29	64	17	1	5		663
2017-07-02	37	33	49	54	34	58	48	53	41	52	47	25	33	46	69	31	2	4		693
2017-07-03	47	37	31	68	45	60	41	46	57	48	62	21	39	37	75	28	4	2	2	746
2017-07-04	51	35	50	64	41	59	45	48	52	47	46	34	27	42	68	26	3	4		785
2017-07-05	44	35	48	60	45	60	42	47	49	54	46	30	30	36	71	24	3	3		768
2017-07-06	47	37	43	61	39	63	46	44	47	54	44	33	27	28	22	66	33	9	3	759
2017-07-07	43	37	51	61	39	58	54	53	51	45	48	27	31	41	72	33	6	5	2	782
2017-07-08	33	40	44	66	37	51	53	47	38	35	49	27	28	28	65	22	1	4	1	797
2017-07-09	41	37	43	55	37	56	40	47	56	48	43	36	27	31	70	45	9	4		708
2017-07-10	46	36	53	56	48	57	46	43	50	41	51	30	35	40	66	45	6	1	2	757
2017-07-11	46	38	49	59	43	59	47	51	51	46	46	31	25	37	76	25	6	4		786
2017-07-12	40	28	48	60	42	53	64	45	53	45	52	31	33	32	80	23	7	1		775
2017-07-13	49	33	48	62	48	64	45	48	52	54	46	33	27	47	72	25	5	2		775
2017-07-14	40	41	44	60	31	52	60	46	34	67	49	32	32	40	66	42	7	2	1	794
2017-07-15	38	35	40	64	38	55	54	47	48	37	48	23	26	34	58	21	3	2	1	786
2017-07-16	44	33	48	55	35	57	46	40	56	44	55	28	31	43	70	30	7	5	1	712
2017-07-17	46	40	51	59	40	60	48	46	48	51	46	31	30	39	77	36	5	1	3	764
2017-07-18	45	31	43	59	45	62	40	52	51	48	49	38	25	46	71	32	8	2	3	790
2017-07-19	42	35	44	67	28	48	54	47	44	44	49	49	27	31	66	38	14	2	1	782
2017-07-20	50	32	39	60	44	59	52	44	47	52	51	33	25	40	79	35	7	4		771
2017-07-21	41	34	50	68	37	59	54	52	46	46	54	28	37	37	76	30	7	5	1	787
2017-07-22	36	33	49	63	38	63	50	44	47	34	50	23	22	37	53	22	5	3		801
2017-07-23	41	35	43	59	37	58	42	49	50	50	43	30	31	51	76	31	4	4		712
2017-07-24	45	37	42	63	37	56	50	53	45	50	55	33	30	36	77	39	5	1	4	770
2017-07-25	40	37	53	61	38	62	40	53	53	46	42	32	32	40	69	32	7	2	2	794
2017-07-26	44	34	54	56	41	60	44	52	50	43	59	27	29	38	76	36	5	2		778
2017-07-27	49	37	47	58	45	63	42	44	52	53	54	32	28	39	73	31	6	3	2	787
2017-07-28	45	33	46	60	35	58	54	48	57	49	46	33	35	44	71	30	7	2	1	797
2017-07-29	37	34	43	64	37	58	56	46	50	40	43	24	23	34	56	23	1	4		793
2017-07-30	41	37	47	57	37	60	44	41	54	48	49	34	32	38	71	34	8	4		710
2017-07-31	50	37	45	64	46	59	47	35	50	54	53	32	37	32	76	37	5	2	1	770
Total	1340	1089	1436	1887	1222	1804	1502	1453	1525	1463	1523	937	919	1173	2131	989	197	98	31	798
Average	43	35	46	61	39	58	48	47	49	47	49	30	30	38	69	32	6	3	2	

Starts 07-2017.

Green indicates more than daily average landings.

Yellow indicates less than daily average landing.

