

Impact analysis on the airside infrastructure of Amsterdam Airport Schiphol

Bottleneck analysis

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Thesis

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Preface

This research report is written as proof of competence for obtaining the Bachelor of Science degree in Aviation Logistics program from the Amsterdam University of Applied Sciences. This bachelor focusses on a wide range of aviation related topics including optimizing processes, airport development, managing logistic chains, airline business and operational decision management. This thesis combines the knowledge obtained during the bachelor degree and applies it to the capacity of the airside infrastructure at Schiphol.

This thesis was part of different research topics commissioned by the Knowledge Development Centre – Centre of Excellence (KDC-CoE). Graduating at the KDC-COE was a unique opportunity to increase my knowledge and follow my interest for airport management/development. The collaboration between Amsterdam Airport Schiphol, LVNL and KLM gave me the opportunity to research the interest off all stakeholders in the airside infrastructure.

In truth, I would like to thank my supervisors Paolo Scala and Frenchez Pietersz for their support and guidance during my graduation. Their ideas, vision and expertise help me achieving more knowledge and supported me in my motivation. The level of success of the project was not achieved without them.

Next to my supervisors, I would like to thank Alina Zelenevska for her efforts in guiding me in combination with the weekly SCRUM meetings. Thanks to her and the SCRUM I was able to structure my research efficiently. During the meetings, she also gave advice how to tackle objectives and achieve the best possible outcomes. Alina also helped me being strait to the point and clear without much details.

Moreover, I would like to express my gratitude to Boudewijn Lievegoed, Coen Vlasblom and Evert Westerveld for the feedback and support during the bi-weekly sprint reviews. With their feedback and guidance the scope of the research was aligned with the goals of the KDC stakeholders.

Furthermore, I would like to thank the employees of the stakeholders who were willing to contribute to my research with the performed interviews. The information gathered during these interviews formed the basis of the research topics of this thesis.

Finally, I would like to thank the other graduate students Bas Broekstra, Martijn Ringelberg, Roel Wouters, Megan Heijke and Marc Eijkens for creating a professional and enjoyable working environment in the office. Together we formed a team which was supporting and helping each other, which contributed to the quality and level of this research.

Gijs Peters

Schiphol, 29-06-2018

Abstract

The airside infrastructure of Amsterdam Airport Schiphol is complex and bring different challenges to ensure the capacity. This research has been conducted to create a better understanding of the different capacity bottlenecks which are influencing the airside infrastructure and stakeholder operations. Interviews with the main stakeholders of the airside infrastructure at Schiphol formed the main research method, in combination with data analysis of the tow movements and visualization of several capacity bottlenecks. The current capacity bottlenecks which are identified by the KLM, AAS and LVNL after conducting the interview were: aircraft stand capacity bottlenecks, space shortage at Schiphol centre, tow-movements, communication & cooperation, continuous flow of traffic and single taxiway Quebec. These airside infrastructure capacity bottlenecks impact the operation at Schiphol and the involved stakeholders, causing delays, increase of workload and last minute changes. To solve the bottlenecks, the stakeholders invest to implement valuable solutions, for example, new buffer positions, more gate capacity or implement new rules. Because the stakeholders at Schiphol's airside infrastructure needs to cooperate, solutions are difficult to design due to the different interest. This is also visible when looking to the infrastructure changes the past ten years, only minor solutions have been implemented on the already existing infrastructure. It is recommended to search for long-term solutions instead of short-term solutions.

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List of Abbreviations

A-CDM	=Airport Collaborative Decision Making
AAS	=Amsterdam Airport Schiphol
AC	=Aircraft
ATC	=Air Traffic Control
AUAS	=Amsterdam University of Applied Sciences
FAA	=Federal Aviation Agency
GA	=General Aviation
GC	=Ground Control
GH	=Ground Handler
IATA	=International Air Transport Association
KDC	=Knowledge & Development Centre
KDC – CoE	=Knowledge & Development Centre – Centre of Excellence
KLM	=Koninklijke Luchtvaart Maatschappij (Royal Dutch airlines)
LVNL	=Luchtverkeersleiding Nederland (Air Traffic Control the Netherlands)
NLR	=Nederlands Lucht- en Ruimtevaart Laboratorium (Dutch Aerospace Center)
RC	=Runway Control
RET	=Rapid Exit Taxiways
RETILS	=Rapid Exit Taxiways Indicator Lighting System

Summary

The current airside infrastructure layout at Schiphol creates different bottlenecks that influence the capacity of the airport. Through the years, the amount of traffic movements at the airside infrastructure increased. The increase of traffic causes that different sections of Schiphol are growing towards their limits and the safety at Schiphol is becoming a major issue (De Onderzoeksraad voor Veiligheid, 2017). Without an inventory study of the current bottlenecks at Schiphol's airside infrastructure, there is a lack of understanding from the stakeholder perspective on the capacity problems at Schiphol.

The results of the research will help to create more awareness of the current problems/bottlenecks at AAS' airside infrastructure. With the identified bottlenecks, the stakeholders will have also an overview of where the problems occur in their perspective. This results in the following main research question:

How do airside infrastructure bottlenecks impact the capacity at Schiphol and the relative stakeholders operation?

The method used during the research is qualitative, which includes in-depth interviews with experts from all the stakeholders, group interviews/discussions and content analysis. During these interviews with the main stakeholders KLM, AAS, LVNL and Ground handlers (e.g. Aviapartner) the experienced bottlenecks, valuable solutions and future perspective were identified. Furthermore, the increase of traffic movements over the past years is analysed, the changes on the airport infrastructure are analysed, a small data analysis on the current tow-movements is performed and some of the identified bottleneck are visualized using Rplot.

Over the last ten years, Amsterdam Airport Schiphol showed an increase of traffic movements of 13,9% with the highest increase in the summer season. This increase of traffic can have a high effect on the operation of all the involved stakeholders at the airside infrastructure when they have not respond correctly on the growth. Looking at airside infrastructure, only minor changes have been introduced, such as extra buffer capacity and gate adjustments.

The current capacity bottlenecks that are identified by the KLM, AAS and LVNL after conducting the interview were: aircraft stand capacity bottlenecks, space shortage at Schiphol centre, tow-movements, communication & cooperation, continuous flow of traffic and single taxiway Quebec. During the interviews, also valuable solutions were identified, such as expansion of the gate and buffer capacity, increase of space at Schiphol centre, double taxiway Quebec, better communication and change of standard procedures.

The research concludes that all the identified airside infrastructure capacity bottlenecks impact the operation at Schiphol and the involved stakeholders. They are causing delays, congested situations, extra planning of schedules, last minute changes and a higher workload for the employees. Because the impact of the bottlenecks are for every stakeholder different, cooperation is hard to achieve and there is little decision making within the cooperation of the stakeholders. Looking at the current/past capacity bottlenecks and solutions applied to solve the bottleneck it became clear that these solutions where short term solutions to solve the capacity bottlenecks. Every solution will cause a new bottleneck at the airside infrastructure and shift the burden. Altogether, the airside infrastructure capacity bottlenecks have impact on the operations of the main stakeholders. Without a leader, the cooperation will not reach an optimal level, which results in non-optimal solutions. This can also affect the capacity when looking at the future growth.

After the conclusion different recommendations are formulated, these recommendations will help the stakeholders to search for solutions that increase the airside capacity and improve the cooperation. The following recommendations are drawn.

- Perform research on the impact of "short-term" solutions on fundamental solutions.
- Research the impact of standard rules and communication on airside capacity.
- Trend analysis on the identified airside capacity bottlenecks with future traffic movements.
- Tow-movement analysis that shows the impact on different operations.

1 Introduction

The current airside infrastructure layout at Schiphol creates different bottlenecks that influence the capacity of the airport. Through the years, the amount of traffic movements at the airside infrastructure increased. In 2017, 496,748 air traffic movements were performed to and from Amsterdam Airport Schiphol, which is an increase of 3.7% relative to 2016. The increase of traffic causes that different sections of Schiphol are growing towards their limits and the safety at Schiphol is becoming a major issue (De Onderzoeksraad voor Veiligheid, 2017). When looking to the average growth for the upcoming years, 1.8% is expected for the airports in the Netherlands. This is lower than the growth of traffic the past years, which is caused by reaching the 500,000 movements limit at Schiphol and the delayed opening of Lelystad Airport.

For Schiphol airport, it is important to meet the expected growth and stay a competitor of the other major airports in Europe. Also for the Dutch economy, it is important that Schiphol stay an attractive, because it is having a large impact.

Looking at the past years, little research has been conducted on the capacity problems at the airside infrastructure of Schiphol. The latest inventory study dates from 2008 and cannot give a clear overview of the current bottlenecks. Which can cause little understanding from the involved stakeholders on the current processes and upcoming changes.

1.1 Problem statement

Without an inventory study of the current bottlenecks at Schiphol's airside infrastructure, there is a lack of understanding from the stakeholder perspective on the capacity problems at Schiphol. Because the previous study, which date from 2008, is outdated, it does not give an overview of the current capacity bottlenecks at the airside infrastructure of Schiphol. This lack of understanding will also negatively influence the relationship between the involved stakeholders. Without this overview and understanding of the capacity problems, the stakeholders are not willing to cooperate in developing solutions for the airside capacity bottlenecks. This makes it more complicated to find solutions that is acceptable for all the involved stakeholders. All this can lead to unwillingness to cooperate, and can causes delays in the development of Schiphol's airside infrastructure. Due to these delays, different congestions are formed. The delays will also cause hinder in the capacity growth of Schiphol airport. (KDC, LVNL, 2008)

1.2 Research Objective

The main objective of this research is to create an overview of the current bottlenecks at the airside infrastructure of AAS. With this overview the understanding of capacity problems is achieved. A better understanding of the current bottlenecks will have improved the cooperation between the main stakeholders, which will help in developing and accepting solutions for the airside infrastructure. The objectives of this research are:

- To identify the current bottlenecks at Schiphol's airside infrastructure;
- To prove/demonstrate the bottlenecks with available data;
- To identify the risk of the bottleneck with a risk matrix, focusing on the frequency and severity;
- To create awareness on the current bottlenecks for all the involved stakeholders;
- To identify solutions/opportunities for the current bottlenecks;
- To prioritize the solutions/opportunities

1.3 Research relevance/significance

The results of the research will help to create more awareness of the current problems/bottlenecks at AAS' airside infrastructure. With the identified bottlenecks the stakeholders will have also an overview of where the problems occur. When all stakeholders are aware of the risks, it will help create a better cooperation between them all. In addition, it will help to accept solutions/opportunities easily.

Without the acceptance of the solutions/opportunities by the main stakeholders, the airport can lose capacity due to the increase of airside traffic. The research of the potential bottlenecks at the airside infrastructure of Schiphol is important for the stakeholders to avoid future situations of congestion. Such congestion can negatively influence the airport attractiveness to airlines and

passengers. The airlines and passengers might choose for the competitors airports (Heathrow, Charles de Gaulle and Frankfurt), which result in a decrease of flights and passengers. This decrease can lead to the loose of Schiphol's position against the competitive airports in Europe. Since Schiphol airport is a crucial actor in the Dutch economy, losing competitiveness will affect also the Dutch national economy. Improving the capacity is beneficial for all involved stakeholders (airport operator, airlines and air traffic operator).

This study will, therefore, be relevant to the stakeholders that operate and control AAS' airside infrastructure.

1.4 Research Questions

The research questions for the thesis "impact analysis on the airside infrastructure of Amsterdam Airport Schiphol" are divided in the main research question (1.4.1), the sub-research question (1.4.2) and the background questions (1.4.3)

1.4.1 Main Research Question

The main objective of this research is to create a better understanding between the main stakeholders of Schiphol's airside infrastructure, which will help to improve the cooperation between the stakeholders. To achieve this the following main research question has been formulated:

"How do airside infrastructure bottlenecks impact the capacity at Schiphol and the relative stakeholders operation?"

1.4.2 Sub-Research Questions

The sub-research questions stated below will help answering the main research question:

1. How did the involved stakeholders respond to the identified capacity bottleneck at AAS in the past?
2. What were the consequences of the response on identified capacity bottlenecks for the operation of the involved stakeholders?
3. What are the current capacity bottlenecks at AAS' airside infrastructure?
4. What potential solution(s) can reduce the impact of the identified bottleneck from stakeholders' perspective?

1.4.3 Background Questions

The background questions stated below will help to find the needed knowledge about the topic to better understand but not answer the main research question:

1. How to identify bottlenecks at the airside infrastructure of an airport?
2. How to evaluate the impact of the bottlenecks to the airport airside capacity?
3. What are the involved stakeholders' interests at AAS' airside infrastructure?
4. What are the main infrastructure solutions that can be applied in order to cope with airside bottlenecks?

1.5 Research scope

This project focuses on creating awareness of the airside infrastructure capacity problems at AAS. The airside infrastructure includes the runways, taxiways and gate/buffer areas. The complexity of the airside infrastructure brings bottlenecks and can create safety issues. These bottlenecks forms the main plot line during the project, together with the main stakeholders at AAS' airside infrastructure.

With the awareness of the stakeholders about these problems, cooperation and agreements between the stakeholders are easily to achieve. To achieve more awareness the following research is in the scope of the project:

- The capacity bottlenecks at AAS' airside infrastructure following from research conducted since 2008;
- Did the capacity bottleneck has been solved, if yes, what changes have been made and what was the impact for the stakeholder;

- The current capacity bottlenecks at AAS' airside infrastructure;
- The connection between the current and past capacity bottlenecks;
- The most feasible solution/recommendations from each stakeholder perspective on high-prioritized capacity bottlenecks;

More in depth research on the solutions is outside the scope of the project. The in depth research on solutions for Schiphol are further investigated in future research.

1.6 Thesis structure

The thesis consist of chapters that form the structure of the research. This paragraph consist an overview of the remaining chapters ant what can be expected in the chapters ahead.

In chapter two, the literature review is found. During this thesis different subject are researched. Some of those have been researched before and external information can be found on the research topic. This can help understand the subject better but can also contribute on the thesis, which makes it important to analyse other studies/reports. Chapter three consist the methodology used during the research. Because the analysis during the research consist of different sections such as analysing tools, databases, interviews or simulations it is useful to setup methods for all the sub-questions. This will help the progress of the analysis and will make the research more structured. Chapter four consist the analysis and research findings for this thesis. With the methodology the analysis will be performed. In this chapter, the answers to different sub-questions are found. Every bottleneck will be described in their own sub-chapter and ends with a conclusion with the research findings. The overall conclusion and discussing follows in chapter five and six. This chapter shows the result for each sub-question. A discussion on some of the findings will be provided to show the differences in operational view of the stakeholders. This will help to understand each other better in the future. In the last chapter (seven), the recommendations are presented. During the research, different bottlenecks will be mentioned, because the analysis of a specific bottleneck is outside the scope of the research those will be mentioned as recommendation for additional research when the bottleneck have a high impact for the operation. In addition, some ideas mentioned by the stakeholders will be presented.

2 Literature Review

Many studies have been performed on the subject of airside capacity. Airside infrastructure has been a field of interest for many researchers, so it is important to review all the different aspects of it. In this chapter will be described the previous research regarding the topic, highlighting the contribution of this thesis in the field of interest. Paragraph one gives a better understanding of the airport growth, paragraph two about the airside infrastructure itself and the different areas. Paragraph three on the bottleneck identification and a conclusion of the reviewed literature in paragraph four.

2.1 Airport Growth

In 2017 a total of 496.748 air traffic movements were made to and from Amsterdam Airport Schiphol, which is an increase of 3.7% relative to 2016 (Amsterdam Airport Schiphol, 2018)). This increase is felt throughout the airport and have large consequences for the operation of Schiphol. The Dutch Safety Board made a report in 2017 about the safety of Schiphol with the growing amount of traffic and showed that different sections of the airside infrastructure are now growing towards their limits (De Onderzoeksraad voor Veiligheid, 2017). They also mentioned that the safety at Schiphol will become a major issue. With the current amount of traffic Schiphol's operation is already complex, but with the increase of traffic movements at the airside infrastructure of Schiphol the complexity will increase even more. The Dutch Safety Board concluded that the growing amount of traffic shows a direct link to the incidents at Schiphol, with the highest growth of incidents at the ground operations such as tow-movements, pushback operation and during taxiing of the aircraft (De Onderzoeksraad voor Veiligheid, 2017). They also conclude that the workload has increased due to the amount of bottlenecks at the airside infrastructure, this leads to deviation of the standard procedures what will lead to unsafe situations.

For the upcoming years, EUROCONTROL made a forecast that shows the expectation for the air traffic movements until 2024. The average growth for the past years was 3.3% for the Netherlands (EUROCONTROL STATFOR Team, 2018). For the upcoming years (2018-2024) EUROCONTROL expect an average growth of 1.8% for the Netherlands. In 2018, the growth will still be 3.3% but a lower growth is expected for the following years. With the current expansions plans of the airports in Europe by the year of 2024, nearly 206.000 flights cannot take place because the airports (departure or arrival) have reached their limits (EUROCONTROL STATFOR Team, 2018). The biggest expansion plan of Schiphol is opening Lelystad airport (EHLE) to accommodate 23.000 flights in 2023. Lelystad airport was planned to open in 2019, but this have already been delayed until 2020 (Ministerie van Infrastructuur en Waterstaat, 2018).

The Ministry of Infrastructure and the Environment, together with the Ministry of Economic Affairs issues that it is essential for the Netherlands and the Dutch business community to uphold their competitive position. A large part of the Dutch economy comes from the export of Dutch companies. Schiphol has a huge influence on the international and European accessibility and helps to ensure that the Netherlands remains an attractive business location for international companies and together with the international air traffic connections Schiphol offers it makes the Netherlands an important economic center (Ministry of Infrastructure and the Environment & Ministry of Infrastructure and the Environment, 2016). For both ministries it is important that the aviation sector will be given enough space to continue to grow in the Netherlands. The ministries state that the demand of air transport will keep growing, especially at Schiphol and want to accommodate this growth.

2.2 Airside Infrastructure

The airside infrastructure consist in different elements, in order to have a smooth running operation these elements need to work perfectly together. When the capacity of one of the elements is reached, it will impact the operation of other elements, for example, when there is no gate available it will cause congestions at the taxiways. When looking to the airside infrastructure the runways, taxiways and gates/aprons form the airside infrastructure (O'Flynn, 2016).

Looking at the runways, it is necessary to have to have visual aids. The visual aids consist of lights, signs and markings on the runway, which is important for the pilot situational awareness. EUROCONTROL says it helps for minimise the runway occupancy time, what will help to increase the runway capacity. Furthermore, the runway capacity can be increased by the use of

Rapid Exit Taxiways (RET) in combination with Rapid Exit Taxiways Indicator Lighting System (RETILS). This RET system should be focusing on the major aircraft operators to decrease the runway occupancy time. EUROCONTROL also suggest that a runway should be equipped with a series of such exits, and positioned with respect to the performance characteristics of the expected traffic mix of the airport (O'Flynn, 2016). Furthermore, EUROCONTROL is implementing RECAT-EU to reduce the safe separation minima between two different aircraft. This re-categorisation will have a positive effect on safety and capacity (EUROCONTROL, 2018).

Next to the runways, the aircraft will use the taxiway to move around on the airport. EUROCONTROL issues that design of the airport should avoid the need to cross a runway to enter the taxiway or another part of the runway. Runway crossings by over an active runway will decrease the runway capacity and can have an effect on the safety of the airport. EUROCONTROL advises perimeter taxiways, which is a taxiway that run around the runway ends. For an airport, the use of holding bays/areas is important to facilitate efficient surface movements. An aircraft will not be stopped on a taxiway but will move to one of the holding areas (O'Flynn, 2016). Furthermore, at the major airports the taxiway network is complex, which can include hot spot, where potential bottlenecks can arise. Therefore, the design of taxiway network is an essential aspect and should be taken into account looking at the future growth.

The gates/aprons also belongs to the airside infrastructure and can bring many capacity problems at an airport. When using a single taxi-lane at the gate it can cause a congestion because no other traffic is able to pass. EUROCONTROL advice all airports to have a parallel taxi-lane, which will allow traffic with a good wingspan to pass the aircraft which is in pushback or waiting on the taxi-lane (O'Flynn, 2016).

2.3 Bottleneck Identification

The current runways, taxiways and gate/buffer area's form the complex airside infrastructure at AAS (LVNL, 2008); this complex infrastructure leads to potential bottlenecks, especially in situation of traffic increase. With the increasing amount of movements at the infrastructure of AAS, bottlenecks will form easily. Some of these bottlenecks exist for a longer period. In table 1 a list with high-prioritized bottlenecks from the past is showed (LVNL, 2007). This list is a good comparison and evaluate the current bottlenecks. To prioritize the bottlenecks LVNL/KDC is using two different methods: Categorize the bottleneck and the frequency/severity of the bottleneck.