APPENDIX VI – HOUR CAPACITY AUGUST

ATA	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	Day
2017-08-01	49	57	43	41	46	49	52	35	50	32	32	42	71	35	32	25	8	16	11	773
2017-08-02	46	67	39	41	56	38	60	31	59	26	31	44	71	38	33	24	9	10	16	782
2017-08-03	47	65	44	39	56	38	49	31	53	40	32	48	61	44	34	28	9	18	11	792
2017-08-04	53	66	40	38	65	35	49	36	54	34	31	51	72	41	31	27	8	13	9	790
2017-08-05	50	69	35	39	56	35	46	32	48	26	21	40	67	18	28	21	12	11	14	709
2017-08-06	47	64	32	43	43	38	52	37	57	24	26	52	64	42	30	26	14	18	11	765
2017-08-07	52	69	34	34	58	35	55	35	62	42	30	42	71	48	29	26	11	12	6	795
2017-08-08	51	67	38	39	51	37	49	34	62	28	34	43	58	47	30	27	10	14	11	767
2017-08-09	53	64	40	42	53	36	48	37	56	25	36	45	72	29	35	22	11	9	14	769
2017-08-10	51	70	37	40	50	39	52	38	57	27	27	52	73	34	27	28	13	13	15	790
2017-08-11	50	69	37	42	55	37	54	29	55	42	30	46	69	35	38	22	10	19	9	788
2017-08-12	47	69	36	41	50	30	52	38	54	22	27	44	61	20	23	22	6	14	16	714
2017-08-13	50	62	30	42	47	38	54	35	57	27	33	49	65	38	33	23	14	15	8	761
2017-08-14	46	66	42	44	50	43	53	37	63	26	34	52	71	35	36	25	12	11	6	791
2017-08-15	53	64	40	39	48	38	57	38	55	32	30	47	66	34	38	23	10	15	6	770
2017-08-16	18	18	40	46	54	64	48	40	40	39	36	45	64	47	35	21	9	8	11	716
2017-08-17	48	69	41	41	51	42	48	38	51	38	33	49	65	42	30	27	14	14	9	799
2017-08-18	46	66	42	40	56	42	51	32	55	32	37	48	68	35	35	23	9	19	11	790
2017-08-19	44	67	39	33	68	35	44	39	52	23	19	41	63	13	27	29	9	10	14	715
2017-08-20	45	69	27	43	48	38	47	34	61	28	29	54	66	36	33	28	8	14	11	765
2017-08-21	49	67	32	43	53	39	55	34	59	32	35	45	70	37	35	28	10	12	4	785
2017-08-22	53	68	38	36	57	44	50	37	61	30	29	45	69	35	33	22	11	17	6	778
2017-08-23	55	71	34	38	57	42	50	37	56	27	40	43	68	36	32	23	10	14	9	777
2017-08-24	49	68	39	43	56	34	50	39	55	31	34	50	71	33	30	24	8	15	10	777
2017-08-25	52	68	38	43	51	37	52	32	58	32	37	53	68	33	28	28	11	15	8	785
2017-08-26	50	67	36	42	56	36	45	34	51	29	24	45	59	17	26	18	12	11	9	710
2017-08-27	48	62	39	40	49	42	57	39	59	30	28	53	72	33	28	27	14	10	20	790
2017-08-28	54	67	30	44	51	31	61	29	61	28	33	54	67	45	33	25	13	12	9	793
2017-08-29	55	64	33	40	60	41	51	36	59	24	38	41	71	31	36	27	8	15	11	782
2017-08-30	41	53	42	35	53	32	42	38	60	40	33	55	56	43	37	31	18	13	9	777
2017-08-31	45	67	38	33	65	32	51	34	54	44	22	50	67	41	34	26	19	15	8	786
Total	1497	1999	1155	1244	1669	1197	1584	1095	1734	960	961	1468	2076	1095	989	776	340	422	322	
Average	48	64	37	40	54	39	51	35	56	31	31	47	67	35	32	25	11	14	10	

Landings 08-2017.

Green indicates more than daily average landings.

Yellow indicates less than daily average landing.