Table 1 Bottleneck conclusion LVNL/LDC 2007 ((LVNL, 2007)

Number	Bottlenecks	Solutions needed related to	Notes
K1	Congestions at head of runways	Continuous flow	The bottleneck especially at the head of runway 24, 18L and 09
K2	(Tow) Traffic from Schiphol center to Schiphol east and vice versa	Continuous flow	Bottleneck will occur when using runway 18L/36R
K7	Platform Sierra have a dead end and crosses runway 06/24	Continuous flow	
K9	Gates and buffer locations	Stability	The number of gates and buffer places in the center area is a bottleneck in the event of disruptions
K11	Congestions during de-icing	Stability	Is a bottleneck during a disruption (winter conditions)
K15	Single taxiway Quebec	Continuous flow	Bottleneck will become a bigger problem with more traffic in the future
K19	Congestions at gates	Workability	Non-optimal coordination with the departing aircraft can lead to delays
K23	Increase of workload when using 2+2 runway combination	Workability	Bottleneck will become a bigger problem with more traffic in the future
K25	Increase of workload during de-icing	Flexibility	
K26	Increase of workload during BZO	Flexibility	Bottleneck due to active accompaniment of the aircraft

Categories that LVNL/KDC (LVNL, 2007) uses in their research are: Continuous flow, Stability, workability and flexibility. Continuous flow and stability will cover the hardware of the airport (Infrastructure and machines), workability and flexibility includes the software of the airport (human and procedures).

The continuous flow will be used when a bottleneck occurs due to the hardware of the airport during normal operations. The difference with the category stability is that it focuses on non-normal operations. When the hardware of the airport cannot facilitate the operation during non-normal situations (e.g. adverse weather conditions), the bottleneck is placed in the category stability. (LVNL, 2007)

The workability focuses on the software of the airport infrastructure. This category is used for bottlenecks during a normal situation and focuses on the workload for the employees if this is within the limits, to prevent them from failing. This software (human actions and procedures) is used to optimize all the movements at the airside infrastructure of Schiphol. Flexibility refers to the non-normal situations and how this is handled by the software (e.g. Increase of workload during de-icing) (LVNL, 2007)

To prioritize the bottleneck LVNL/KDC make use of a matrix where they identify the frequency and severity of the bottleneck. The frequencies are measured in three different categories: occasionally, medium and high. Where the severity is measured with: no reduction of capacity, medium reduction of capacity and high reduction of capacity. The two categories will show the impact on the operations in the matrix. An example of the matrix is shown in figure 1. For every identified bottleneck, the LVNL/KDC prioritize it. This was based on experience of operational experts and different reports.

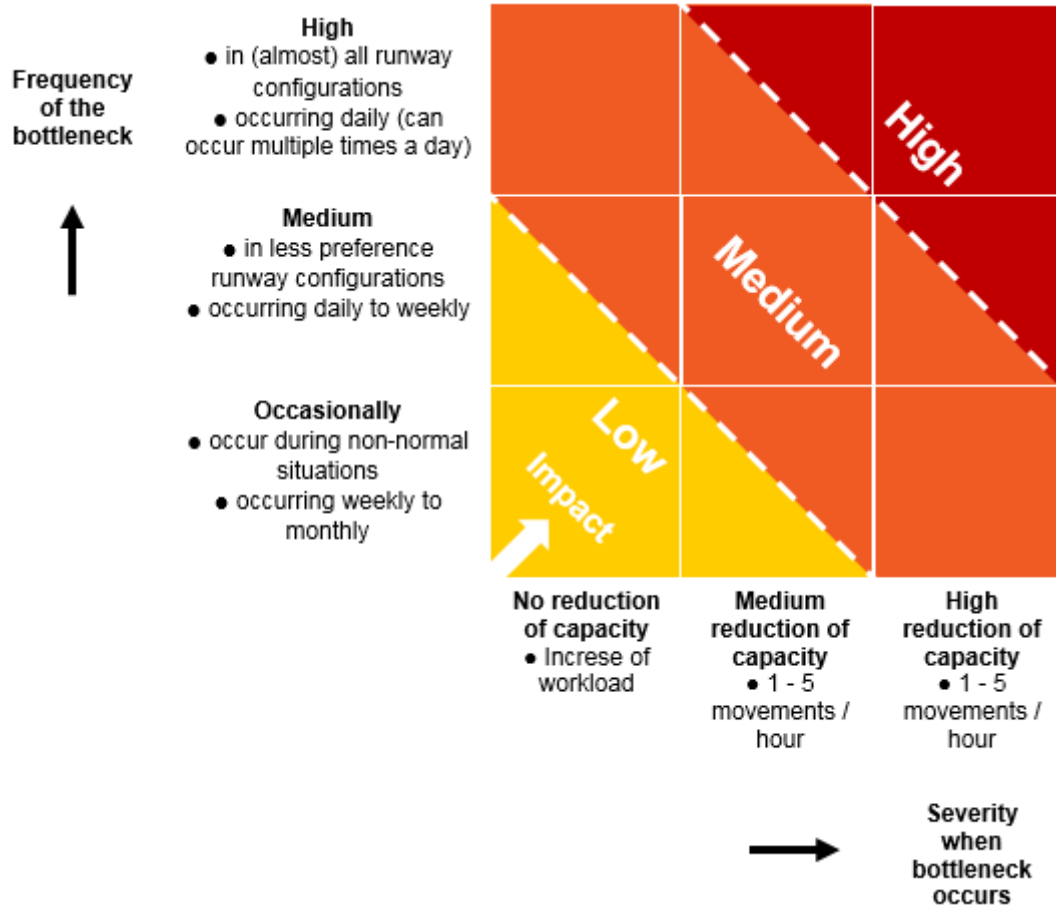


Figure 1 Impact Matrix (LVNL, 2007)

Bottleneck impact on stakeholders

A bottleneck can have consequences for every stakeholder, but the impact can differ for each of them. The NLR and MovingDot researched the impact of bottlenecks during the turnaround (MovingDot, NLR, 2017). The impact on the stakeholders' operations was analysed in different steps. The first step is to get a better understanding of the bottlenecks during the turnaround of the aircraft with interviews of all involved stakeholders. They start with the stakeholders' role and interest in the operations, in this case the turnarounds. Followed by the stakeholders' experienced bottlenecks and the stakeholders' recommendations on solutions (MovingDot, NLR, 2017).

With the interviews MovingDot and NLR did, the roles and interest in the turnarounds at Schiphol airport were defined. This information is used to show the strategic/tactical/ adjustments a stakeholder can take to decrease the effect of the identified bottleneck. It will also show what solutions are associated with the interest of the stakeholder.

Next to the roles and interest, the interviews also focused on the experienced bottlenecks. MovingDot and NLR give an overview of bottlenecks from each stakeholder's perspective. Which is also used to show the strategic/tactical/ adjustments a stakeholder can take to decrease the effect of the identified bottleneck.

Due to the consequences of the bottleneck, MovingDot and NLR also ask the stakeholders to give their view on possible solutions. These solutions have been added in the analysis of the report and included in the recommendation. In paragraph 3.2.3, more literature about bottleneck solutions can be found.

2.4 Conclusion

After reading all the reports used for the literature review for the analysis of the airside infrastructure capacity bottlenecks at Amsterdam Airport Schiphol, the first step that has to be taken is to understand the growth at Schiphol. During this research a timeframe of ten years is used (2008-2018) to understand the changes in air traffic movements the last ten years, but it is

also important to understand the upcoming increase of air traffic. Schiphol is already reaching its limits, but seen from the literature review the air traffic will keep growing the upcoming years. These trends show the need of actions from the involved stakeholders to keep the competitive position Schiphol has today. It is also important to know that the government is willing to cooperate with the stakeholders of Schiphol. They see the role of Schiphol in the economy of the Netherlands and are willing to accommodate in this growth.

The airside infrastructure itself is for every airport in the world different. However, with the help of organisations like EUROCONTROL, ideas are shared to invest in solutions that are beneficial for all the stakeholders. The three main parts of the airport, the runways, taxiways and gates/aprons are always connected with each other. When a bottleneck occurs at one section, it will also be felt at the other two sections.

For the bottleneck identification, it is important to understand the old bottlenecks. These bottlenecks have been identified and can still occur at the airside infrastructure of Amsterdam Airport Schiphol. During previous research, a matrix is used for the prioritization of the previous bottleneck to understand the impact of the bottlenecks better. The categories used were high, medium and low. For the current runway infrastructure it is useful to know if one of the past bottlenecks still occurs and if the impact of the bottleneck became higher than before, and if the bottleneck impact is different for each stakeholder. In addition, it is important to understand why the impact of the bottleneck has become higher.

3 Methodology

The method used during the research is qualitative, which includes in-depth interviews with experts from all the stakeholders, group interviews/discussions and content analysis. During the research, different sub-questions have been formulated to answer the main research question. The first paragraph consist of the research design that include the different sub-research question and the methods used to answer these. Paragraph 3.2 includes the used research instruments, paragraph 3.3 the sample of the used data. Collected data is found in paragraph 3.4 and paragraph 3.5 consist a global overview of how the data is used.

This research consist of different sub-questions, which are used to form sub-chapters in the research design. Here the methods that are used are described to form an answer in chapter 4 (analysis). Furthermore, a better description of the different methods will be given in chapter 3.3 and chapter 3.4 and 3.5 consist the collection of data and way tools used to analyse the data.

3.1 Research Design

This section describe the methodology of the research with the tools that are used divided per sub-question (SQ).

SQ.1. How did the involved stakeholders respond to the identified capacity bottleneck at AAS in the past?

Methods: Desk research (content analysis), interviews.

To find the response on identified bottlenecks of the stakeholder, first, the past bottlenecks need to be determined from previous research in combination with interviews with the involved stakeholders. To determine the past bottlenecks a timeframe for this research has been set from 2007 until 2018, but will also look to the future demand for possible capacity bottlenecks on the airside infrastructure of Schiphol airport.

Research Timeframe selection

The timeframe of the research is essential for answering SQ.1, because of the analysis of past bottlenecks. The airside infrastructure did not change much during the past 10 years, which will form a perfect baseline for the comparison of the old bottlenecks. With a comparison of the two situations (2007 and 2018) the differences of the airside infrastructure is provided and compared with increase of traffic movements. This comparison of the two situations are performed by using the “Schiphol AERODROME CHART” from November 2007 and April 2018. The charts are analyses on the following infrastructure elements:

- Amount of gates (Differences per pier),
- Amount of buffer positions (Location included),
- Amount of holding positions,
- Enlargement of the aircraft stands,
- Driving lines on taxiways and gate areas,
- Airside building changes (enlargements),
- Taxiway changes,
- Runway changes.

Gate/Buffer/Holding positions

To present differences in the amount of gates, buffer positions and holding positions the charts are showed next to each other. Both charts are analysed on the amount of gates, buffers and holding positions. At each pier the amount of gates are counted, and presented in a table with the difference between the 2007 and 2018 situation. The gate area's with the remote aircraft stands (A – Apron and B – Apron) will also be counted and presented in the table with the difference between the two situations. This same method is used to count the buffer- and holding positions. An addition on the analysis with the buffer- and holding positions is that the charts are merged to see if there are any new positions on the field of Schiphol.

The merge of the two situations will also be used to see if enlargements of the aircraft stands have been performed.

Driving lines/Buildings/Taxiways/Runways

The merge of the two charts (stated above) is used to analyse the four remaining topics. This shows the changes with the driving lines within the bays (area between piers), and driving directions. The charts also includes the space of the buildings of AAS, the merge of the charts

will show if AAS has enlarged their existing buildings, build new buildings or removed buildings at Schiphol Airport.

The taxiway and runway changes will show the improvements of the system, such as runway exits, new taxiways, wider taxiways and directions. These elements are showed with the analysis of the two situations.

Schiphol's air traffic movements.

Over the last ten years, (2007-2017) the amount of traffic movements have increased. Knowing this increase will help understand the possible changes that have been made at Schiphol's airside infrastructure. The needed data for the traffic movements is presented by Schiphol in the following documents:

- Statistical Annual Review 2007 (Amsterdam Airport Schiphol, 2008)
- Traffic Review 2017 (Amsterdam Airport Schiphol, 2018)

Data build-up

Both documents present the same table with the amount of traffic movements each month of the year. The movements showed in the table are not including the general aviation at Schiphol airport and have been divided in in the following categories:

- Passenger services (scheduled)
- Full-freighter services (scheduled)
- Subtotal (scheduled)
- Passenger services (non-scheduled)
- Full-freighter services (non-scheduled)
- Subtotal (non-scheduled)
- Total air transport

To complete the dataset three extra categories are added to make a comparison possible. The Total passenger services are calculated for each month (Passenger services scheduled together with non-scheduled), difference total air transport (total air transport 2017 minus 2007) and the difference total passenger services (total passenger services 2017 minus 2007). During the research, these different categories are assigned to a bottleneck that occur at the airside infrastructure of Amsterdam Airport Schiphol.

Past bottlenecks at Amsterdam Airport Schiphol.

For the identification of the past bottlenecks, different reports are used with previous analysis on the airside infrastructure of Schiphol. These reports (mentioned below) are made during the selected timeframe period, which will give a good indication of the problems during the years between 2008 and 2018.

- Verhoging van de grondafhandelingscapaciteit op basis van het huidige banenstelsel (Knowledge & Development Centre, 2008)
- Managing of Turnaround Priorities for Schiphol Airport (NLR & Moving Dot , 2016)
- Overzicht knelpunten LVNL-AAS (LVNL & Amsterdam Airport Schiphol, 2017)

The bottlenecks described in the previous research are categorised using the same method that has been used for the research conducted in 2008.

Bottleneck Categories

It is important to know how high the impact of the past bottlenecks were on the airside infrastructure of Schiphol. To identify the impact of a certain bottlenecks the "Impact Matrix" is used. This matrix described in the "review of literature" will measure the bottleneck with two factors. The "frequency of the bottleneck" will show if the bottleneck occur in (almost) all the runway configurations where the "severity of the bottleneck" indicate if the bottleneck reduce the capacity of movements per hour. The categorised bottlenecks will later be used for the comparison of the past and current bottlenecks.

Reaction of main stakeholders

For the identified bottlenecks, the main stakeholders might have created solutions or processes to deal with the bottleneck. Some of the changes found in the analysis of the airside infrastructure (performed with the charts) are assigned to one of the bottlenecks presented from the previous research. During different interviews that are conducted during the research, reaction of the stakeholders are analysed. To scope the project the focus will lay on the medium and high impact bottlenecks at Schiphol, but the low impact bottlenecks can always be named if necessary from

the stakeholder perspective. In addition, different solutions/actions could have been performed by different stakeholders. The following stakeholders are interviewed, this interview will consist questions about different topics, **the past bottlenecks and solutions/actions**, operational consequences of past bottlenecks, current capacity bottlenecks and valuable solutions for current bottlenecks. The interview list for the main stakeholders is showed below:

- LVNL:
 - Air traffic control / Ground Control
- KLM:
 - Airline
- AAS:
 - Airport
- AviaPartner
 - Ground Handler

Interview Questions

During the interviews different questions are asked, the full interview question list can be found in chapter 3.3. For the reaction on past bottlenecks, different questions have been asked to indicate the bottlenecks, solutions and consequences. For each area (Gate/buffer/remote, Taxiway and Runway) different question are formulated, which are stated below:

1. *How did your company reacted on the airside capacity bottlenecks in the past?*
 - a. *What were the capacity bottleneck that influenced the operation of you company?*
 - b. *How did this reaction/solution performed over the last years? (2008-2017)*

SQ.2. What were the consequences of the response on identified capacity bottlenecks for the operation of the involved stakeholders?

Methods: Desk research (content analysis), surveys/interviews, data analysis.

The responses on the identified capacity bottlenecks can have a high impact on the operation of the involved stakeholders. For each stakeholder the consequence is also different and can have a higher impact on the operation then for another stakeholder. To find the consequences for all the stakeholders' different interviews are conducted, together with a content analysis on previous research.

Increase of traffic movements

Over the past years, the air traffic movements have grown rapidly at Amsterdam Airport Schiphol. SQ.2. is a follow-up question on the SQ.1. and will use some of the same datasets and results following by the analysis of SQ.1. It is important to see if the increase of air traffic also increased the severity of the identified past bottleneck, or see that the solution presented by the stakeholder result in low consequences.

Also, the increase of air traffic movements can result in extra operations. These operations can increase the ground movements at the airside infrastructure. This means that not only the increase of air traffic is causing more movements at the ground infrastructure, but also external operations. Therefore, when a bottleneck is identified it is possible that this is caused by external operations, which increase the ground movements instead of the increase of departing and arriving traffic. It is important to analyse and assign the right increase, air traffic movements or ground movements, to the identified bottleneck. Furthermore, this research will focus on the increase of tow-movements. The tow-movements create extra ground movements and runway crossings that can cause more bottlenecks at the airside infrastructure. Nowadays there is no information how many extra movements this generates and what the other consequences are. To present these details a baseline measurement is performed, which is used in the future to see if the increase of air traffic can be related to the tow movements.

Baseline measurement for tow-movements

To perform a baseline measurement for the tow movements at Amsterdam Airport Schiphol, a dataset is required. This dataset is presented by AAS that control the tow movements at the airport, and an example is found in appendix II. Not all the data in the dataset is required to make the baseline measurement, the data required to fulfil the baseline measurement from the dataset "TowMovements" are:

- ACR_AIRCRAFT_REGISTRATION (aircraft registration)
- START_DATETIME (start time of tow movement)

- END_DATETIME (end time of tow movement)
- GAR_POSITION (aircraft stand after tow)
- GAR_POSITION_PREVIOUS (aircraft stand before tow)
- TRACTOR (used tow truck)
- MINUTEN_DEEL (time of tow in minutes)

Before being able to analyse the dataset need to be extended with different extra data. This data is presented by different companies and institutions. The following data is implemented in the dataset:

1. "AIRLINES", with the aircraft registration the airline is assigned to the right row. The required data comes from a different dataset from AAS. With an "Index Match" function, the data is implemented.
2. "AIRCRAFT", will show the type of aircraft which belongs to the aircraft registration. This data will also be added with the "Index Match" function from the same dataset as used for the "AIRLINES".
3. A new page is created with a classification of all the aircraft stands at Amsterdam Airport Schiphol. These aircraft stand classifications are added for the "GAR_POSITION" and the "GAR_POSITION_PREVIOUS".
4. The page with the aircraft stand classifications will also include the crossing classifications. This will show what crossing type might have been taken by the performed tow movements and directly show what runways have been crossed.
5. For the capacity of the airport, crossing an active runway can have a large impact. To final data that is implemented in the dataset is the active runways at the time of a tow movement.

During the analysis, made for the tow movements, different elements are included. The following elements for the capacity are analysed:

- Amount of movements made monthly/weekly. This is calculated with the date and times in the dataset.
- Amount of movements with a runway crossing, which will also show if the runway was active at the time of the tow.
- Usage of the tow trucks, showing how long the truck was used for tow-movements daily.
- Amount of movements made by airlines, which also differentiate between a movement with and without a crossing

The analysis together with the baseline measurement will provide information to compare in the future what have happened with the movements and all the elements that are included. Also, the analysis should provide information if the tow movements causes other bottlenecks at the airside infrastructure of Amsterdam Airport Schiphol and have the tow movements' consequences for the involved stakeholders in their operation.

Consequences for main stakeholders

Further identification of the consequences for the main stakeholders are researched using interviews and analysing different reports of the stakeholders, which are presented by the main stakeholders. The interview stated at SQ.1. will also include the questions for SQ.2. and are conducted with AAS, LVNL, KLM and AviaPartner. These stakeholders can give their view of the consequences for their company and give examples of the situation on the airside infrastructure of Amsterdam Airport Schiphol.

Interview questions

During the interviews, different questions are asked to find the consequences of the bottleneck and the consequences of the response on the bottleneck. The full question list is found in chapter 3.3.2 the questions for the consequences are stated below:

1. *How does your company handle the identified bottlenecks?*
 - a. *Does the bottleneck influence the operation?*
 - b. *Was your company influenced by responses of other stakeholders on the bottleneck?*
2. *How was the operation influenced due to the "shortage of aircraft stands"?*
*shortage of aircraft stand can be replaced for all the different areas

With the interview and report analysis the consequences for the stakeholders are visible, which can help understanding the cohesion between different bottlenecks and the relation between bottlenecks occurred in the past and the current bottlenecks at Amsterdam Airport Schiphol.

SQ.3. What are the current capacity bottlenecks at AAS' airside infrastructure?

Methods: Desk research, interviews, data analysis.

The current capacity bottleneck at the airside infrastructure are indicated using interviews with the main stakeholders, content analysis, and data analysis. The research will concentrate on the capacity bottlenecks that have a large impact for the stakeholders.

Current capacity bottlenecks

Bottlenecks will always influence the operation of a process and can have a high impact on the stakeholder. That is why it is urgent to understand what bottlenecks are currently occurring on the airside infrastructure of Schiphol. The main stakeholders KLM, LVNL, and AAS came together and discussed about the bottlenecks and summarized them in an overview which is used to compare the outcomes of the interviews with what is being said in the overview.

Interview questions

During the interviews, questions are asked which to indicate the current bottlenecks at Schiphol. The severity of the bottlenecks can differ for each stakeholder, which is important to know. The questions that are asked will include the gate/buffer areas, taxiways and runways. Some of the questions are asked three times to indicate the bottlenecks at all the stated areas. The following questions are asked to indicate the bottlenecks:

1. *What are the current capacity bottlenecks at the gate/buffer areas?*
 - a. *How does your company categorise the capacity bottleneck?*
 - b. *Do the bottleneck shift to another place when there is a change in runway configuration?*
2. *Did the bottleneck occurred in the past also? If yes, what is the reason that this bottleneck is not solved yet?*

Question no. 1 can be assigned to all the infrastructure areas within the scope of the research. It will only change the last part of the question (gate/buffer area).

Indication of bottlenecks with data

During the desk research for the capacity bottlenecks data will also be used to indicate problem areas. LVNL will provide Rplot, a tool that show the ground movements made on the airside infrastructure of Amsterdam Airport Schiphol. The visualization of the ground movements will concentrate on the movements made on the taxiways and gate/buffer areas. This will help showing the hotspot positions on the airside infrastructure of Schiphol, it will also show what the consequences are when a bottleneck occur. In chapter 3.3, the description of the tool has been provided.

Comparison of past and current bottlenecks

With the identified current bottlenecks it is important to know if the bottleneck is new at Amsterdam Airport Schiphol, or that the bottleneck already existed. If the current bottleneck already existed, it is important to know the different conditions of the bottleneck, and see if there has been done anything to react on the bottleneck in the past. The following element are included in the analysis of the past and current bottleneck:

- Location of the bottlenecks.
- The different element during the bottleneck (e.g. amount of movements).
- Solution on the past bottleneck.
- Connection between different bottlenecks.
- Effect of changes in airside infrastructure on the indicated bottlenecks.

New capacity bottlenecks

Some of the indicated bottlenecks are new at Amsterdam Airport Schiphol. For the new bottlenecks the same analysis are used, excluding the comparison of the past and current bottlenecks.

SQ.4. What valuable solution(s) could reduce the impact of the identified bottleneck from stakeholders perspective?

Methods: Desk research, interviews.

To solve a bottleneck at the airside infrastructure, a solution can help to solve the problem. For an airport it is challenging to find a solution that is interested for the involved stakeholders because of the different operations. This can lead to misunderstandings, friction between the stakeholders and a low cooperation between the stakeholders. By presenting the ideas of valuable solutions from each stakeholders perspective, a comparison between the solutions can lead to a better cooperation between the involved stakeholders.

Valuable solutions

Finding a valuable solution for the identified bottlenecks is achieved by conducting interviews with the main stakeholders of Amsterdam Airport Schiphol, and by conducting analysis on previous research, which can give an indication what could be a valuable solution for the identified bottleneck. Outside the scope of this research is if the indicated valuable solutions is helpful for the bottleneck. The solutions are a recommendation for further research on the mentioned topics.

Content analysis

The reports that are used for the analysis on the valuable solutions are also used for finding the past bottlenecks (mentioned at SQ.1.). These reports consist of an analysis of the bottlenecks in 2007 and valuable solutions that could help solve the problems. When SQ.3. conclude that some of the bottlenecks already existed, the old solutions can help to solve the problems for the current bottleneck. For the current bottleneck without a history at the airside infrastructure of Schiphol it is useful to see if there are any similarities that can lead to a valuable solution mentioned in the previous research. Below the reports is found:

- Verhoging van de grondafhandelingscapaciteit op basis van het huidige banenstelsel (Knowledge & Development Centre, 2008)
- Managing of Turnaround Priorities for Schiphol Airport (NLR & Moving Dot , 2016)
- Overzicht knelpunten LVNL-AAS (LVNL & Amsterdam Airport Schiphol, 2017)

Interview questions

During the interviews different questions are asked to find the ideas on valuable solutions from stakeholder perspective. For the other stakeholders it is important to know what the ideas are at the other stakeholders and see if they can agree in situations and solutions for the airside infrastructure at Schiphol. The questions asked to identify the valuable solutions from stakeholder perspective are stated below:

1. *What can be a valuable solutions for the identified bottlenecks at the airside infrastructure of Schiphol?*
 - a. *Do you think this is also valuable for the other stakeholders? Why?*
 - b. *How will this solution change the operation of your company?*

Location indication

If a solution include a change in the infrastructure of Amsterdam Airport Schiphol, it is important to show the location of the solution. These indications can help to create a better view of how and where the valuable solution should help decreasing the impact of the identified bottlenecks. For this location indication the charts of Schiphol's airside infrastructure from April 2018 is used.

3.2 Research instruments

During the research four main research instruments are used for researching the airside infrastructure capacity bottlenecks at Amsterdam Airport Schiphol. The first instrument that follows from the research time frame is the chart comparison. Next to the chart comparison different interviews are being performed, numerical data is used and visual simulations are used. There instruments will indicate the bottlenecks with the largest impact for the main stakeholders and the valuable solutions to cope with the identified bottlenecks.

3.2.1 Chart comparison

As mentioned, this research is using a timeframe of ten years (2008-2018) and used to understand the changes that have been made at the airside infrastructure of Amsterdam Airport Schiphol. In chapter 3.1 "SQ.1.", the chart comparison have been mentioned, with the expected outcome of the comparison between 2008 and 2018. For this comparison the following charts are used to show the airside infrastructure changes at Schiphol (AIS the Netherlands, 2018):
November 2007:

1. AM-ADC-A2 (Full airport map)
2. AM-APDC-1-A2s (Parking positions Schiphol centrum and Schiphol Rijk)
3. AM-APDC-2-A3m (Parking positions Schiphol East)
4. AM-GMC-A2s (Ground Movement Chart)

April 2018:

1. EH-AD-2.EHAM-ADC-A2s (Full airport map)
2. EH-AD-2.EHAM-APDC-1-A2s (Parking positions Schiphol centrum and Schiphol Rijk)
3. EH-AD-2.EHAM-APDC-2 (Parking position Schiphol East K-apron)
4. EH-AD-2.EHAM-APDC-3 (Parking position Schiphol East M-apron)
5. EH-AD-2.EHAM-APDC-4 (Parking position Schiphol East U-apron)
6. EH-AD-2.EHAM-GMC-A2s (Ground Movement Chart)

In appendix V to XIV all the charts mentioned above are found in the same order as showed in the list.

3.2.2 Interviews

To find the current bottlenecks at the airside infrastructure of Schiphol, interviews are conducted. The main stakeholders at Schiphol's airside infrastructure are KLM, LVNL and AAS. At these stakeholders a minimum of two employees are interviewed. During the research the aim is to also conduct an interview with one or more of the ground handlers at Schiphol, to understand the impact of bottlenecks at their operation.

The interview questions have been structured to correspond with the different areas of the airside infrastructure to create a better overview, and for all the different areas the same questions can be applied. The areas used for the research are the gate/buffer areas, taxiways and runways. The questions that will be asked are as follows:

1. *What are the current capacity bottlenecks at the airside infrastructure of Schiphol?*
 - a. *How was the operation influenced by this bottleneck?*
2. *Did one of the mentioned bottlenecks also occur in the past? If yes, what is the reason that this bottleneck is not solved yet?*
3. *How did your company respond to the bottlenecks at the airside infrastructure of Schiphol?*
4. *What are valuable solutions for the bottlenecks mentioned earlier?*

3.2.3 Numerical data

Solutions for the current bottlenecks can be in conflict with the optimal processes of the airside infrastructure at Amsterdam Airport Schiphol. During the first meeting AAS asked to research the tow-movements more closely, which have been formed into a baseline measurement. This measurement will use different datasets to form a datasheet with the needed information to perform an analysis. In chapter 3.1 "SQ.2. Increase of traffic movements" the baseline measurement is mentioned.

The numerical data used for the research contained the tow-movements during July and August 2017. This was the summer season at Amsterdam Airport Schiphol according to IATA (IATA, 2018), which was between 26th of March to 29th of October. The data is presented by AAS and is combined with different data sources stated in chapter 3.1, this chapter includes also the data that has been used and the way it has been processed. A sample of the data is found in appendix II.

3.2.4 Visual simulations

Rplot is a visual tool, which helps in visualising the different bottlenecks at the airside infrastructure of Schiphol. The visualization can help to better understand the capacity bottlenecks. To find a bottleneck a visual analysis is performed on different moments at a selected day (use of peak moments).

3.3 Sample

As described in 3.3 the summer of 2017 has been chosen as period to analyse. This period will include a higher amount of movement on the ground. At Amsterdam Airport Schiphol July and August are the busiest months (Amsterdam Airport Schiphol, 2018), which falls in the "aviation summer season" according to IATA, this is why these two months have been selected

for the analysis. For the research data from 2017 have been chosen because this is the most comparable year with the current situation.

The interviews are kept with at least two employees of each main stakeholder. Next to the main stakeholders a ground handler is asked to share their experiences on the airside infrastructure of Schiphol.

3.4 Data Collection

During this research different data is collected to conduct the research. This data is mostly from the KDC Mainport stakeholders which is easier to collect and analyse because of the knowledge at the stakeholders' employees. To give the stakeholders a good understanding why the data is requested a meeting is scheduled to show how the data is processed and why this is important for this research. For some sensitive data, the stakeholders do not agree on sharing it, providing other type of data, less sensitive instead. In addition, some data is required from external institutions. All the data that is used will come from the following companies:

- Knowledge & Development Centre (Reports)
- Air Traffic Control the Netherlands (Reports, Rplot, Lynx)
- Amsterdam Airport Schiphol (Reports, Dataset)
- IATA (Dataset)

For the data analysis and the interviews it is important follows the ethical considerations before, during and after the research. For the interviews in the report only the function and kind of company is mentioned (Types of companies: airline, airport, air traffic control, etc.)

3.5 Data Analysis

For analysis of the data and presenting results many tools are available nowadays. For the analysis of the data from Schiphol, IATA and LVNL Microsoft Excel Spreadsheets are used. All the data is gathered in on datasheet and filters are applied to analyse what data is reliable for the research. It is important to filter the data in order to consider only data useful for the analysis. After finishing the data analysis another tool is used for displaying the results on a clear way. The tool that is used during this research is Spotfire. This tool is used for data visualization, and is also used by KLM for displaying different data for better decision making. Spotfire can use the datasheet created in excel and provide more options to easily change or filter the data in to charts, tables, etc. (TIBC Spotfire, 2018).

4 Analysis & Research Findings

To answer the main research question the analysis will show how the research has been conducted. The sub-chapters in the analysis part will provide answers on the sub-questions, which are stated below:

1. *How did the involved stakeholders respond to the identified capacity bottleneck at AAS in the past?*
2. *What were the solutions applied previously for the identified capacity bottlenecks and were they effective?*
3. *What are the current capacity bottlenecks at AAS' airside infrastructure?*
4. *What potential solution(s) can reduce the impact of the identified bottleneck from stakeholders perspective?*

Because the research uses a timeframe period of ten years (2008 – 2018) the changes in air traffic movements will be analysed (4.1) and chapter 4.2 will show the changes in the airside infrastructure. Furthermore chapter 4.3 contains the past capacity bottlenecks at the airside infrastructure of Schiphol where 4.4 show the current bottleneck. Every sub-chapter will include a conclusion that will show the research findings per part and give a short summary of the analysed parts. The analysis is conducted on different data collected at one of the main stakeholders of the airside infrastructure of Amsterdam Airport Schiphol.

4.1 Air traffic movements

As mentioned, this research is using a timeframe from 2008 until 2018. To understand the different situation on the airside infrastructure it is important to know what has happened the last ten years. Over the past ten years the amount of air traffic movements showed a high increase. In chapter 4.1.1 the yearly traffic movements have been analysed from 2007 until 2017 and a comparison have been made between the monthly movements in 2007 and 2017.

4.1.1 Yearly/Monthly increase of movements

To analyse the yearly movements the data of the traffic movements from 2007 until 2017 will be used. Schiphol, as mentioned in chapter 3.1 presents this data used for the analysis. In this chapter only the monthly analysis have been included in the research, however the yearly increase of movements can also show the trend the aviation market have been through and help to understand the choices made by the stakeholders. In appendix III the table is showed with the yearly movements since 2007. In the data a distinction have been made between the amount of traffic movements with general aviation (GA) and without. Over the past ten years the average difference between with and without GA was 16.258 movements, where in 2007 the difference was 18.388 movements and in 2017 17.877 (Royal Schiphol Group, 2018).

In 2008, an agreement was set that Schiphol will not be able to exceed 500.000 flight before 2020. This agreement included a growth of air traffic at Eindhoven (25.000 movements) and Lelystad (45.000 movements) (KLM - Royal Dutch Airlines, 2017). When looking at the movements at Schiphol in 2017 of 496.748 movements without GA, Schiphol is already close to the limitation set by the agreement. In the table also the growth in percentages is showed. As discussed in the literature review, EUROCONTROL expect an average growth of 1,8% in air traffic movements for the Netherlands, and with the postponement of the opening of Lelystad Airport, Schiphol will reach the limit of 500.000 flight in 2018. Already with the current amount of movements Schiphol's airside infrastructure is reaching its limits at different locations, which are showed in chapter 4.4. The air traffic movement without the GA are taken in to account for the analysis of this research.

In appendix IV, the monthly differences are showed in the table "Monthly differences 2007-2017". For the infrastructure developments/changes it is interesting to see how the air traffic movements have developed monthly over the past years. The dataset that is used is build up as it was mentioned in methodology, chapter 3.1. The movement data that is showed also excludes the general aviation, which is not taken into account for the 500.000 movements mentioned in the agreement. When analysing the months it is clearly visible that the summer period shows the highest increase of traffic movements. In table 2 the dates of the IATA winter and summer season are showed. When analysing the two seasons it becomes visible that the summer season shows a higher increase of air traffic movements. Where the summer season shows an average growth of 15.9% (6,151 movements average) the winter season shows a growth of 10.7% (3,543 movements average).

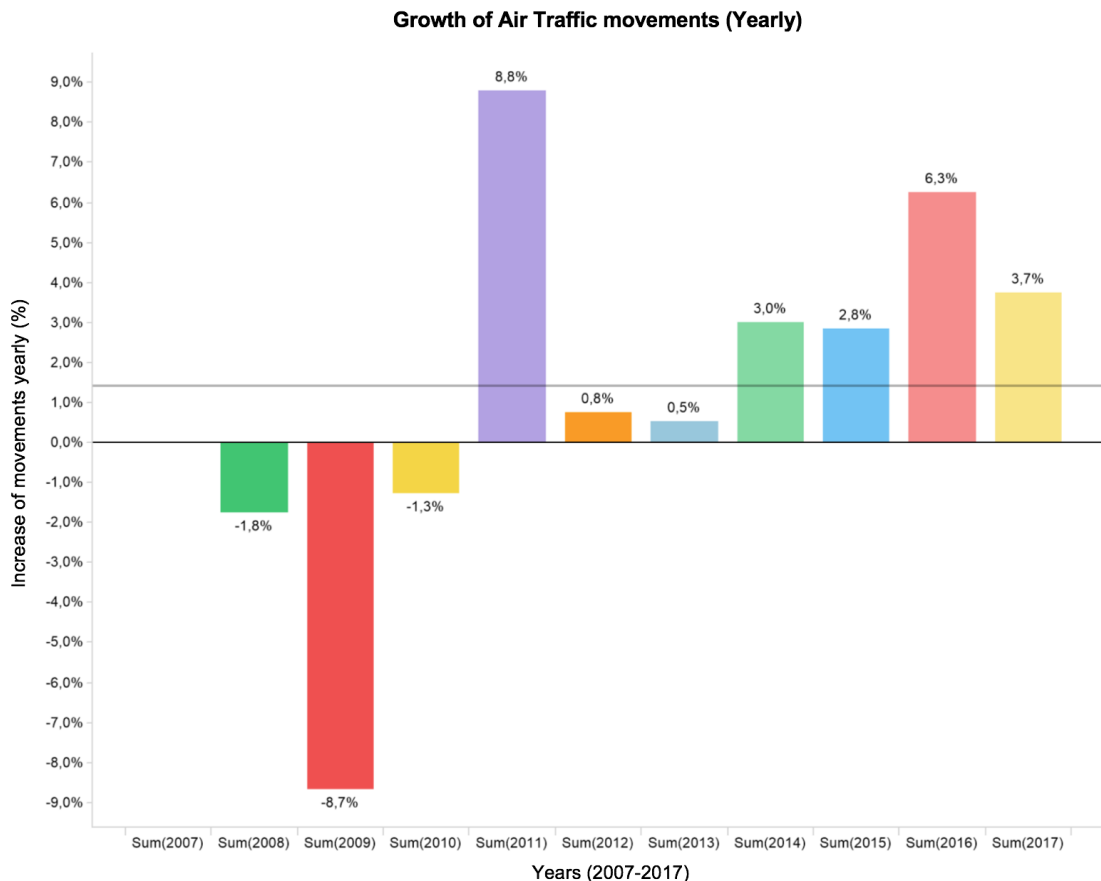
Table 2 – CALENDAR OF COORDINATION ACTIVITIES – IATA (IATA, 2016)

Activity	Typical Dates	Winter 06/07	Summer 07	Winter 07/08	Summer 08
Start of season	Last Sunday in March (Summer) &	29-Oct-06	25-Mar-07	28-Oct-07	30-Mar-07
	last Sunday in October (Winter)				
Activity	Typical Dates	Winter 16/17	Summer 17	Winter 17/18	Summer 18
Start of season	Last Sunday in March (Summer) &	30-oct-16	26-Mar-17	29-Oct-17	25-Mar-18
	last Sunday in October (Winter)				

As mentioned before, the summer season shows the highest increase of traffic movements. When dividing these total extra flights in the summer season by the amount of days during this season, an average of 201 extra traffic movements are performed daily in the summer season in comparison with the summer season of 2007. In August, the highest increase is visible of 217 extra daily movements, and in the lowest increase of 89 extra daily movements in February 2017.

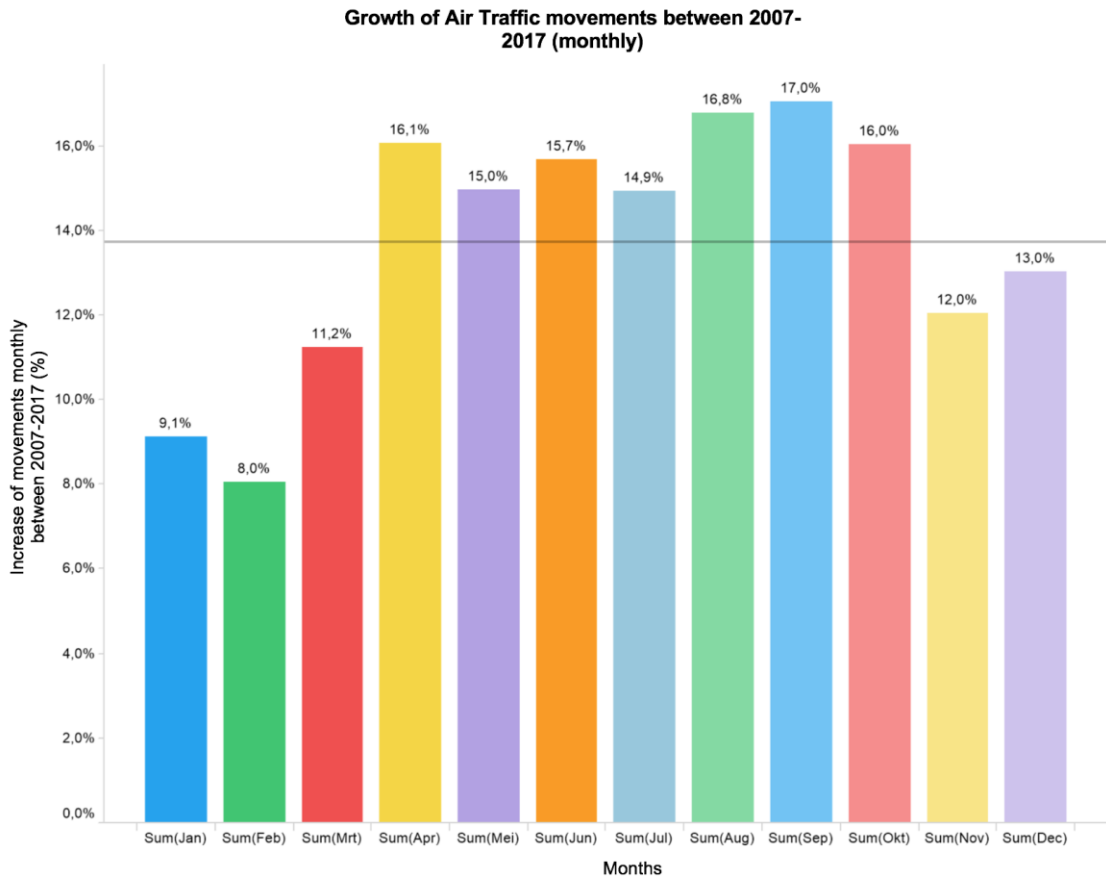
4.1.2 Conclusion

Over the last ten years Amsterdam Airport Schiphol showed an increase of traffic movements of 13.9% with the highest increase in the summer season. This increase of traffic can have a high effect on the operation of all the involved stakeholders at the airside infrastructure when they have not respond correctly on the growth. The comparison of the airside infrastructure situations in 2007 and 2018 will provide information on what have been done by the airside infrastructure to cope with the high increase of ground movements. Looking at graph 1 the increase of the air traffic movements are showed. The first three years showed a decrease in air traffic, which can be related to the financial crisis. After this, a high increase is showed with an average of 1.3% yearly.



Graph 1 – Growth of traffic movements yearly at Amsterdam Airport Schiphol

As mentioned, the differences between the months in 2007 and 2017 are analysed. In graph 2, the increase percentages are showed, with an average growth of 13.9% over the whole year. In the graph it is visible that the highest growth is reached in the summer season.