APPENDIX VI – HOUR CAPACITY AUGUST

ATD	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	Day
2017-08-01	42	35	44	59	45	49	56	51	46	47	54	31	27	39	72	27	12	2		773
2017-08-02	44	36	48	64	40	56	48	50	47	46	53	29	32	40	77	25	5	4		781
2017-08-03	46	36	45	62	40	56	47	53	46	47	55	31	32	43	72	33	5	3	1	793
2017-08-04	44	35	38	63	37	59	61	51	51	42	56	26	31	41	74	37	6	2		794
2017-08-05	38	33	46	62	41	59	52	44	44	36	47	12	28	33	70	13	5	4	1	708
2017-08-06	39	36	49	56	36	55	42	50	46	54	44	27	37	38	79	27	5	2	1	761
2017-08-07	50	37	51	60	34	60	52	50	46	50	54	30	33	43	73	34	5	1	1	802
2017-08-08	43	36	47	62	44	56	45	46	35	56	50	24	32	40	74	28	8	3		765
2017-08-09	39	40	51	57	34	62	42	52	43	49	44	27	34	43	73	26	5	2		763
2017-08-10	47	39	46	63	47	63	35	45	47	58	45	29	37	45	71	27	6	5		793
2017-08-11	41	35	45	66	37	61	50	53	51	44	54	29	29	44	77	28	6	4	1	792
2017-08-12	34	35	49	58	35	60	49	48	44	42	51	15	28	36	56	20	3	5		711
2017-08-13	38	36	45	59	30	61	46	56	48	49	43	30	33	49	64	28	4	3		758
2017-08-14	48	34	50	57	48	61	45	55	44	43	54	33	30	43	77	27	4	1	3	794
2017-08-15	41	34	43	67	35	56	41	58	55	45	52	35	29	38	64	37	5	3	1	776
2017-08-16	24	25	16	25	50	47	60	66	53	43	47	39	37	38	66	42	3	2		718
2017-08-17	51	34	46	60	37	62	49	50	48	50	52	34	35	34	72	29	6	4	2	793
2017-08-18	42	39	41	64	33	61	52	59	49	41	47	29	31	39	49	54	13	6	1	792
2017-08-19	34	37	46	61	36	62	52	45	50	47	47	18	20	37	52	18	4	3	2	708
2017-08-20	42	35	44	57	33	64	45	44	54	46	54	23	35	47	72	30	4	5	2	774
2017-08-21	53	32	50	57	43	57	45	49	54	41	51	38	33	32	74	32	5	2	2	785
2017-08-22	48	33	53	57	36	60	40	50	59	44	42	35	29	44	67	32	10	3		775
2017-08-23	42	39	51	61	39	62	52	47	47	49	46	38	28	41	75	20	3	3		782
2017-08-24	47	33	46	62	36	59	50	47	49	52	46	37	33	45	74	21	2	4	1	786
2017-08-25	42	36	45	62	40	63	48	51	51	50	43	33	39	41	75	24	6	3		791
2017-08-26	40	34	46	63	38	61	56	44	42	38	50	18	25	36	59	17	2	2	1	706
2017-08-27	39	38	43	57	38	61	43	54	54	42	57	25	32	43	77	40	8	10		794
2017-08-28	41	39	54	57	33	62	46	51	46	52	47	30	37	42	73	33	2	1	3	782
2017-08-29	46	39	48	61	32	62	45	56	50	51	46	37	29	45	72	31	13	3		803
2017-08-30	42	36	40	56	40	55	45	43	30	59	50	37	41	46	64	42	9	1		772
2017-08-31	43	44	54	60	38	65	49	43	52	43	57	29	31	39	77	24	9	3	1	793
Total	1310	1110	1420	1835	1185	1837	1488	1561	1481	1456	1538	908	987	1264	2171	906	183	99	24	
Average	42	36	46	59	38	59	48	50	48	47	50	29	32	41	70	29	6	3	2	

Starts 08-2017.

Green indicates more than daily average landings.

Yellow indicates less than daily average landing.

APPENDIX VII – CAPACITY FORECAST SHEET

Luchtverkeersleiding Nederland
Air Traffic Control The Netherlands

Capacity Forecast Schiphol

APP Supervisor : Daenen, J.K.

Date & Time (LT) : 20-09-2017 14:00

WEDNESDAY 20 SEPTEMBER 11 UTC TILL THURSDAY 21 SEPTEMBER 18 UTC	12	13	14	15	16	17	18	21	00	03	06	09	12	15	18
Visibility < 5km and/or ceiling < 1000 ft(%)	0	0	0	0	0	0	0	10	30	50	50	5	0	0	0
RVR <= 1500m and/or ceiling <= 300 ft(%)	0	0	0	0	0	0	0	0	5	5	5	0	0	0	0
RVR < 550m and/or ceiling < 200 ft(%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RVR < 350m (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Visibility and ceiling	G	G	G	G	G	G	G	G	G	M	M	G	G	G	G
Wind direction (deg)	250	250	240	240	230	220	210	200	200	190	180	190	200	170	140
Windspeed (kt)	9	10	10	10	9	7	7	6	6	6	7	8	11	10	6
Gusts (kt)	14	15	15	15	14	-99	-99	-99	-99	-99	-99	13	16	15	-99
Standard deviation wind direction (deg)	20	15	15	15	25	25	25	25	25	20	15	15	20	15	35
Standard deviation wind speed (kt)	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2
Temperature (°C)	17	17	17	17	16	16	15	13	12	12	11	15	18	19	15
Dewpoint (°C)	10	10	10	11	11	11	11	11	11	11	10	11	12	12	11
Snow (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moderate or heavy snow (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Freezing rain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CB (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thunderstorm (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Shortterm											Longterm			
Visibility and ceiling	Risk VIS blw 5km and/or CEIL blw/at 2000ft: equal marginal VIS.											-			
Wind												-			
Temperature/dewpoint												-			
Precipitation	-											-			
CB in FIR	E-part isol -SHRA, tops FL070/100, mov E 10-15 kt.											-			