Graph 2 – growth of traffic movements monthly since 2007 at Amsterdam Airport Schiphol

4.2 Airside infrastructure changes

The increase of air traffic movements described in chapter 4.1 have impact on the ground movements at the airside infrastructure. The airside infrastructure is designed for a certain amount of ground movements, and needs updates, expansions or system upgrades to cope with the increase of ground movements. Looking at the timeframe period of eleven years, a comparison is made to show the differences between the infrastructure in 2007 and 2018. In chapter 3.1 (SQ.1) the methodology is described and the areas that are analysed are showed. In chapter 4.2.1 and 4.2.2, the airside infrastructure situations are described and will provide information of the aircraft stands (gates, buffers and holding positions), the taxiways, the runways and buildings. The conclusion (4.2.3) will be a comparison of the two situations, and changes that have been made on the airside infrastructure of Schiphol.

4.2.1 Situation 12-2007

The airside infrastructure at Amsterdam Airport Schiphol is based on the runway layout. The runway layout has five main runways plus a limited use of the sixth runway 04-22. Looking at the history, the base of Schiphol is formed by the runways around Schiphol Centre (18C-36C, 18L-36R, 09-27 and 06-24). The 18R-36L is north-west of Schiphol Centre, which takes more time to reach, but is preferably used. In appendix V (AM-ADC-A2s) the map of the airside infrastructure in 2007 is showed, which also includes a map of all the runways, with the overview of runway exits and runway characteristics.

Table 3 – Aircraft stands 2007

2007	Apron	Amount
Gates	B	50
	C	13
	D	34
	E	14
	F	8
	G	8
	H	7
Buffer	D	6
	E	3
	J	8
	Y	3
	M	7
	U	0
De-Icing	P	5
Full Freigl	R	11
	S	17
Holding	P	3
	Total:	197

Other things that are noticeable after looking at the graphs are the taxi-lanes within the bays and the standard driving directions. Looking at the different bays, it is visible that some bays make use of a parallel taxi-line. This helps to create a better traffic flow and decrease the change of congestion situations. Exceptions of a double taxi-line are the A-apron together with the taxi-lines in between F- and G-pier and at the G/H-pier.

Looking at the driving directions, the standard for taxiway Alfa is clockwise, where bravo is counter clockwise. Within some bays (between C - D, D - E and E - F piers) a driving directions have been assigned which helps the continues flow of traffic.

4.2.2 Situation 04-2018

Looking at current airside infrastructure situation at Schiphol, the layout is still the same. The runway layout consists of the same structure as mentioned in chapter 4.2.1, with five main runways plus a limited use of the sixth runway 04-22. This also applies for the taxiway system at Schiphol centre, the only big infrastructure change is the extra connection to the cargo platforms at Schiphol-Rijk. A connection from the head of runway 06-24 is created. This will decrease of runway crossings and create faster movements. In appendix IX (EH-AD-2.EHAM-ADC-A2s) the whole layout of Schiphol is showed.

Looking at the terminal, several new buildings are created at Schiphol centre. Within the bay at the D-pier a small extension is built, a new temporary terminal is built between the B and C-pier and currently Schiphol is constructing the new A-pier, located in the south of Schiphol centre, showed in appendix X (EH-AD-2.EHAM-APDC-1-A2s). This chart (appendix X), also gives a detailed overview in the changes of the Gates, buffer positions and holding positions. In table 4 the overview of showed of the amount of gates, buffer, etc. In 2018, 129 aircraft stands are used for the handling of commercial aviation, where 32 of these stands are located at the A-apron. Furthermore, the table shows an increase of buffer positions, with a new area created at the M-apron and U-apron. At the M-apron, it is an expansion of the already existing area, where the “U” stands are new as buffer for the increasing traffic at Schiphol. In appendix XII the new M-apron is visible and appendix XIII shows the chart of the U-apron.

Table 4 – Aircraft stands 2018

2018	Apron	Amount
Gates	B	45
	C	14
	D	33
	E	14
	F	8
	G	8
	H	7
Buffer	D	6
	E	3
	J	8
	Y	3
	M	21
	U	5
De-icing	P	7
Full Freigh	R	10
	S	11
Holding	P	5
	Total:	208

4.2.3 Conclusion

Looking at both situations, no major differences are visible, but only minor changes are made. The minor changes are the increase of space at some of the gates, the expansion of buffer locations and new buffer locations. Looking at both tables the highest increase is at the buffer locations from 27 in 2007 to 46 in 2018.

4.3 Past airside infrastructure capacity bottlenecks

The past bottlenecks are important to understand, and can be related to the changes at the airside infrastructure of Amsterdam Airport Schiphol. In the past, several different researches were conducted to determine the bottlenecks at that moment. The analysis of the airside infrastructure is consistent with the timeframe chosen and described in the methodology (chapter 3.1). Furthermore, this chapter will focus on the bottlenecks/congestions with a medium or high impact, which is awarded with the impact matrix showed in chapter 2.3. Moreover, the stakeholders' opinion is included based on the interviews that have been conducted.

4.3.1 Congested situations at start of runway

When a runway is used for the departing aircraft (AC) congestions at the start of the runway occurred. This happens when the supply of departing AC is higher than the capacity of the runway or that a waiting AC is not ready for departure and consequently, the AC behind will wait. When the intersections at the runway are full, the AC might have to wait at taxiway Alfa or Bravo. This happens at runway 24, 36C, 18L and 09.

4.3.2 (Tow) traffic from Schiphol centre to east (vice versa)

Traffic from Schiphol centre to Schiphol-East and vice versa will cross runway 18L/38R and 04/22. While runway 04/22 is not used frequently, 18L/36R is one of the main runways being used by Schiphol. A runway crossing will cause a decrease in the runway capacity, and therefor will be a potential bottleneck. When the tow traffic needs to wait for a runway crossing it also can cause a congestion situation on the taxiway when blocking the runway entrance. For the GC and RC of the ATC this will also increase the workload. Other traffic that needs to cross the runway can also be delayed, and can cause delays elsewhere in the system.

4.3.3 Congestions at the gates

The departing traffic at Schiphol shows high deviation on the initial planning as result of a non-optimal coordination. This occurs due to the fact that there are no pushback trucks available or that the pilot already asked for a pushback when they are not ready yet. All this leads to delays that can affect the arriving AC. The arriving AC have to wait, mostly on the taxiway, and result in congestions and more delays.

4.3.4 Single Taxiway Quebec

The congestions at taxiway Quebec occurs when runway 36C and 36L are in use for the departures at Schiphol. The traffic towards 36L will pass the runway at the south of runway 36C, at junction A27 traffic from taxiway Bravo and Quebec needs to be sequenced which can cause congestions at both taxiways (figure 3). But also waiting AC for their take-off at runway 36C are causing congestions.



Figure 3 – Sequencing of traffic Quebec & Bravo taxiways

4.3.5 Gates and Buffer locations

During normal and especially non-normal operations there is not enough gate or buffer capacity to give the AC a location. Due to the growth of Schiphol airport, buffer places are replaced for more gate capacity. The lack of gate capacity can lead to congestions at the taxiways and delays in the schedule of Schiphol.

4.3.6 Congestions during de-icing

During the de-icing operations, there are three positions available near Schiphol Centre (shown in figure 4). Due to the demand of traffic the de-icing operations leads to congestions at the taxiways Alfa because of the limited available space. Due to this, it can lead to delays for the departing and arriving aircrafts. The de-icing positions at this location will also take away the holding positions at Schiphol centre.

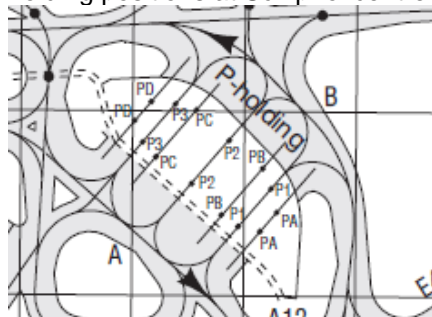


Figure 4 – Three de-icing positions

4.3.7 Congestions taxiway Alfa due to push-back

Some of the gates are located at the end of the piers at Schiphol (C and F-pier), and during a pushback the AC is pushed to the taxiway Alfa. After the pushback, an AC needs time before it

starts to drive. The time the AC is standing on the taxiway, it can form a congestion for other traffic.

4.3.8 Smaller bottlenecks

In the next chapter, the current infrastructure capacity bottlenecks are mentioned. For the conclusion and recommendations, it is helpful to see if old bottlenecks still occurs or have become bigger. The following list with low impact airside infrastructure bottlenecks is used for the cohesion between old and current capacity bottlenecks, to link them to current capacity bottlenecks:

- Different officials are active in the manoeuvring area (miscommunication).
- Congestions due to non-uniform taxi driving speed.
- Restrictions due to the wingspan of new AC.
- More traffic for runway 04/22

4.4 Current infrastructure capacity bottlenecks

The current capacity bottlenecks at the airside infrastructure will give the stakeholders a good overview and understanding of what are the main airside area where to focus for improving the aircraft flow and avoid congestion. This awareness will contribute to the cooperation between the stakeholders and create more transparency of what the stakeholders are experiencing when a bottleneck occurs. To determine the bottlenecks that are influencing the capacity, different interviews are conducted to all the involved stakeholders. The interviews can be found in appendix XV to XVIII and are divided per stakeholder.

In this chapter the current bottleneck are described and the opinion of the stakeholder is included. During the interview the stakeholders where ask for the most valuable solutions for the identified bottlenecks. In addition, the description will analyse if the bottleneck was already identified in the past.

4.4.1 Aircraft stands bottlenecks

One of the main capacity problems is the shortage of aircraft stands at Schiphol. The aircraft stands are divided in gate positions (passenger handling), buffer positions (storage position for AC with long turnaround) and holding positions (positions for arriving AC which need to wait for a gate, without causing a congestion at the taxiway). This shortages also results in different other bottlenecks, for example congestions on taxiway due to an AC which is waiting for a gate. This is related to the aircraft stand bottleneck. Looking at chapter 4.2.2 the current stands are described, without the general aviation. In 2018, there are 208 stands available, including 129 gate positions, 46 buffer positions, 7 de-icing positions (used as buffer positions in summer season), 21 positions for the cargo AC and 5 holding positions.

Gate capacity

As mentioned in chapter 4.1, Schiphol have showed a high growth of air traffic movements, on the other hand the gate availability did not grow, therefore leaving room for a potential congestion. After analysing the airport charts (2007 and 2018) it was visible that the gate capacity did not grow. During the interviews with the involved stakeholders, the gate capacity was in all interviews one of the most discussed topics. Anonymous 1, 3 and 8 (LVNL, AAS and Aviapartner) mentioned the different bottlenecks that are related to the gate capacity. Anonymous 1 (LVNL) sees that the gate capacity is influencing the smooth flow of traffic at the taxiways of Schiphol, which is explained in chapter 4.4.5. During the interview with anonymous 3 (AAS) they see that the buffer capacity is most negatively influences due to the shortage in gate capacity. For Aviapartner (Sven Pots) the handling of AC on the buffer (remote gate stands) creates a bottleneck for the ground handlers. For the GH it cost time to reach the remote gate stands, which effect the on time performance of the GH.

Valuable solutions

To cope with the problem of the available gates at Schiphol the different stakeholders are asked to think about solutions for the identified bottleneck. Anonymous 1 (LVNL) thinks that Schiphol should focus to first create new gates before renewing existing gate areas, considering if the decision of the new terminal building and the new pier at centre will help Schiphol with the upcoming growth. Anonymous 8 mentioned to extend the "Schiphol tunnel" to create more space

at centre and extend pier-H. In contrast with LVNL, anonymous 3 (AAS) are looking for more gate capacity outside Schiphol-Centre. One of the options is a new terminal in the north of Schiphol near the Uniform-platforms. Because the enlargement of Schiphol is a huge discussion in the politics of the Netherlands, this is something that will take years to take place.

Buffer capacity

To increase gate capacity at Schiphol, the buffer positions are used to store AC that have a long turnaround time. At Schiphol, the buffer positions are used for the wide body AC and mostly by the home carrier KLM. With the increase of traffic the increase of wide body AC have increased faster than expected, which caused a bigger problem at the gate positions and with the introduction of the turnarounds at buffer positions also for the buffer capacity.

Introducing the “zero tow” concept (anonymous 4, KLM) the buffer capacity have decreased. The zero tow concept means that arriving AC will not go to the gates at Schiphol centre but will have the entire turn around at one of the buffer locations. The buffer position is used as remote gate and increase the gate capacity but decrease the buffer capacity. As showed in table 4 the amount of buffer location have growth with 19 positions, at the M-apron and the Uniform-platform, but this growth also include the buffer locations used for the remote handling.

Anonymous 2 (LVNL) also sees that the buffer capacity is forming other problems. Now that the M-apron has expanded more AC are towed to Schiphol-East, which forms runway crossings. This identified bottleneck can be related to the growth, and aircraft stand capacity bottlenecks, which is discussed in chapter 4.4.3.

Valuable solutions

The shortage of buffer capacity will be a problem the upcoming years due to the use of larger AC by airlines to cope with the limitation of 500000 movements. In order to create new buffer capacity, five extra buffer positions will be created at the uniform-platform showed (location showed in figure 5) (anonymous 4, AAS).

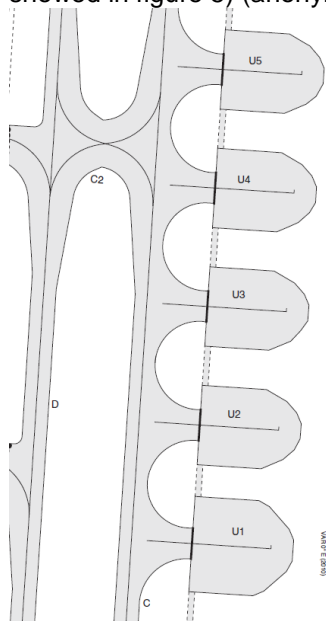


Figure 5 – Position of valuable solution, expansion of Uniform area

4.4.2 Space shortage Schiphol-Centre

The shortage in available space at Schiphol centre is a bottleneck that comes back in all the interviews with the involved stakeholders. The main problem why Schiphol cannot expand at centre is because of the regulations and limitations related to the runways, four of the six runways are located around Schiphol centre. However, not only the runways causes the shortage in available space. The amount of aircraft movements showed a growth and as result the amount of equipment needed for the operation, employees and companies also increased. Because the whole passenger operation takes place at Schiphol centre, the stakeholders do not want equipment to be stored far away or crew centres located elsewhere. Doing this will result in delays (anonymous 3, 6 and 8).

Anonymous 7 (KLM) mentioned during the interview that underneath the piers different companies are located (e.g. security and cleaning companies) which increased also over the

years, and who take much of the available space near the gates with their office and parking spots. Furthermore, anonymous 8 explains that for all the ground handlers, the storage of equipment is becoming a major issue in the on-time performance.

Besides the problems with storage of equipment, Schiphol also needed to create more space on the existing gates over the years. In some cases the gates were going to be used for wide-body aircraft (for example at the D-pier), and over the years the wingspan of the narrow-body aircraft increased. This increase of space at the existing gates causes also the decrease of available space at Schiphol airport. In some cases, the space between two aircraft is too narrow to drive there (anonymous 7).

Valuable solutions

Beginning with the needed space for the ground equipment, anonymous 7 suggested that Schiphol should invest in a new area before starting to invest in Schiphol centre again. As example, the new A-pier is built on already existing gate capacity. The “new” capacity will not increase the needed space at Schiphol centre. A suggestion is to invest in accessibility to other areas, like a tunnel to the uniform platform. When there is a faster connection, companies which are now located underneath the piers, can be relocated to a new business centre at the uniform platforms.

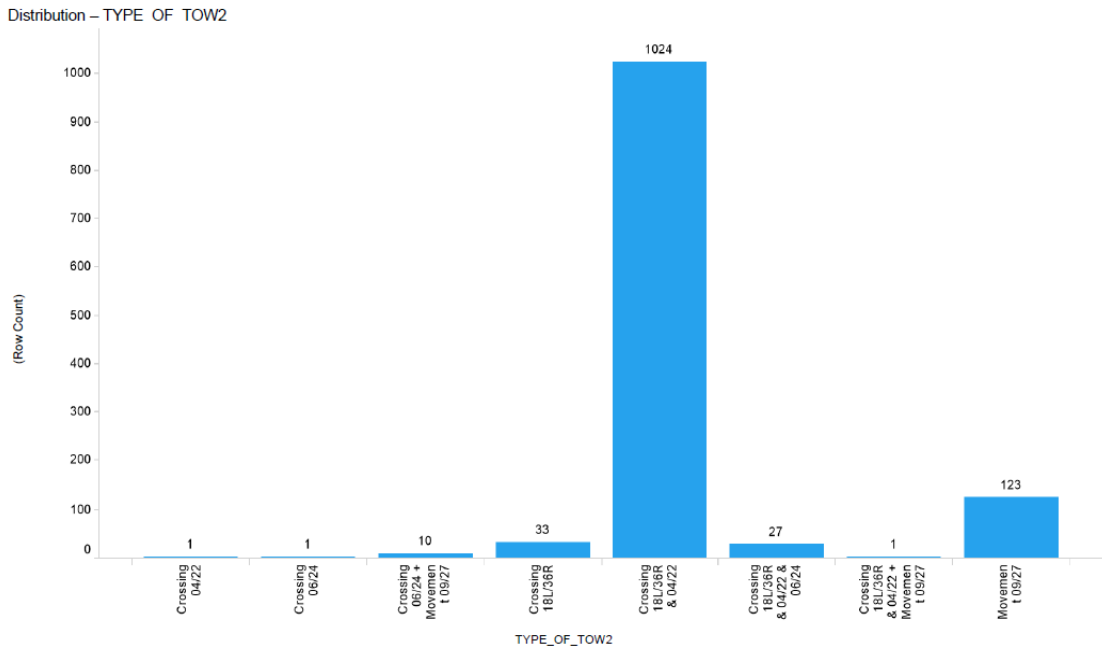
Another idea to create more space at Schiphol centre is mentioned in 4.2.1, an extension of the “Schiphol tunnel”. Furthermore, the relocation of the taxiway Quebec is useful. This makes the extension of the new pier possible.

4.4.3 Tow-movements

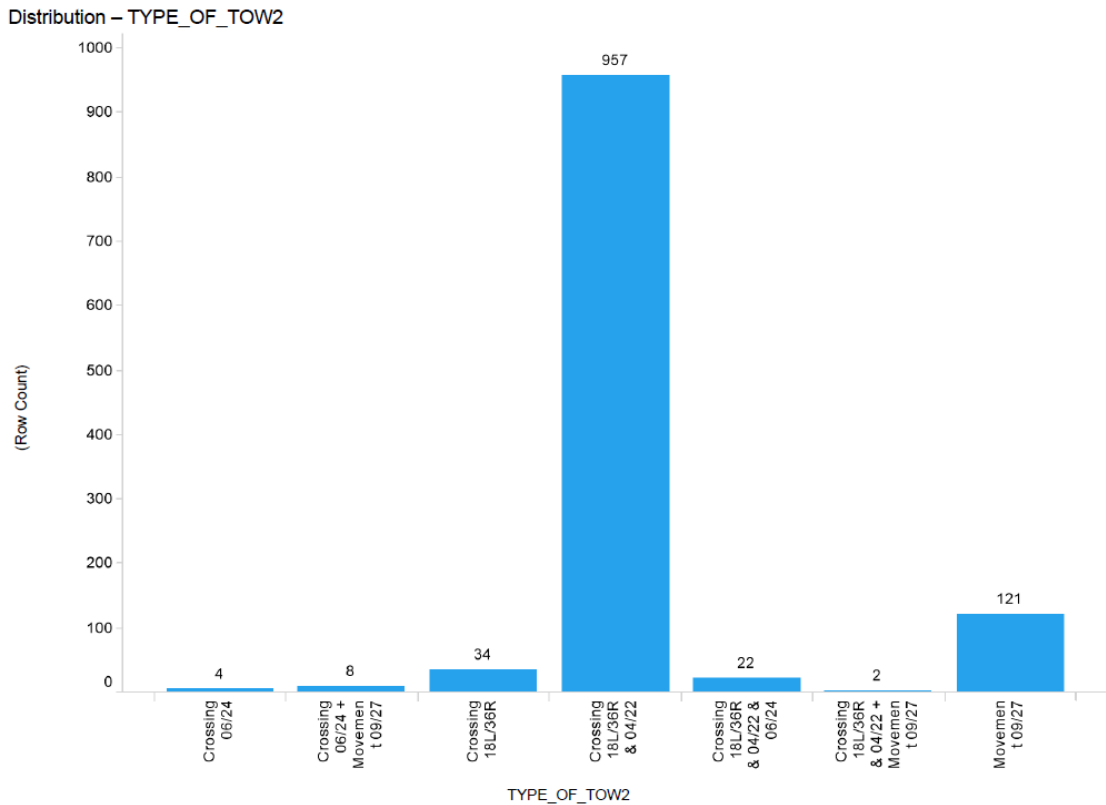
To cope with the amount of traffic, tow-movements need to be made to secure enough gate capacity to handle the traffic at Schiphol. These tow-movements, mostly wide-body AC, increase the amount of ground movements. Almost all the movements at Schiphol are coordinated by LVNL, the only exception are the tow-movements. These are coordinated by Schiphol themselves, and causes trouble for the operation of LVNL. From the perspective of LVNL is every movement a potential disruption in the capacity of the airport (anonymous 1, LVNL). However, Schiphol needs to make these movements to offer the capacity needed for the amount of traffic (anonymous 5, AAS). Furthermore, anonymous 4 stated that with the use of the new remote gates (turnaround at buffer positions) the amount of tow-movements from gates to buffer positions will decrease with 10-15%.