ILS degradation:

Runways not available (incl. reason):

18L/36R due to maintenance

Time (UTC)	Planned		Alternative		Taxi Time	Remarks				
	Landing	Take Off	Landing	Take Off						
1140-1300	27	-	24	36L	22	-	24	27	14	depending wind
Capacity	38	-	40	40	30	-	30	35		
1300-1410	18R	18C	24	-	-	-	-	-	14	
Capacity	34	34	37	-	-	-	-	-		
1410-1540	27	-	24	36L	22	-	24	27	14	depending wind
Capacity	38	-	40	40	30	-	30	35		
1540-1820	18R	18C	24	-	-	-	-	-	14	
Capacity	34	34	37	-	-	-	-	-		
1820-2010	18R	-	24	09	27	-	24	36L	14	depending wind
Capacity	38	-	40	40	38	-	40	40		

Meteorological advisor (MAS) will be present:

Date & Time(LT):

No

APPENDIX VIII – REFLECTION

The objective of this thesis is to proof the skills and competences for obtaining the degree Bachelor of Science in Aviation Logistics. For the completion of this thesis a reflection is written based upon experiences and goals which were achieved throughout this research. The competences and skills which are addressed above are set by the faculty Logistics Engineering of Amsterdam University of Applied Sciences as:

The competence and skill to:

- solve an industry issue or problem based on solutions which are in the context of the issue and makes use of the most recent developments in the industry.
- apply relevant industry insight and/or research methods, concepts and theories to solve the issue.
- propose a solution which is in the context of the problem with a visible link between relevant theories and research.
- provide a solution of which the client is satisfied and willing to implement.

For this reflection I will use the STARR-method. STARR stands for Situation, Task, Action, Result and Reflection. The STARR method is used as it is an effective methodology to reflect on your work and experiences during the research (Swaen, 2017). I chose three core activities to reflect on from which I have learned the most.

QUANTITATIVE RESEARCH

The thesis is written according standards set by Amsterdam University of Applied Sciences & Knowledge Development Centre (KDC) Mainport Schiphol. Beforehand the research subject was formulated in a small case and the student had the opportunity to formulate the research. In the research proposal there was determined that quantitative research methods are used. One of the main activities during the research was quantitative analysis.

Situation

During the research I used different quantitative research methods. At first, I began with data analysis in Excel. At last, I used Access to analysed bigger databases. Using these two programs had the main objective which was to determine the deviations during runway changes.

Task

As described before, the main objective was to find deviations or variations within the data during a runway change. To conclude from the datasets, the dataset size needs to be big and raw. As I determined this, I had to filter a lot of data before I could conclude anything. During my study, I did not really learned how to analyse big datasets with programs such as Excel and Access. However, an expert in data analysis, Ferdinand Dijkstra, learned me the basics and do's and don'ts about Access. With Ferdinand's guidance, trial & error and self-study I quickly learned to analyse datasets and thus the key elements to quantitative research methods.

Action

During the writing of the thesis, I gathered all kinds of datasets with different parameters which concluded how the operations were executed throughout the day. As Access is sensitive for errors in queries, I had a lot of discussion moments with Ferdinand and if there was an error I tried to relate back to where it went wrong. The learning of data analysis took longer than expected, as I also had a lot of other research activities going on at the same time.

Result

Via the work method as described under the section "Action", the result was a list of queries leading to one table with the deviations and variations during a runway change. This table is used for the answers

on the sub-questions of this research. The main results came in the last weeks of the writing of the thesis, because at that moment I had the skills and competences to perform data analysis by myself.

Reflection:

At first, I didn't thought that quantitative research methods were complicated. Mainly because I underestimated the amount of raw data which was available. And secondly, I thought that my Excel skills were good enough to perform data analysis. My learning moment was that I should have taken earlier steps in learning how to analyse big datasets. As I really enjoyed generating results with the queries, I could have performed more in depth and other kind of analysis' if I started earlier. Moreover, I learned to analyse big datasets using Access a program which work via SQL principles. For the future I want to learn how to use SQL as it is a powerful program to analyse big datasets.

SCRUM

Each project has a deadline but everyone has their own way to deliver a report within the given time. This was also applicable to me. At first I was a little chaotic in reaching project objectives as I tended to work on different things at the same time. At the end, because of using the Scrum principle, I was able to work structured and effective towards a report. That is why I want to reflect back on how I learned to work in a structured way.

Situation

Each week, on Monday, Tuesday and Thursday, I participated in Scrum meetings. The Scrum meetings have the main objective to work structured, transparent for others and effectively on any given process. To work according the Scrum principles, I had the luxury of the expertise of a Scrum master, namely Alina Zelenevska.

Task

Part of the Scrum meetings were the two-weekly Sprint reviews, which I experienced as a pitch moment where stakeholders determined the progress. During the Sprint review I presented the finished work, and discussed if the results were good enough for the stakeholders. The usage of Scrum and the Sprint really made me aware of what I was doing, and how much work there was left before the upcoming Sprint. The work to-do was written on a scrum-board, a handy tool which provided transparency in my work.

Action

All my to-do's were written on post-its and placed on my scrum-board. Firstly a user-story is determined to state the main objective. Secondly, to-do's are placed upon the board to give an indication of what work is needed to provide the objective at the user-story. The section "doing" (or waiting for response) on the scrum board can only have one post-it, via this method you will only work on one thing at the same time effectively. The last section "done" represents what is finished and can be removed if the stakeholders accept the work during the sprint reviews. In short you have four main activities on the scrum-board:

1. User-story
2. To-do's
3. Doing (and waiting for response)
4. Done

Result

Via the work method as described under the section "Action", the result was effective working throughout the research. For me it was a good working method of which I had never heard before. For the others, interested in my progress, it gave transparency.

Reflection

The usage of Scrum had a positive impact on me, as I now work more organised than before. At first, I was sceptic about using this kind of working method. After all, I am glad that I took the Scrum sessions seriously as it has the advantage that it indicates your working efficiency. I am definitely going to use this approach for the future, and it also provided me with the insight of how unorganised I used to work.

BUSINESS WRITING

The reflection is not writing according to business writing standards, however the entire thesis is writing in business English. For some it might be easy to write via the business standards, but I have some more trouble with writing in vernacular. For me and the reader this will lead to less powerful sentences. As I had weekly reading sessions and a masterclass in writing skills, I want to reflect on how I went from vernacular writing to business writing.

Situation

At the beginning of the thesis I used to write long and excessive sentences. As Frenchez Pietersz reviewed some of our writings, we collectively agreed on a weekly reading session. In this session the KDC students swapped their documents with one another, with the objective to review each other's writing. Moreover, halfway through the thesis we had a writing masterclass. As it was not intended for writing a thesis, it focused on bringing the main story in a powerful way. At the end of the thesis, I experienced better business writing skills.

Task

The usage of business writing in a thesis is very important. As mentioned before, it is important to ensure that the writing is clear and effective for the reader. Also keeping the reader's attention is one of the focus points of business writing.

Action

As I was used to write qualitative researches, with less technical subjects, I found it hard to write in a clear and effective way. I had some conversations with experts who said that a quantitative research should be straight to the point to be effective. Luckily I had the opportunity to work with fellow students, who gave me feedback on my writing skills. With the feedback, I learned some mnemonic for business writing. Also the weekly reading sessions had an impact on my writing skills. Not only the feedback which I got from others, but also the feedback which I could give to others. It learned me to read discerningly and to review my own writing as well. The last action which contributed to improving my business writing was a masterclass in writing skills.

Result

Via the work method as described under the section "Action", the result was effective writing throughout the research. Moreover, I reviewed some parts of my thesis and corrected where necessary. The effective result is a research thesis which is written in business English.

Reflection

In order to write effective and clear, I needed to adjust my writing. Via multiple ways I learned to write clear about some difficult subjects. I tried to make the thesis accessible and readable for everyone, so that anyone who is interested can read the research. For me the guidance of others, and in particular of my fellow students, improved my writing skills. I will use the writing mnemonics and knowledge for further writing of proposal, research plans or research projects.

OVERALL REFLECTION

After the research, I will continue my professional career and this thesis gave me new knowledge and experiences which I am able to apply. The ability to perform quantitative research on a specific process is very valuable in every work field. Moreover, I learned to present my thoughts on the problem and solution in front of a group of experts. I now have more confidence in speaking about a specific subject in front of a big group.

I learned very much during the writing of the thesis. From specific aviation processes and data analysis to structural working and a professional attitude.

Concerning the three core activities on which I reflected on, I have one overall conclusion: working together is the key to success. And this can be related back to LVNL's purpose:

ENABLE AVIATION, TOGETHER

(Samen luchtvaart mogelijk maken)