Looking at the increase of traffic movements this year and the upcoming years, the wide-body AC will keep growing at Schiphol. This means more gates are needed to handle the new traffic. To offer this capacity, more AC are towed to a buffer position or handled at a remote gate, which will decrease the capacity of buffer positions at Schiphol centre and more movements will be made to Schiphol-East, which includes a runway crossing. The increase of air traffic movements will also cause the increase of runway usage and more crossings will decrease the runway capacity. To understand the effects of the tow movements on the daily operation of Schiphol, a baseline measurement is performed. As described in chapter 3.2 SQ.2. the baseline measurement for the tow movements is performed with the tow-movement data of Schiphol. After performing the steps described in the methodology, the datasheet used for the analysis is completed and can be found in appendix XIX. In appendix XX the datasheet shows if the tow movement included a runway crossing over an active runway.

The data is shows that in July and August 7.443 tow-movements have been performed. These movements were made to and from different locations, as example from gate to gate, gate to buffer/remote (centre) or from gate to buffer/hangar (M-apron). In appendix XXI, the different movements are showed with the type of crossings. From the total amount of tows these months, 2.368 movements had a runway crossing, in graph 3 and 4 the amount of tow crossings over all the runways of both months are found.

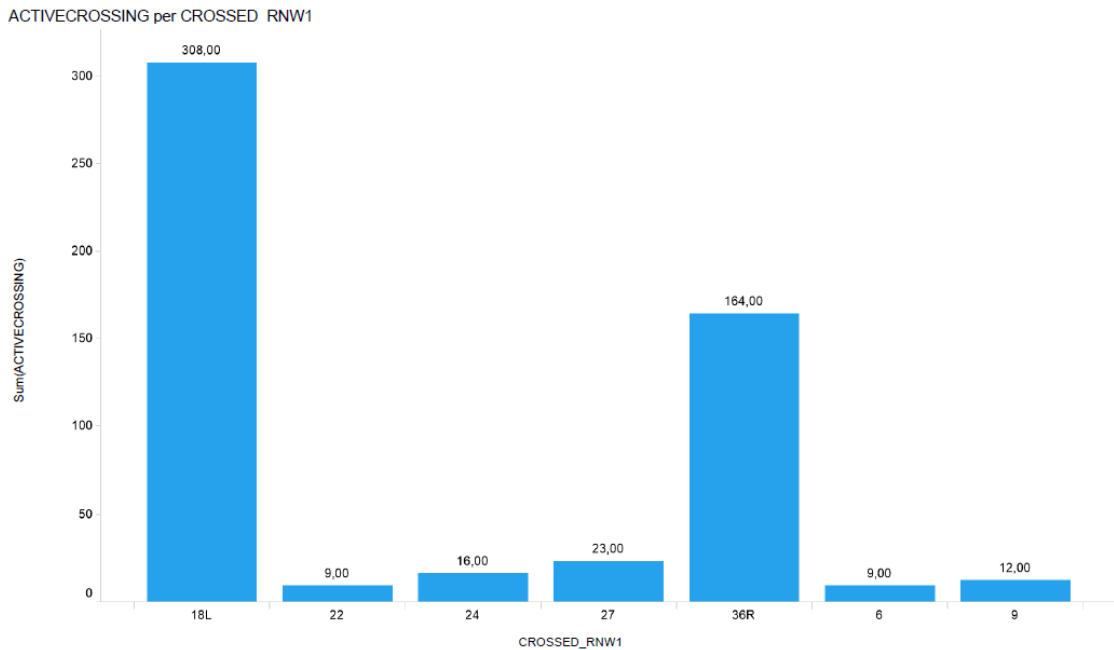


Graph 3 – Tow-movements with runway crossing (July 2017)

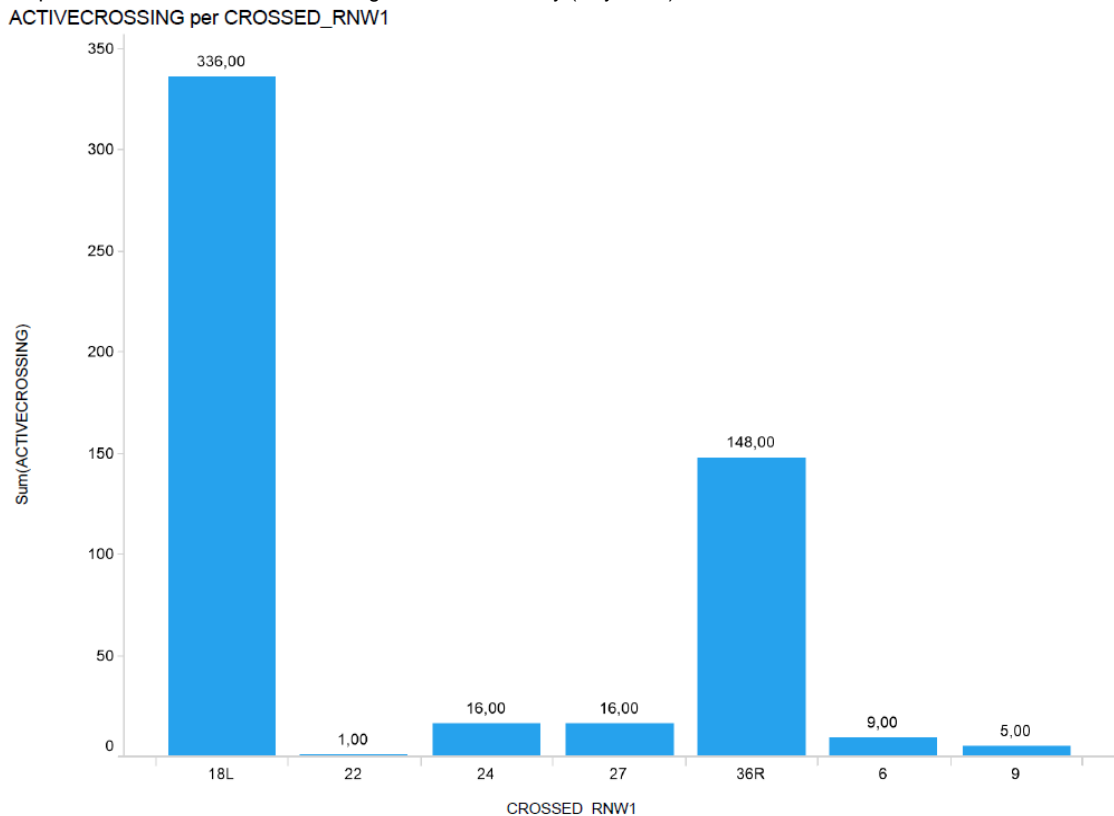


Graph 4 - Tow-movements with runway crossing (August 2017)

To know the amount of crossing over an active runway the historical runway data is insert in the datasheet. In July and august 1.042 to crossings are performed crossing an active runway. In 30 cases two active runways where crossed. In graph 5 and 6 the amount of tow crossings over the active runways of both months are found.



Graph 5 – Tow-movement with crossing over active runway (July 2017)



Graph 6 - Tow-movement with crossing over active runway (August 2017)

Anonymous 1 (LVNL) thinks that these crossings and tow-movements are limiting the capacity of the airport, where anonymous 4 and 7 (AAS and KLM) are convinced that without these movements the airport already had reached its capacity. These opposed opinions are not helping the cooperation between the stakeholders. AAS sometimes experience extreme long waiting times when a tow needs to cross an active runway and thinks this will contribute in the future to congested situations on the taxiways due to waiting tow traffic. Because this is a baseline measurement, it can be helpful to perform an extended version with more data, in the upcoming years to see what has happened. From the information in datasheets many more correlations can be found, for example the usage of the tow truck or what aircraft is mostly towed. This can help to create better understanding of the situation.

Valuable solutions.

To cope with the current amount of traffic tow-movements and looking at the future demand solutions are required to create new capacity at the gates and buffer positions. Anonymous 4 (AAS) also admits that with the tow-movements crossing the runway, the runway throughput will be affected negatively, but on the other hand, without tow movements the gate capacity will not be enough to accommodate all the aircraft. Because the runway throughput is important for LVNL a crossing can affect their operation and capacity. To decrease the severity of the bottleneck a good cooperation between the air traffic controllers and tow controllers should be achieved. Also anonymous 4 mentioned that awareness needs to be created at the air traffic controllers on the importance of the tow-movements.

4.4.4 Communication & cooperation

Communication between the stakeholders is important for securing a smooth running operation and for the cooperation between the stakeholders. Over the years, different agreements have been made which were necessary for the growth of the airport, but the interest of these agreements were always different for the stakeholders. Due to this different interest, the cooperation is not optimal and during the years different agreements have not been executed on time. Because several stakeholders fail to comply with the agreements a lack of confidence is created and because the solution have not been performed more congested situations occurs at the airside infrastructure. For example, the single taxiway Quebec, which is delayed (anonymous 2, LVNL). Looking at the agreements about expansions/construction of the airside infrastructure, AAS is mostly responsible for the investments. These investments always affect the other stakeholders, for example: AAS invest in the airside infrastructure, to pay for the investment AAS will increase the airport fees for the airlines, which is negative for the airlines and mainly KLM. Anonymous 5 (AAS) mentioned that the financial stability of the airlines is a problem with the decision of the agreements. An airline can easily be effected by the economy or fuel prices and charging more airport fees is not possible in some cases, which effect the decision of the agreements.

Next to the cooperation between the stakeholders about agreements, the communication between different ground officials (ground control (LVNL) and Tow control (AAS)) is currently not optimal. Where all the movements at Schiphol are coordinated by LVNL, AAS is responsible for the tow-movements. Because there are many tows made daily the communication between the two officials is necessary for the safety and capacity. Anonymous 5 (AAS), sees that LVNL deviates much from the standards to secure the capacity. When this happens, it is important to have good communication between the involved stakeholders so this will not lead to safety issues or new congestions. For example, there is no direct communication between the two officials of the ground infrastructure, but the tow controllers are listening on the radio frequencies of ground control to know what they are doing, missing a deviation can lead to unsafe situations.

4.4.5 Continuous flow of traffic

The continues flow of traffic is influenced easily by other capacity bottlenecks. At Schiphol the available gates-, buffer-, holding positions and space are influencing the continues flow of traffic. With the growing amount of traffic, more congested situations are expected and more delays will occur. As described in the methodology (chapter 3.1 SQ.3.) the traffic movements are partly analysed with the use of Rplot. With the use of this simulation tool it is possible to visualize the ground track data and identify situations of congestion. As example, a congested situation is explained on May 6th 2018 around 10:00 UTC. The situation take place at the D-pier on taxiway Bravo where a tow is waiting on taxiway bravo (t_3841_KM), flight KLM1613 got a push back in the Delta-bay waiting to taxi over taxiway Bravo, flight UAL947 also had a push back and is waiting to taxi over taxiway Bravo and flight AUI101 is waiting to taxi to a gate in the Delta-bay. In figure 6 the situation is showed with the red circles around the two departing flights and blue circle around the arriving flight, also the driving directions are showed.

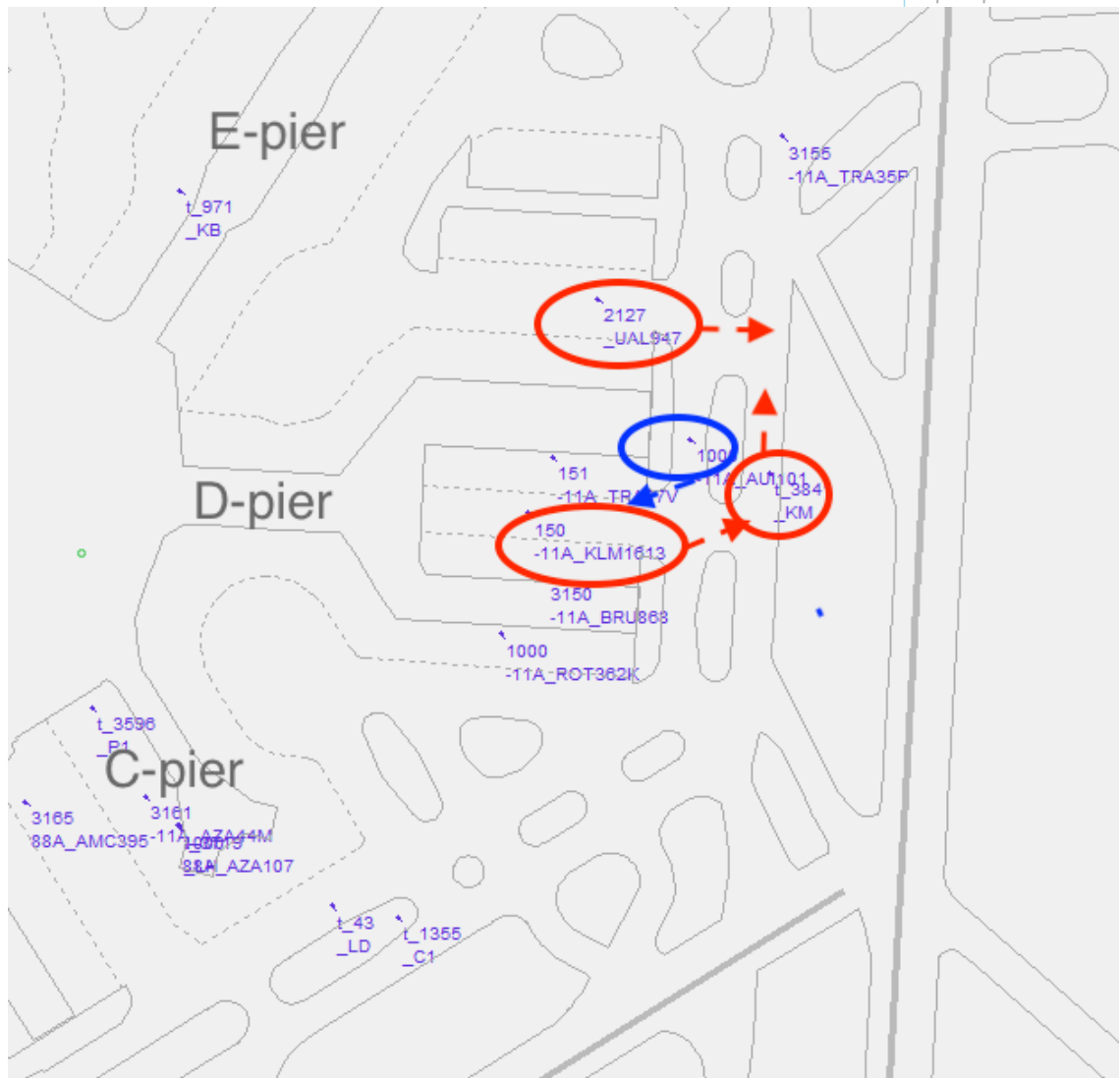


Figure 6 – Rplot visualisation of congested situation Delta-bay (part 1)

After three minutes, KLM1613 begin to taxi towards taxiway bravo where it is stopped and will wait behind tow t_3841_KM which have to wait until UAL947 have passed. In this time, two other AC (AMC395 and KLM1565) and another tow (t_257_SG) were placed in the row behind KLM1613 and now all need to wait before UA947 has passed. After a waiting time of 6 minutes, arriving flight AUI101 is able to enter the Delta-bay. Figure 7 shows the situation with the waiting AC and tows and the movement of the arriving flight.

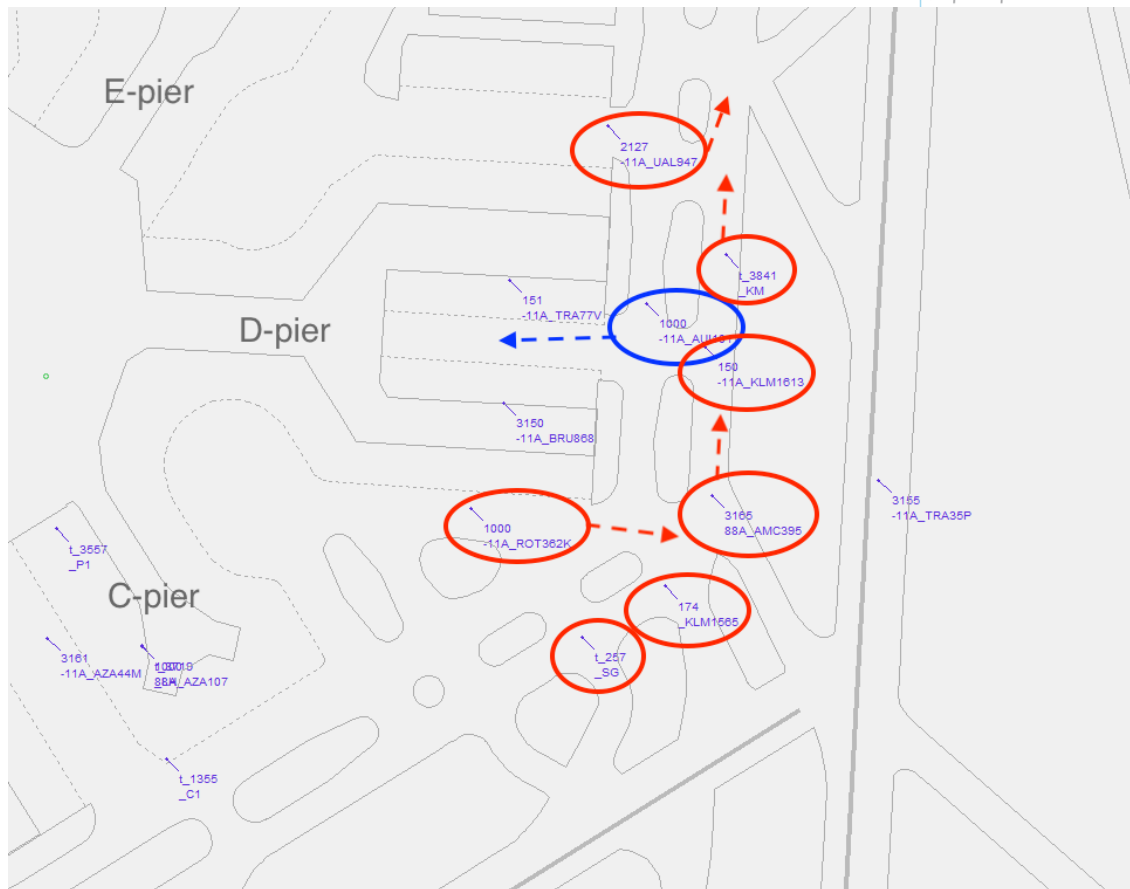


Figure 7 – Rplot visualisation of congested situation Delta-bay (part 2)

One minute after AUI101 begin to taxi to its gate, UAL947 begin to taxi towards the runway and the other traffic was able to continue their route. This congestion took in total 8 minutes before the taxiway was cleared. At Schiphol, these congestions are easily formed at different locations, which are showed in appendix XXII (hotspot areas Schiphol centre). In some of the cases, ground control make use of the other taxiway if this is not blocked by other traffic, so the deviate from the standard procedures.

Valuable solutions

As mentioned earlier, making use of the opposite taxiways can help to taxi around the congested situation. To do this the communications needs to be optimal for the safety on the taxiways. Also parallel driving lines within the bays are useful to make sure no traffic needs to wait on the taxiway (anonymous 2, LVNL). Furthermore, the importance of tow-traffic needs to be accepted by LVNL (anonymous 5, AAS), when always give the priority to taxi traffic congested situations will occur due to the waiting tow-traffic at the taxiway. In figure 6 tow t_3841_KM has to give priority to UAL947, even when this aircraft is still waiting to start taxiing.

4.4.6 Single taxiway Quebec

Related to the continues flow of traffic (chapter 4.4.5) the single taxiway Quebec forms a bottleneck for the continues flow of traffic. This taxiway connects the Alfa and bravo taxiway and completes the taxiway circle around Schiphol centre. The congestions at taxiway Quebec still occurs when runway 36C and 36L are in use for the departures at Schiphol. The traffic towards 36L will pass the runway at the south of runway 36C, at junction A27 traffic from taxiway Bravo and Quebec needs to be sequenced which can cause congestions at both taxiways, as showed in figure 3 at chapter 4.3.4. But also waiting AC for their take-off at runway 36C are causing congestions. The current plan is to have a double Quebec taxiway in 2021 (anonymous 2, LVNL).

5 Conclusions

To keep the airside infrastructure capacity optimal, cooperation between the main stakeholders KLM, AAS and LVNL is required. The main research question: ***“How do airside infrastructure bottlenecks impact the capacity at Schiphol and the relative stakeholders operation?”*** helps to understand the impact of the bottleneck. The sub-questions are answered with combining literature research, data and interviews with the main stakeholders of the airside infrastructure. In this chapter, first the conclusion for the sub is discussed after which the main research questions is discussed.

5.1 SQ1 Conclusions

Using the timeframe period, the first research question concerned the bottlenecks occurring in the past at Schiphol: *“How did the involved stakeholders respond to the identified capacity bottlenecks at Schiphol in the past?”*. For the answer this question the past bottlenecks were identified using research conducted in the past and after this, interviews were conducted to determine if a solutions has been implemented to cope with the bottlenecks.

At the airside infrastructure of Schiphol many airside bottlenecks occurred in the past. To scope the research only the bottlenecks with the highest impact are analysed during the research, which were congestions at the start of the runway, tow-traffic, congestions at the gates, single taxiway Quebec, aircraft stand locations, congestions during de-icing and congestions at taxiway Alfa due to push-back. Looking at the changes in the airside infrastructure of Schiphol, different bottlenecks are (tried to) solved by building new buffer stands, using a new location for de-icing of the AC, create parallel driving lines and increase the surface of different gates.

Not only changes in the airside infrastructure were used to solve the bottlenecks, but also the use of buffers for relative short periods was introduced to increase the gate capacity, increase of personal at all involved stakeholders to cope with the traffic growth, digitalization of processes for better time management/less human errors and the implementation of CDM (Wouters, 2018) should help for different elements at the airside infrastructure.

Now looking at the sub-question, different investments have been made by the main stakeholders of the airside infrastructure. Mostly AAS was responsible for making these investments because they are responsible for the airside infrastructure. Looking at the timeframe, the financial crisis starting 2007 causes that several investments where delayed or cancelled, which also influence the capacity at the airport. With the growth of the airport after 2011, solutions where implemented to cope with the growing amount of bottlenecks. In almost all cases, the solution was for a short-term solution, not looking to the future demand of traffic.

5.2 SQ2 Conclusions

The response of the stakeholders identified in SQ1 could have had consequences for the operations at the airside infrastructure, the consequences were analysed using the second sub-research question: *“What were the consequences of the response on identified capacity bottlenecks for the operation of the involved stakeholders?”*. To answer this sub question interview were conducted with the involved stakeholders.

The airside infrastructure changes conducted between 2007 and 2018 where only minor changes, but still have had effect on the operation of different stakeholders. The space for equipment storage decreased over the years, which is still a problem for the ground handlers at Schiphol. This resulted in a lower on time performance because more equipment needs to be picked up from locations further away from the gates. Furthermore, the use of buffer locations to increase the gate capacity increased the taxiway usage, due to the increase of tow-movements. At this moment the tow-movements are necessary to guarantee the gate capacity. Furthermore some smaller consequences for the stakeholders are: Investments costs, moving of company to other location, further driving distances due to relocation, increase of cost (employees, equipment, etc.) and change of standard rules at Schiphol.

5.3 SQ3 Conclusions

After looking at the past bottlenecks at the airside infrastructure of Schiphol, the current bottlenecks were researched by using the third sub-research question: “*What are the current capacity bottlenecks at Schiphol’s airside infrastructure?*”. To answer this question interviews were conducted at the main stakeholders and simulations of ground movements were analysed.

The current capacity bottlenecks that are identified by the KLM, AAS and LVNL after conducting the interview were: aircraft stand capacity bottlenecks, space shortage at Schiphol centre, tow-movements, communication & cooperation, continuous flow of traffic and single taxiway Quebec. The continuous flow of traffic also included the simulations of the ground movements to identify the hotspot areas showed in appendix XXI and the tow movement includes a baseline measurement to see the amount of tows made right now. When comparing the past bottlenecks with the current bottlenecks (mentioned above), some of the past bottlenecks still occurs at the airside infrastructure. A short overview of each bottleneck is given below:

- When looking at the aircraft stand bottlenecks (4.4.1), the gate and buffer capacity are reaching their limits. The biggest problem is that the gate capacity did not grow with the increase of air traffic, and as a result of this more aircraft are towed to the buffer positions. In addition, these buffer positions are used as remote gates nowadays, which decrease the buffer capacity. Despite a growth in buffer capacity over the years, the buffer positions are also reaching their limit. This bottleneck also occurred in the past (chapter 4.3.5), the only solution implemented for this problem between 2007 and 2018 was an increase of buffer capacity as mentioned above.
- The space shortage at Schiphol centre (4.4.2) is for the operation of the stakeholders a major bottleneck. Not only the traffic movements increased, but also the amount of equipment, employees and companies necessary to cope with the growing amount of traffic. At the same time, different gates were extended to handle larger AC.
- As mentioned above, the capacity shortage of gate positions increased the amount of tows (4.4.3). The tow-movements are extra ground movements and decrease the capacity of the taxiways and runways. In July and August 7,438 tows were made and 1,042 movements had an active runway crossing. With the use of the remote gates at the buffer locations around Schiphol centre an increase of runway crossing is expected, which will decrease the runway capacity. This bottleneck is also mentioned in the past bottlenecks, here already warn for an increase of runway crossing in the future.
- Another bottleneck that influences the ground capacity is a lack of communication & cooperation between the main stakeholders (4.4.4). The communication is mainly related to ground movements at the airside infrastructure of Schiphol. At Schiphol LVNL and AAS both are controlling the area, where AAS is controlling the tow-movements, LVNL is responsible for the rest. Due to these two officials, congestions are easily formed and miscommunication can lead to unsafe situations.
- The continuous flow of traffic (4.4.5) at Schiphol is easily influenced by other capacity bottlenecks. In appendix XXI, the hotspot locations are indicated and is mainly visible at taxiway Alfa and Bravo. Multiple factors are causing the congestions in the traffic flow, such as pushback movements directly on taxiway Alfa or deviate from standard rules.
- Furthermore, the single taxiway Quebec forms a bottleneck (4.4.6) for the continuous flow of traffic. This bottleneck is also mentioned at the past bottlenecks and is still an issue at the current airside infrastructure. Over the years, this project has been delayed and in the current plans taxiway Quebec needs to be completed in 2021.

To conclude it turned out that different bottlenecks are still occurring at the current infrastructure. The financial crisis had been one of the factors that influenced the decision-making, because of the uncertainties in the aviation industry, but also the cooperation between the stakeholders has not been optimal.

5.4 SQ4 Conclusions

To solve the current bottlenecks at the airside infrastructure of Schiphol, valuable solutions are required. Following the sub-research question, “*What potential solution(s) can reduce the impact*”

of the identified bottlenecks from stakeholders perspective?” the stakeholders were asked during the interview for their view on the valuable solutions.

The valuable solutions presented at each identified bottleneck (chapter 4.4) are almost all “long-term” solutions. The reason of many bottlenecks can be related to the capacity problems at the gates and buffer locations, which can be solved with the investment in new gates and buffer locations. But not all the problems can be related to the capacity shortage at the gates and buffer locations. Communication, standard procedures and rules at the airport can also help to solve different issues. For example the congested situations due to waiting tow traffic is in some cases caused by the rule that tow traffic should always give priority to departing or arriving traffic. In this case the cooperation between LVNL and AAS is required but also the change of rules.

Because “long-term” valuable solutions are difficult to implement, “short-term” solutions are also named. These short term changes are mostly the same as the previous solutions, such as the construction of more buffer locations or single or double taxi-lines.

5.5 Overall Conclusions

The conclusions following from the sub-research questions indicate that the most of the identified bottlenecks also occurred in the past. With the current amount of ground movements, the bottleneck impact increased and finding valuable solutions have become harder. By using short-term solutions LVNL, AAS and KLM are able to cope with the bottleneck and offer the desired airside infrastructure capacity, but negatively influence the long-term solutions. The conclusions of the sub-research questions together with results of the analysis are now used to answer the main research question.

How do airside infrastructure bottlenecks impact the capacity at Schiphol and the relative stakeholders operation?

All the identified airside infrastructure capacity bottlenecks impact the operation at Schiphol and the involved stakeholders. They are causing delays, congested situations, extra planning of schedules, last minute changes and a higher workload for the employees. Because the impact of the bottlenecks are for every stakeholder different, cooperation is hard to achieve and there is little decision making within the cooperation of the stakeholders. The lack of decision-making is related to the wishes of the involved stakeholders. When a solution is not beneficial for one of them, they will not cooperate in these solutions. Furthermore, within the group of stakeholders there is no head/boss of the group, this also makes it harder for the decision-making.

Looking at the current/past capacity bottlenecks and solutions applied to solve the bottleneck it became clear that these solutions where short term solutions to solve the capacity bottlenecks. Every solution will cause a new bottleneck at the airside infrastructure and shift the burden. In figure 8 a schematically overview is presented of how problems (bottlenecks) are solved. In the case of the bottlenecks at the airside infrastructure of Schiphol, mainly symptomatic solutions (short term) have been implemented because of time limitations, the implementation of a fundamental solution (long-term) will take more time. Also, the symptomatic solution can influence a fundamental solution. The side effects a symptomatic solution causes can influence or delay the fundamental solutions. So when a problem comes back a new symptomatic solution will be implemented. A good example is the shortage of the gate capacity (Problem symptom), this is now solved by the use of remote gates at the buffer some buffer positions (symptomatic solution). A fundamental solution could have been the construction of a new terminal at a different location then Schiphol centre (fundamental solution), but would cost more time to achieve. The side effect of the symptomatic solution is that new buffer locations have to be constructed which will take space at the airside infrastructure of Schiphol and makes it more difficult to find a suitable location for a new terminal. Looking at the airside

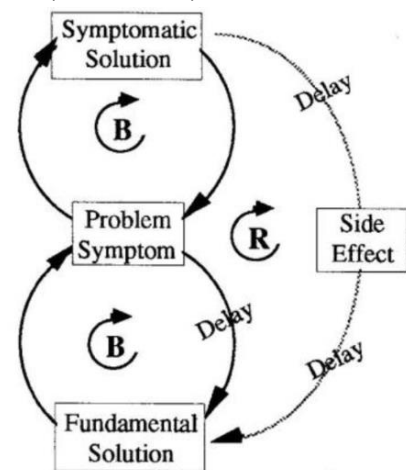


Figure 8 – Shifting the Burden (archetype) (Kim, 2018)

infrastructure, shifting of the burden (figure 8) occurs often and also impact the capacity of Schiphol due to the side effect it includes.

Altogether, the airside infrastructure capacity bottlenecks have impact on the operations of the main stakeholders. Without a leader, the cooperation will not reach an optimal level which results in non-optimal solutions. This can also affect the capacity when looking at the future growth.

6 Discussion

The research analysis, results and conclusion provides insight in the current airside infrastructure capacity bottlenecks which are indicated by the main stakeholders of Schiphol (airlines, airport, air traffic control and ground handlers). For the research, certain decisions were made and limitations were set which resulted in the research conclusion as it is presented now. In this section the research method and interpretation of the results are discussed on how these can be improved for new research on these topics.

Decisions

The decisions made before and during the research were all to scope the project to be able to finish the research within the set time period. First of all, for this research a qualitative research method was chosen to find the current bottleneck at the airside infrastructure of Schiphol and the impact of these bottlenecks. Where different research make more use of quantitative research this research focussed more on the stakeholder feelings. This made it possible to understand the different expectations, impacts and ideas on problems/bottleneck related to the airside infrastructure capacity. However, the identified bottleneck were not verified with data. This would have given the research more depth and substantiation.

Another decision that was made is the baseline measurement for the tow movements at Schiphol. The used data for this measurement was only for the two busiest months of 2017 and no data from other years to see the changes in tow movements. Using data over the whole year will provide a more detailed overview of the tow movements and combining this with different year gives the opportunity to link the findings to different elements, such as increase of traffic movements. Additionally, with this information trend analysis could have been performed.

Furthermore, with intensive use of simulation tools a better overview of congested situations and locations can be identified. Because of the limited time, only Rplot is used to verify some of the congested situations. A simulation for every bottleneck did not fit in the scope and time of the research, but would have added value to the research.

Limitations

Because the KDC is a cooperation between KLM, LVNL and AAS there were not many limitations that could affect the research. Because the three main stakeholders all have a large database about many different topics all data could be gathered. When AAS was not able to provide additional data for tow-movements, the data was found at KLM or LVNL.

A limitation related to the gathered tow data was that it only included two months (July and August 2017). If the data consisted more months also different seasons could have been analysed to see if the season (weather) increased the effect on capacity at the airside infrastructure.

Follow-up research

The conclusion and analysis both includes different suggestions on valuable solutions for the airside infrastructure. These solutions are both short-term as long-term and necessary from the perspective of the stakeholders to invest in. Because short-term solutions have effect on a long-term solution it is important to know what the influences are. A better understanding of the valuable solution will provide necessary information whether the solution initiated by the stakeholders will help the airport with the capacity problems.

Another research topic that is interesting for the stakeholders are the amount of tow-movements and the problems it causes. For example, the amount of runway crossings and how much this effects the runway capacity will help in the decision for more or less tow-movements.

Connection with other KDC research topics

Within the KDC - CoE different topics have been research the last five months which can influence the airside infrastructure. The gate capacity is one of the main bottlenecks identified by the stakeholders which was part of the research topic of Martijn Ringelberg. The research "*Airline strategies' impact on gate occupancy at Schiphol airport*" can contribute to the gate and buffer capacity (Ringelberg, 2018). Furthermore, the implementation of A-CDM can contribute to an optimal use of the ground capacity, the research of Roel Wouters will provide more information on the "*Impact of local A-CDM on the operational efficiency at Mainport Schiphol*" (Wouters, 2018).

7 Recommendations

The analysis of the current airside infrastructure capacity bottlenecks together with the solutions and past bottlenecks have determined the problems that the main stakeholders experience at the airside infrastructure of Schiphol. When a bottleneck occurs it not only affect the operation at the airport, but it also put pressure on the cooperation between the stakeholders to solve the problem. In an ideal situation, every stakeholder will agree on the same valuable solution and changing the infrastructure accordingly.

Concerning the solutions, the stakeholders now chooses for fast (short-term) solutions to solve the capacity bottlenecks. These solutions are contributing to the airside infrastructures capacity, but will have side effects to fundamental solutions (long-term). Therefore new research should be performed concerning the effects of short-term solutions how this effects the long-term solutions. During such research the master planning is taken into account to see what fundamental solutions are planned for the upcoming years and how the short-term solution will affect this. Furthermore, for the development of the airport the stakeholders should provide details to each other about their future ideas to see the correlation. This should create more transparency and boost the cooperation to implement valuable solutions together.

Another recommendation for further research is to analyse the impact of the standard rules and communications. Because there is a limited capacity the stakeholders deviate from those standards to generate the needed capacity. When a stakeholder deviate, communication is essential for the rest of the operation. When one of the stakeholders is not aware of the deviation, it will increase the safety risks at the airport infrastructure and can cause congested situations which will decrease the capacity. It is important to understand that every action can have side effects for other operations. But not only deviations are causing problems, also following the standard rules creates congested situations or bottlenecks. The stakeholders should also think in a wider perspective than just their own operation, review the current rule and develop new standards.

Furthermore, the airside infrastructure capacity will always be influenced by the traffic movement. During this research the expected traffic growth have been analysed but without simulations or calculations it is not possible to show the impact on the identified bottleneck. Where this research can speculate about possible increase of impact of the bottleneck on the capacity additionally research is required. The bottlenecks suggested for a trend analysis are: aircraft stands bottlenecks, space shortage at Schiphol centre, tow-movements and continues flow of traffic.

The last recommendation is to extend the analysis of the tow traffic at Schiphol airport. As mentioned in the conclusion and discussion the tow movements have impact on all the stakeholders negative and positive. For the aircraft stand bottleneck, this creates extra capacity, but the runway capacity can be influenced negatively. Additionally research should create a better understanding how the tow-movements affect different locations at the airside infrastructure and can create understanding of the choice for tow-movements.

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

- Perform research on the impact of “short-term” solutions on fundamental solutions.
- Research the impact of standard rules and communication on airside capacity.
- Trend analysis on the identified airside capacity bottlenecks with future traffic movements.
- Tow-movement analysis which shows the impact on different operations.

List of References

- AIS the Netherlands. (2018, 05). *EHAM AD 2.24 CHARTS RELATED TO AN AERODROME*. Opgehaald van Electronic AIS publications: <http://www.ais-netherlands.nl/aim/2018-06-07-AIRAC/html/index-en-GB.html>
- Amsterdam Airport Schiphol. (2008). *Statistical Annual Review 2007*. Market Development. Schiphol: Amsterdam Airport Schiphol.
- Amsterdam Airport Schiphol. (2018). *Traffic Review 2017*. Schiphol: Amsterdam Airport Schiphol.
- De Onderzoeksraad voor Veiligheid. (2017). *Veiligheid vliegverkeer Schiphol*. The Hague : Onderzoeksraad voor Veiligheid.
- EUROCONTROL STATFOR Team. (2018). *SEVEN-YEAR FORECAST FEBRUARY 2018*. Brussels: EUROCONTROL.
- IATA. (2016). *CALENDAR OF COORDINATION ACTIVITIES*. Montreal: IATA.
- IATA. (2018). *CALENDAR OF COORDINATION ACTIVITIES*. Montreal: IATA.
- KDC, LVNL. (2008). *Verhoging landingscapaciteit, tijdens marginaal en slecht zicht condities*. Schiphol: LVNL.
- Kim, D. (2018). *Shifting the Burden: The "Helen Keller" Loops*. Opgehaald van The Systems Thinker: <https://thesystemsthinker.com/shifting-the-burden-the-helen-keller-loops/>
- KLM - Royal Dutch Airlines. (2017). *Selectiviteit van belang voor ontwikkeling Mainport Schiphol*. Schiphol: Royal Dutch Airlines.
- Knowledge & Development Centre. (2008). *Verhoging van de grondafhandelingscapaciteit op*. Schiphol: Knowledge & Development Centre.
- LVNL & Amsterdam Airport Schiphol. (2017). *Overzicht knelpunten LVNL-AAS*. Schiphol: LVNL & AAS.
- LVNL. (2007). *CONOPS Verhoging van grondafhandelingscapaciteit op basis van het huidige banenstelsel*. Schiphol: KDC.
- LVNL. (2008). *Verhoging van de grondafhandelingscapaciteit op basis van het huidige banenstelsel*. Schiphol: KDC.
- Ministerie van Infrastructuur en Waterstaat. (2018). *Factsheet proces Luchthavenbesluit Lelystad Airport*. The Hague: Ministerie van Infrastructuur en Waterstaat.
- Ministry of Infrastructure and the Environment & Ministry of Infrastructure and the Environment. (2016). *Schiphol Action Programme*. The Hague : Ministry of Infrastructure and the Environment & Ministry of Infrastructure and the Environment.
- MovingDot, NLR. (2017). *Managing of Turnaround Priorities for Schiphol Airport*. Schiphol: KDC.
- NLR & Moving Dot . (2016). *Managing of Turnaround Priorities for*. Schiphol: Knowledge & Development Centre.
- O'Flynn, S. (2016). *AIRPORT CAPACITY ASSESSMENT METHODOLOGY*. Brussels: EUROCONTROL.
- Onderzoeksraad voor Veiligheid. (2017). *Veiligheid vliegverkeer Schihol*. Den Haag: Onderzoeksraad voor Veiligheid.
- Ringelberg, M. (2018). *Airline strategies' impact on gate occupancy at Schiphol airport*. Amsterdam : KDC mainport.

Royal Schiphol Group. (2018, 05). *Annual traffic Reviews* . Opgehaald van Amsterdam Airport Schiphol:
<https://www.schiphol.nl/en/schiphol-group/page/traffic-review/>

TIBC Spotfire. (2018, 6). *TIBC Spotfire Overview*. Opgehaald van TIBC Spotfire:
<https://spotfire.tibco.com/overview>

Wouters, R. (2018). *Impact of local A-CDM on the operational efficiency at Mainport Schiphol*. Schiphol:
Knowledge & Development Centre .

Appendix I – Reflection

For this reflection the STARR method is used, which includes Situation, Task, Action, Result and Reflection. The reflection will discuss the primary used and developed skills during my graduation research. Additionally the SCRUM method is used to reflect on how I structured the research.

Primary skills

During the research, qualitative research methods were used which means conducting interviews for the data collection. During this research I mainly learned how to deal with different import of different stakeholders and how to visualize the ideas.

Situation

When beginning this research it was first important to understand the current situation of the airside infrastructure and traffic movements, also it was important to see what the changes on the airside infrastructure were performed. For the analysis of both of the subjects data of AAS was used. The bottleneck identification was analyzed by the use of interviews with the main stakeholders. Using interviews gave me the opportunity to understand the bottleneck from stakeholder perspective. Understanding how the interviews were formed would have a large impact for reaching my goals

Task

This research is for every stakeholder important because it will give an inside view of the other stakeholders perspectives. During the curriculum I have learned to work with different parties, but what I have seen is that finding an agreement is always difficult. Because this research should help all the stakeholders the task was for me to be neutral and not help or contribute to one of the stakeholders. I set the goal to have an equal amount of interview at every stakeholder and ask the same question.

Action

Conducting the interviews was for me a new experience and was challenging because of the sensitivity of the research topic. Every stakeholder have their own interest in the airside infrastructure and want it the way they see it. Together with some data, and visualization I was able to give a better understanding in the capacity problems, but also the problems which are causing the bottlenecks. For this research it helped me a lot to have bi-weekly meetings where my results were discussed. Because the stakeholders attend those meetings the feedback came from different perspectives which helped me in being neutral.

Result

The results of the conducted interviews with the stakeholders resulted in an overview of the experienced bottlenecks at the airside infrastructure and valuable solutions from stakeholder perspective. It also led to my final conclusion with the help of the bi-weekly meeting and feedback of my supervisors.

Reflection

Looking back on the graduation research at the KDC I very much enjoyed working and research neutral for all the involved stakeholders. I have learned a lot about the airside infrastructure in general, how this is formed, the processes that take place and the difficulties of maintaining capacity. But I have also gained much knowledge about Schiphol airport. To see how the stakeholders maintain the capacity and what the importance is of cooperation. This assignment have helped me to be satisfied with the first thing I hear, but listen carefully to others and also try to create understanding at others.

Furthermore, thinking about what the future changes in the airside infrastructure have extent my knowledge. It was interesting to share ideas with operational experts.

SCRUM/Sprint Review

For a project time management and working towards a deadline without a delay is one of the most difficult aspects. During my bachelor at the AUAS I have completed numerous projects, but managing have always been difficult. Because I want to finish everything at the same time, the project is not structured and have a negative effect on this thesis. The SCRUM method during the research at the KDC turned out to be a successful way for me to structure and manage the project.

Situation

During the entire research two SCRUM meetings weekly were planned, on Monday and Thursday morning. In this meetings every student had five minutes to present what they were doing at the moment and what was going to be finished. On the SCRUM board, task were placed which had to be finished at the end of a two week period, which led to the results for the sprint reviews. The SCRUM meetings were chaired by the SCRUM master, who helped the graduate student get back on track with their tasks.

Task

After every two weeks a sprint review was organized were the progress and results of the research are discussed with the KDC stakeholders. During these meetings every graduate student had five minutes to present their findings and five minutes for a Q&A/discussion session. Also the stakeholders were able to give suggestions and input in the regarding the direction of the research.

Action

To keep a good overview of the tasks which needed to be performed a SCRUM board was used. This board contains the objective for the upcoming two weeks. After these two weeks the accomplished work will be presented in the sprint review, mentioned before. The scrum board starts with the “user story” which is the overall goal for the client. This overall goal will be split in several tasks needed to be done to finish the user story. These tasks will be showed in the “to do” list. Next to the to do list the doing list is provide, this can never be more than one task. When finishing a task it can be transferred to the done list.

Result

With the weekly SCRUM meetings and the sprint reviews, I had a good overview of the project and a good research structure. Furthermore, the SCRUM board helped me to stay focused on the topics I was researching on particular moments and to do any other tasks to stay full focused. All the meetings we had also contributed to my presentation skills, how to be clear without much details.

Reflection

During the SCRUM meetings and sprint reviews I gained a lot of presentation skills, and the effective communication with the main stakeholders was established. The SCRUM meetings helped me to stay focused on the research and the feedback helped me to add value to the research.

Overall reflection

The last five months my goal was writing my thesis research for the KDC – CoE about the capacity problems at the airside infrastructure of Amsterdam Airport Schiphol. Overall I gained much knowledge and experience in the fields of airside infrastructure and cooperation between stakeholders. Also working with the other students helped me to get my thesis to a higher level. I will use the gained experience and knowledge for my future studies or jobs and look back on a successful graduation project at the KDC – CoE.

Appendix II – Tow-movement data Schiphol

ACR_AIRCRAFT_REGISTRATION	START_DATETIME	END_DATETIME	GAR_POSITION	GAR_POSITION_PREVIOUS	TRACTOR	MINUTEN_DEEL
PHEXL	9-7-2017 04:43	9-7-2017 04:56	A56	HG73	MQ	13
PHEXL	8-7-2017 17:31	8-7-2017 17:50	HG73	A43	MI	19
PHEXN	8-7-2017 22:18	8-7-2017 22:34	HG73	A55	MQ	16
PHEZB	9-7-2017 05:32	9-7-2017 05:46	B20	HG73	LF	14
PHEZB	8-7-2017 23:02	8-7-2017 23:14	HG73	B20	MQ	12
PHAKD	9-7-2017 11:09	9-7-2017 11:23	D07	Y72	KF	14
PHAKD	9-7-2017 07:11	9-7-2017 07:22	Y72	F05	KF	11
PHAOC	9-7-2017 12:41	9-7-2017 13:22	E02	Y73	KM	41
PHAOC	9-7-2017 07:04	9-7-2017 07:15	Y73	E05	KH	11
PHAOE	9-7-2017 15:19	9-7-2017 15:24	E09	J81	KF	5
PHAOE	9-7-2017 11:36	9-7-2017 11:44	J81	E17	KL	8
PHAOM	9-7-2017 10:59	9-7-2017 11:10	D49	P11	KD	11
PHAOM	9-7-2017 07:34	9-7-2017 07:44	P11	G04	LH	10
PHAON	9-7-2017 13:35	9-7-2017 13:47	E18	Y71	KH	12
PHAON	9-7-2017 07:03	9-7-2017 07:17	Y71	G06	KD	14
PHBCD	9-7-2017 13:30	9-7-2017 13:41	C11	R87	LA	11
PHBCD	8-7-2017 20:38	8-7-2017 20:45	R87	B31	LH	7
PHBFC	9-7-2017 12:23	9-7-2017 12:38	F04	HG11	KH	15
PHBXF	22-7-2017 20:02	22-7-2017 20:27	R87	D29	LG	25
PHBXF	23-7-2017 11:34	23-7-2017 11:42	C04	R87	LE	8
PHBXN	22-7-2017 23:21	22-7-2017 23:26	D25	C07	LD	5
PHBXP	23-7-2017 06:28	23-7-2017 06:54	C07	R72	LG	26
PHBXP	22-7-2017 23:37	22-7-2017 23:43	R72	C12	LI	6
PHAOA	23-7-2017 11:31	23-7-2017 11:39	G04	Y72	KG	8
PHAOA	23-7-2017 07:05	23-7-2017 07:31	Y72	E02	KG	26
PHAOB	23-7-2017 13:10	23-7-2017 13:24	E02	E75	KG	14
PHAOD	22-7-2017 18:43	22-7-2017 19:04	J81	HG11	LC	21
PHAOD	23-7-2017 07:56	23-7-2017 08:06	E06	J81	LG	10
PHAOF	23-7-2017 17:37	23-7-2017 17:52	E02	G73	LE	15
PHAOF	23-7-2017 12:13	23-7-2017 12:25	G73	E19	KA	12
PHAON	23-7-2017 13:05	23-7-2017 13:18	E06	E77	KK	13
PHBCA	23-7-2017 05:26	23-7-2017 05:35	C11	J83	LG	9
PHBCA	23-7-2017 00:02	23-7-2017 00:10	J83	D43	LD	8
PHBFC	23-7-2017 11:13	23-7-2017 11:29	G09	J85	KJ	16

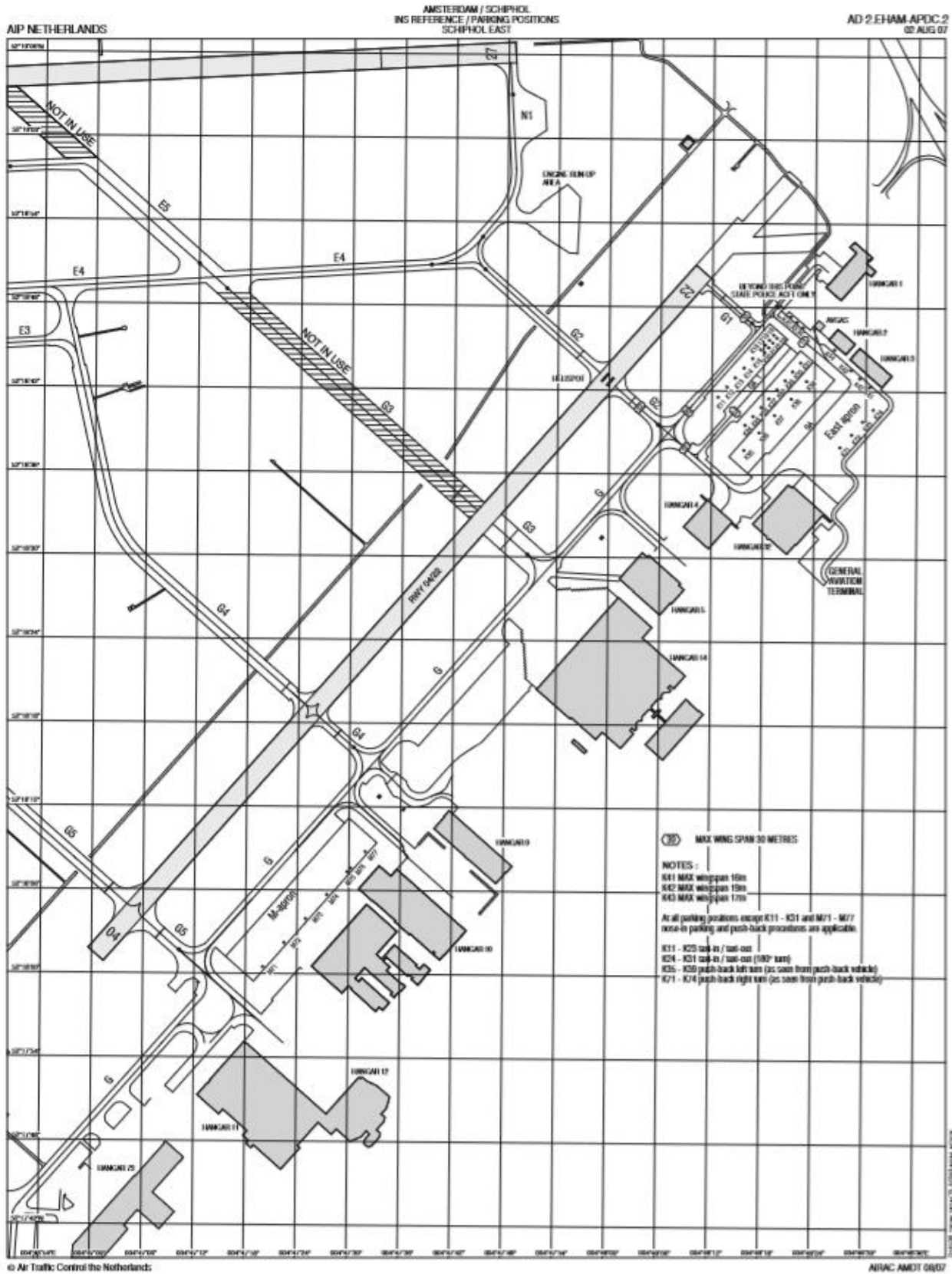
Appendix III – Yearly air traffic movements

Air Traffic Movements (2007-2017)	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Movements (excl. general aviation(GA))	435973	428332	391264	386316	420249	423407	425565	438296	450679	478864	496748
Movements (incl. general aviation(GA))	454361	446693	406975	402375	437082	437904	440057	452687	465521	496256	514625
Growth Movemments (excl. GA)		-1,8%	-8,7%	-1,3%	8,8%	0,8%	0,5%	3,0%	2,8%	6,3%	3,7%
Growth Movemments (incl. GA)		-1,7%	-8,9%	-1,1%	8,6%	0,2%	0,5%	2,9%	2,8%	6,6%	3,7%

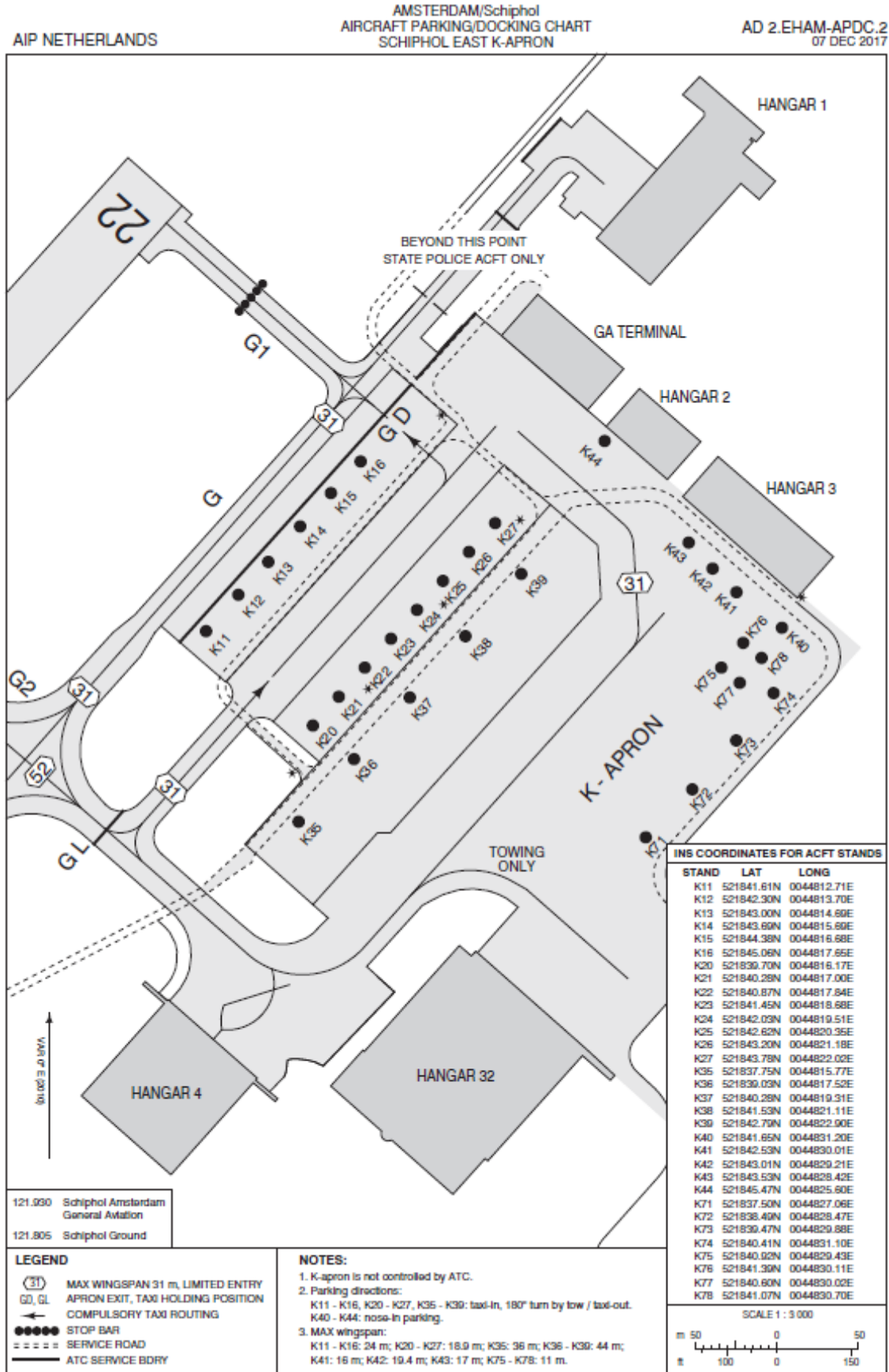
Appendix IV – Monthly air traffic movements (2007-2017)

2007	Jan	Feb	Mrt	Apr	Mei	Jun	Jul	Aug	Sep	Okt	Nov	Dec
Scheduled												
Passengerservices	30352	28585	32576	32807	34762	33712	34545	34320	33284	34256	31158	29539
Full-freighterservices	835	820	1018	973	898	1044	1067	1047	1077	1101	1065	1047
Subtotal	31187	29405	33594	3378	3566	34756	35612	35367	34361	35357	32223	30586
Non-scheduled												
Passengerservices	1035	1013	1315	1819	3286	2764	4377	4276	2953	2730	1012	1119
Full-freighterservices	464	497	550	480	564	534	475	493	518	566	651	594
Subtotal	1499	151	1865	2299	385	3298	4852	4769	3471	3296	1663	1713
Total air transport	32686	30915	35459	36079	39510	38054	40464	40136	37832	38653	33886	32299
Total Passengerservices	31387	29598	33891	34626	38048	36476	38922	38596	36237	36986	32170	30658
2017												
Scheduled												
Passenger services	33475	31363	37082	39053	41998	40681	42083	42224	40554	41519	36039	34523
Full-freighter services	1238	1159	1354	1288	1328	1314	1314	1353	1339	1325	1184	1132
Subtotal	34713	32522	38436	40341	43326	41995	43397	43577	41893	42844	37223	35655
Non-scheduled												
Passenger services	721	666	772	1328	1887	1824	289	3121	2171	1763	551	664
Full-freighter services	229	212	228	204	207	193	209	164	210	242	189	181
Subtotal	950	878	1000	1532	2094	2017	3099	3285	2381	2005	740	845
Total air transport	35663	33400	39436	41873	45420	44012	46496	46862	44274	44849	37963	36500
Total Passengerservices	34196	32029	37854	40381	43885	42505	42372	45345	42725	43282	36590	35187
Differences												
Difference Total air transport	2977	2485	3977	5794	5910	5958	6032	6726	6442	6196	4077	4201
Difference Total Passengerservices	2809	2431	3963	5755	5837	6029	3450	6749	6488	6296	4420	4529
Difference Total air transport (%)	9%	8%	11%	16%	15%	16%	15%	17%	17%	16%	12%	13%
Difference Total Passengerservices (%)	9%	8%	12%	17%	15%	17%	9%	17%	18%	17%	14%	15%

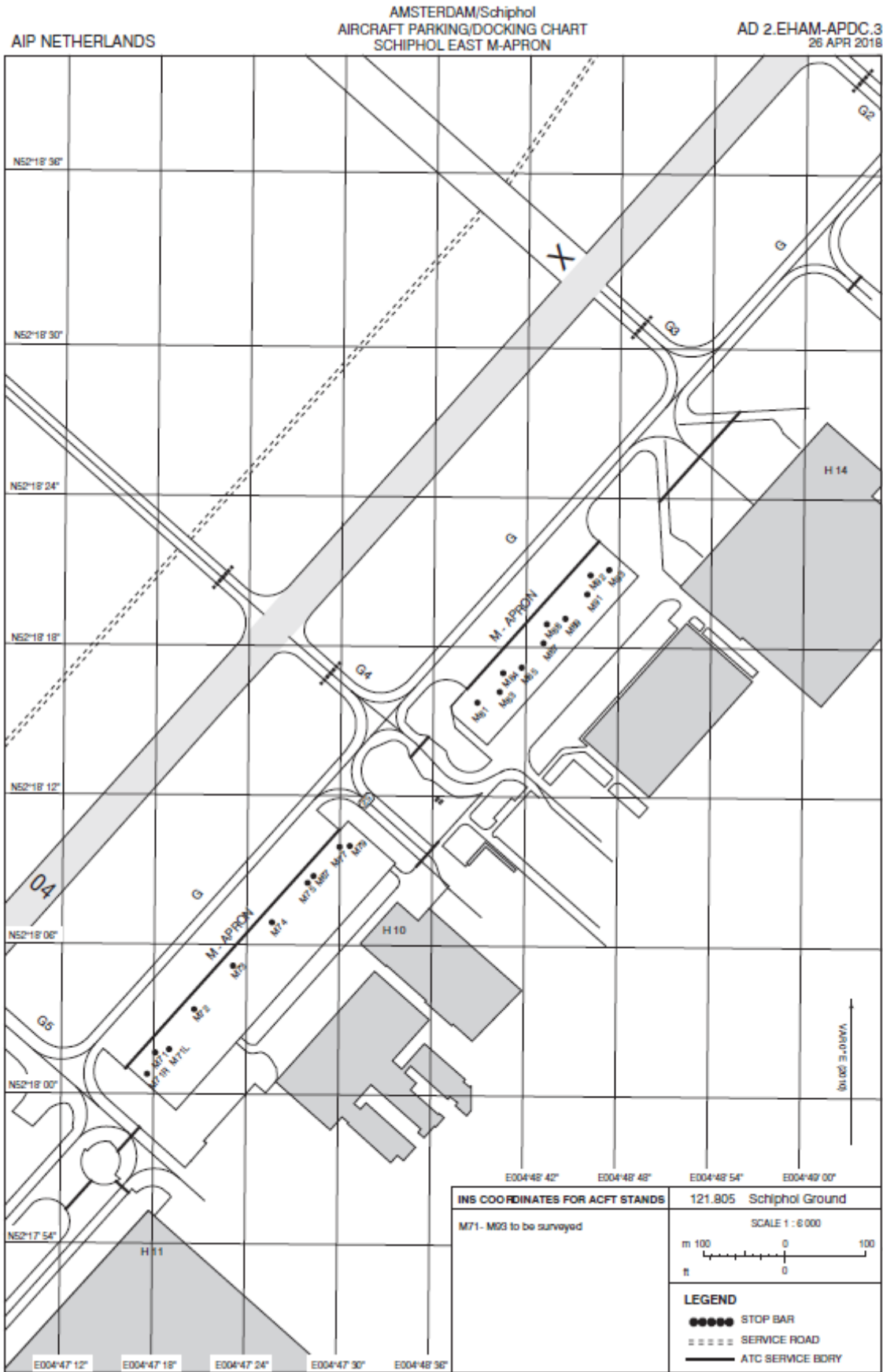
Appendix VII - AM-APDC-2-A3m



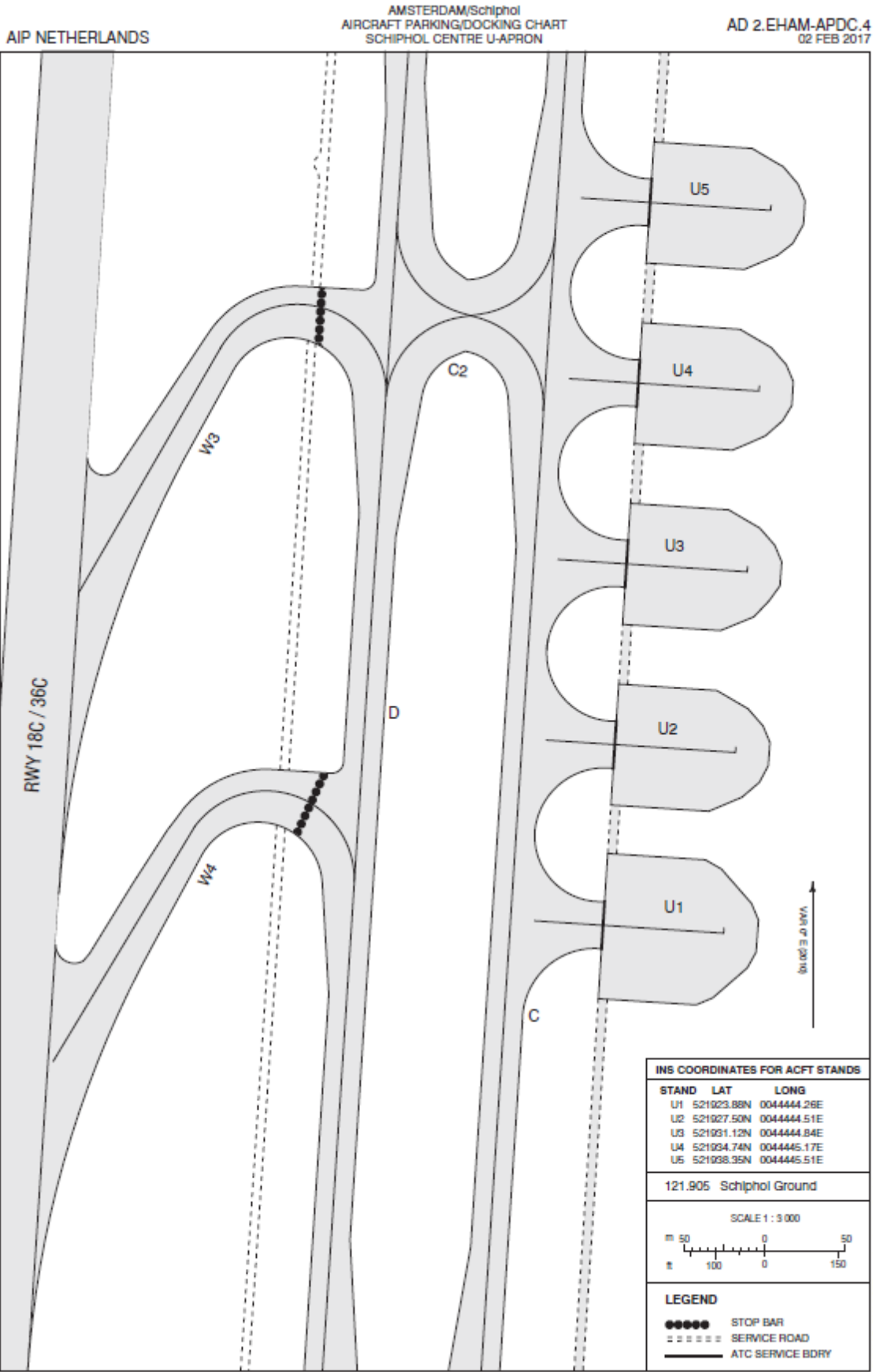
Appendix XI- EH-AD-2.EHAM-APDC-2



Appendix XII - EH-AD-2.EHAM-APDC-3



Appendix XIII - EH-AD-2.EHAM-APDC-4



Appendix XV– Interview summary LVNL

Anonymous 1, LVNL

Anonymous 2, LVNL

1. *What are the current capacity bottlenecks at the airside infrastructure of Schiphol?*
 - a. *How was the operation influenced due to the identified bottleneck?*

Looking at Schiphol, it always had problems with the airside infrastructure. This is related to the fact that Schiphol have built too many at the current location.

For LVNL there are a couple bottleneck which are currently very important, starting with taxiway Quebec is only one-way, during the day this leads to congestions. This can be an effect of the "Peak moments", but nowadays every peak is going in to the next one. There is a continues flow of traffic. The runway changes also contribute on the problems at taxiway Quebec.

Furthermore, aircraft stand capacity is one of the biggest bottlenecks at Schiphol, there are not enough gates to handle all the aircrafts, but also the capacity at the buffers is now becoming a bigger problem. More and more airlines are now going to operate with larger AC because Schiphol doesn't have any slots available anymore (500.000 movements). Due to this, there are not enough wide-body gates and Schiphol starts to handle their aircraft at the buffer locations.

Also the flexibility within the bays have become less good due to the enlargement of the gates to cope with the newer aircrafts. Due to this in some areas manoeuvring the AC have become a problem. Also at some areas, the double taxi-lines have been renewed to one single taxi-line. All the points described above contributes to the a less good continues traffic flow.

That Schiphol uses buffer positions to create extra capacity at the gates is not new. But now that Schiphol is reaching their limits it is starting to use the buffer positions at Schiphol-East more and more. This includes that tow movements are creating more runway crossings and the trend shows that this will become more when more airlines choose to fly with wide-body aircraft to and from Schiphol. The increase of traffic also causes that the runways are used a lot, and sometimes it can take a while before there is found a gap to make the move over the runway.

Another bottleneck related to the gate usage is that some gates are free, but the aircraft cannot park there because the ground handler haven't set the guidance systems for the new AC or gave clearance to the pilot. I think that it can help when the ground handlers start working with a "Ready Team" to make sure that the AC does not form an congestion at the taxiways or within the bays.

Last but not least is the communication and cooperation between the main stakeholders. Over the years a lot of agreements have been set by the three main stakeholders Schiphol, KLM and LVNL. These agreements, mostly improvements or expansions, were given a date when it was going to be completed. Afterwards we can conclude that many of these agreements have not been executed, which leads to friction and the loss of confident between the stakeholders. We can also understand the risk an investment brings for a stakeholder, this can always have an effect for our self or another stakeholder too. For example, if LVNL want something at the airside infrastructure, Schiphol needs to make the investment. To pay for the investment, Schiphol might increase the landing fees to create a return on investment, which KLM will feel in their payment on landing fees.

2. *Did one of the mentioned bottlenecks also occurred in the past? If yes, what is the reason that this bottleneck isn't solved yet?*

If we compare two charts of Schiphol now and 10 years ago, there haven't been many changes at the airside infrastructure. Of course processes have been updated, systems have been replaced and CDM have been implemented but over the years, almost zero extra infrastructure have been added to the airport. One of the changes is the U-apron and the expansion of the M-apron and maybe some minor changes. Will some of the bottlenecks have been there in the

past? I would say so. Back in the days we already wanted a double Quebec, more gates, buffer and remote positions. But with the growing amount of movements the problems have only become more intense.

The biggest challenge when a stakeholder wants something to be done is, who will pay for it? With the market always being thrown from side to side you never know how the future will be.

3. *How did your company respond to bottlenecks at the airside infrastructure of Schiphol?*

To cope with the problems at Schiphol, we need to work together and we are working together. Every two weeks we have meetings to talk about the situation at the airport and the challenges ahead of us. It is very important that we keep communicating and working together. But also show why some of the solutions are important for us and for the whole airport. During the time, we have looked for solutions and found them to cope with the problems at that moment, now it is important that we go a step further. We need to invest in the airport and invest in solutions which are not helping just now, but will help also looking to the upcoming demand.

4. *What are valuable solutions for the bottlenecks mentioned earlier?*

First of all I would like to start with the taxiways at Schiphol, I think there are a couple ideas:

- Create double taxi-lines everywhere where possible. This will help the operation and the continuous flow of traffic.
- Create possibilities to exit the bays on two different sides. So no traffic has to wait for each other.

Then we have the problem with the amount of gates at Schiphol.

- Now we are creating a new pier at an already existing area with gates. This does not give extra gates, so I suggest for in the future to first build something new, and then we can renew the old areas.
- Then I also suggest to create more holding positions at Schiphol-Centre, to be able to let the aircraft wait when a delay occurs, without forming a congested situation.
- More aircraft stands in general.

To create more space at Schiphol-Centre, I would say, extend the "Schiphol tunnel (A4)". This can create more space and can be used for an extension at the H-pier. Also the use of the U-apron and the area next to this can be useful.

Appendix XVI– Interview summary AAS

Anonymous 3, AAS

Anonymous 4, AAS

Anonymous 5, AAS

1. *What are the current capacity bottlenecks at the airside infrastructure of Schiphol?*
 - a. *How was the operation influenced due to the identified bottleneck?*

Looking at the airside of Schiphol a lot of processes can be optimized with technology instead of building more concrete. I think process innovations will help with the development of the current bottlenecks. One of them is the capacity of the gates, right now we already see it is not enough. This due to wrong trend analysis, for example with the long-haul aircrafts. Last year we expected a growth of 10 AC, well the reality shows us it will be in the summer around 17. Schiphol is having and will have a shortage of gate and buffer capacity.

This shortage is now solved by working together with all the stakeholders and try to find solutions with the infrastructure we have. An example is the use of buffer positions for the handling of the aircraft. This concept “Zero-Tow” mean that a arriving AC will go directly to the buffer, where the ground handler will do the turnaround of the AC.

Furthermore, one of the main bottleneck is the lack of space at the airside infrastructure, which have effect on all the stakeholders. Schiphol has a shortage on gate capacity, and this will become more in the upcoming years, right now we are creating capacity with the tow movements to the buffer positions, but this can lead to delays, because of the shortage of tow capacity. Some tows needs to go to Schiphol-East, which will take long. In this time the tow-truck is not available for other movements. Also Schiphol understands the cons against tow-movements, but right now with the current infrastructure, we need to conclude that tow-movements are a way to create capacity.

Now we talked about the shortage of capacity Schiphol is offering, but Schiphol is also the one who need to pay for the new buildings, infrastructure, etc. Making a long term planning is very difficult in the aviation industry. This is mainly due to the fact that the airline economy are very unsteady, which can cause problems when raising the landing fees. What we have seen with an economic crisis is happening for an airline every 2/3 years. This can be due to the oil prices or other cost.

Last is that the communication at Schiphol is not optimal, where Schiphol is responsible for the tow movements, is LVNL responsible for the rest of the ground movements. At Schiphol there are a lot of standards which includes the way of the push back, but in many cases LVNL is not following these standards. This should not be a problem if all the stakeholders know what is happening, but tow-control and Ground control are not operating on the same frequency with communication, which is not safe. The operators should know what each other is doing, every single moment.

2. *Did one of the mentioned bottlenecks also occurred in the past? If yes, what is the reason that this bottleneck isn't solved yet?*

Most of the mentioned bottlenecks occurred also in the past, I'm sure about that. But with the current traffic movements the impact of a bottleneck is higher. We also have to think about the technical solutions that have been implemented and which helps to cope with the amount of traffic.

3. *How did you company respond to bottlenecks at the airside infrastructure of Schiphol?*

For Schiphol it is important to solve problems and keep the airport running smoothly. In some cases investment need to be made, like the buffer locations. Over the years Schiphol invested in the expansion of the M-apron at Schiphol-East, and created a new U-apron in the north of the Schiphol area. To deal with some smaller situations double driving lines have been created at the GH-pier to create a better traffic flow.

Next to the buffer places Schiphol also created two holding positions, which can be used by LVNL at the R-apron. Furthermore, Schiphol is always looking for innovations for the capacity bottlenecks.

4. *What are valuable solutions for the bottlenecks mentioned earlier?*

For optimizing the available space at Schiphol centre, AAS suggest the pooling of equipment of the ground handlers. This will help to create a better overview and decrease the amount of delays when a GH is searching for their equipment. Also the use of all the same equipment (e.g. tow-trucks) will help to create a better traffic flow.

Besides that Schiphol wants to stimulate in decreasing the amount of Human Factors and use more technology. Also the focus should be on process innovations such as the remote aircraft handling (Zero-Tow concept).

The last solution which was mentioned is digitization. Which include placing digital boards at the remote gates, but also that every stakeholder should use the same source of information. This can lead to a decrease of miscommunications and increase the reliability of the system.

Appendix XVII – Interview summary KLM

Anonymous 6, KLM

Anonymous 7, KLM

1. *What are the current capacity bottlenecks at the airside infrastructure of Schiphol?*
 - a. *How was the operation influenced due to the identified bottleneck?*

The first bottleneck that was given during the interview at KLM was the shortage of space at Schiphol nowadays. Schiphol has grown rapidly over the past years and processed 68 million passengers in 2017. The amount of movements also grew rapidly but the last ten years the gate capacity hasn't grown at all. Now the airport wants to put airlines at remote stands and handle the aircraft over there, but this is not an option for KLM. KLM wants to keep the service level high to its customers. Also related to the growth is the increase in ground equipment at all the involved stakeholders, but there is no space available to store the equipment. It now has led to a chaotic situation, where GH's have to search for enough equipment, which results in more delays due to the ground handlers.

Next to the space limitations the trend analysis and master planning of Schiphol are also a big bottleneck for the airside infrastructure. Schiphol didn't invest to increase the ground capacity for ten years, then didn't watch the trends for the future demand. Now Schiphol is reaching its limits but still is not expanding their infrastructure. The question that was raised during the interview was: what will the benefit of the new terminal be? KLM doesn't understand why Schiphol didn't invest this money to create a new area at Schiphol (for example at the U-platforms)

In the years that Schiphol didn't show their plans KLM invested a lot of money in the existing cargo warehouses at Schiphol. When Schiphol had better future plans and discussed this much earlier, KLM wouldn't have made those investments in these buildings. Now KLM needs to wait for their return on investment.

What KLM also sees is that the space at the aircraft stands has developed with the newer aircraft but this also means that the space between two AC is sometimes limited and no traffic can pass the AC in between. It seems that the manoeuvring area is decreasing,

Furthermore, the cooperation between the stakeholders should be better. Now all the stakeholders mainly think about their self and pay no attention if the thing they want is beneficial for the other stakeholders. A lot of decisions are now made to solve the current problems but still we are not making steps forward. This also applies for the new A-pier, will this help if the traffic movements further increase or should we try to find another area to place the aircraft?

2. *Did one of the mentioned bottlenecks also occur in the past? If yes, what is the reason that this bottleneck isn't solved yet?*

Due to the fact that we (Schiphol, KLM and LVNL) didn't have a good constructive master planning almost all the bottlenecks occurred, but the impact was less high. Now with the current traffic mix and amount of traffic the consequences are felt.

3. *What are valuable solutions for the bottlenecks mentioned earlier?*

One of the main solutions which can be valuable for the airside infrastructure is starting with the investments at the U-area in the north of Schiphol. At this location still space is available, which first can be used to locate the ground equipment and outsourcing of the companies which are located underneath the piers at Schiphol. By doing this space is created at Schiphol centre, which can be used for the ground equipment. To start using the area in the north, the accessibility needs to be optimized, we can think about a tunnel. Furthermore, searching for a new layout of the Romeo area can help to increase the airside capacity of Schiphol.

Also the communication and cooperation between operational experts and the higher management should be better. The introduction of a group of specialists which can review and test the designs with their experience will help develop the airside infrastructure.

Appendix XVIII – Interview summary Aviapartner

S. Pots, Aviapartner

1. *What are the current capacity bottlenecks at the airside infrastructure of Schiphol?*
 - a. *How was the operation influenced due to the identified bottleneck?*

For the ground handler the gate capacity is very important, what we see nowadays is that the ground handler needs to wait before there is space for the new AC. When we start too late it can cause delays which are not easy to recover.

For us as GH, there are also different bottlenecks then for KLM, LVNL or Schiphol. Decisions they make can be negative for us as GH, but we just have to deal with the situation. For example the space to store the equipment have decreased drastically. Before we go to an AC we first need to check if we have enough equipment. Next to the equipment the space between two aircraft is getting smaller, and in some cases we can't even drive in between the two AC. This is not beneficial for the operation of the GHs.

Furthermore, a bottleneck for us is the way push-backs where handled. At Schiphol the rule was, first come first serve, with the result that in some cases the AC wasn't ready for the pushback but already requested it. This was causing different delays for other AC and also contribute to the low gate capacity. Now we start working with the TSAT the push-back schedule is organized on a better lever.

2. *What are valuable solutions for the bottlenecks mentioned earlier?*

To cope with different problems tool will be beneficial in different cases. We have to make sure that the tools are easy to work with for the personal and also that one format is used at Schiphol. Using tools will decrease the change of human errors.

Furthermore, Equipment pooling should be implemented faster at Schiphol. With this we are sure that for all the aircraft stands enough equipment is available and the equipment is all the same, which is cost saving. The only problem with pooling is: who is financially responsible? When there is some technical issue, who will pay for the costs.

Appendix XIX – Tow-movements with crossing information

AIRLINE	AIRCRAI	WEEKNUMBER	WEEKDAY	MONTH	ACR_AIRCRAFT_REGISTRATION	START_DATETIME	END_DATETIME	MINUTEN_DEEL	TYPE_OF_TOW2	FROM_1	TO_1	FROM_2	TO_2	AIRCRAFT_CLASS	TRUCK
ACG-Air Cargo Global	B744	28	donderdag	07	OMACJ	13-7-2017 16:41	13-7-2017 17:08	27	Crossing 06/24 + Movement 09/27	Buffer/Taxi-	Rnwy	S87	U04	V	KM
ACG-Air Cargo Global	B744	28	vrijdag	07	OMACJ	14-7-2017 09:40	14-7-2017 10:08	28	Crossing 18L/36R & 04/22 + Movement 09/27	Hangars	Buffer/Taxi-	U04	HG11	V	KJ
ACG-Air Cargo Global	B744	28	zaterdag	07	OMACJ	15-7-2017 19:17	15-7-2017 19:38	21	Crossing 18L/36R & 04/22 & 06/24	Vracht/SHLRIJK	Hangars	HG11	S94	V	KD
ACG-Air Cargo Global	B744	28	zondag	07	OMACJ	16-7-2017 15:25	16-7-2017 15:49	24	Crossing 18L/36R & 04/22 & 06/24	Buffer/Hangar	Vracht/SHLRIJK	S94	M74	V	KE
ACG-Air Cargo Global	B744	29	vrijdag	07	OMACJ	21-7-2017 16:04	21-7-2017 16:07	3	No Crossing	Hangars	Buffer/Hangar	M74	HG11	V	KR
ACG-Air Cargo Global	B744	29	zaterdag	07	OMACJ	22-7-2017 21:04	22-7-2017 21:08	4	No Crossing	Buffer/Hangar	Hangars	HG11	M62	V	KR
ACG-Air Cargo Global	B744	30	maandag	07	OMACJ	24-7-2017 07:53	24-7-2017 08:15	22	Crossing 18L/36R & 04/22 & 06/24	Vracht/SHLRIJK	Buffer/Hangar	M62	S94	V	KG
ACM Air Charter	F2TH	29	woensdag	07	DBIKA	19-7-2017 12:20	19-7-2017 12:21	1	No Crossing	GeneralAvi	GeneralAvi	K13	K12	II	XX
Aer Lingus	A320	29	woensdag	07	EIDER	19-7-2017 17:22	19-7-2017 17:23	1	#N/B	ONWAAR	Centrum	D29	P2	III	XX
Aeromexico	B788	33	zondag	08	N964AM	20-8-2017 06:26	20-8-2017 06:45	19	No Crossing	Remote/Buffer	Centrum	F03	P15	V	KD
Aeromexico	B788	33	zondag	08	N964AM	20-8-2017 15:52	20-8-2017 15:58	6	No Crossing	Centrum	Remote/Buffer	P15	F07	V	KO
Aeromexico	B788	34	maandag	08	N964AM	21-8-2017 01:08	21-8-2017 01:16	8	No Crossing	Remote/Buffer	Centrum	F07	E72	V	KB
Aeromexico	B788	34	maandag	08	N964AM	21-8-2017 08:34	21-8-2017 08:50	16	Crossing 18L/36R & 04/22	Buffer/Hangar	Remote/Buffer	E72	M70	V	KK
Aeromexico	B788	34	maandag	08	N964AM	21-8-2017 09:18	21-8-2017 09:20	2	No Crossing	Hangars	Buffer/Hangar	M70	HG11	V	KX
Aeromexico	B788	34	dinsdag	08	N964AM	22-8-2017 13:40	22-8-2017 13:58	18	Crossing 18L/36R & 04/22	Centrum	Hangars	HG11	E09	V	KE
Air Astana	A321	29	donderdag	07	P4NAS	20-7-2017 14:21	20-7-2017 14:33	12	No Crossing	Vracht/Buffer	Centrum	D28	R72	III	AN
Air Cairo	FA7X	29	donderdag	07	MSCMG	20-7-2017 19:39	20-7-2017 19:40	1	No Crossing	GeneralAvi	GeneralAvi	K35	K36	III	XX
Air Canada	A333	28	zaterdag	07	CGHKX	15-7-2017 12:27	15-7-2017 12:34	7	No Crossing	Remote/Buffer	Centrum	D47	E75	V	GI
Air Canada	A333	31	zaterdag	08	CGHLM	5-8-2017 15:15	5-8-2017 15:21	6	No Crossing	Centrum	Centrum	G07	E02	V	XX
Air Canada	A333	31	zaterdag	08	CGHLM	5-8-2017 21:08	5-8-2017 21:25	17	No Crossing	Remote/Buffer	Centrum	E02	G76	V	GA

Appendix XX – Tow-movements with active runway crossings

AIRLINE	AIRCRAI	START_DATETIME	END_DATETIME	ACTIVE_RNWWY_1	ACTIVE_RNWWY_2	ACTIVE_RNWWY_3	ACTIVE_RNWWY_4	CROSSED_RNWWY_1	CROSSED_RNWWY_2	CROSSED_RNWWY_3	CROSSED_RNWWY_4	CROSSED_RNWWY_5	CROSSED_RNWWY_6	ACTIVECROSSING	CROSSED_RNWW1	CROSSED_RNWW2
ACG-Air Cargo Global	B744	13-7-2017 16:41	13-7-2017 17:08	6 36R	36L	***		6	24	9	27	-	-	1	6	
ACG-Air Cargo Global	B744	14-7-2017 09:40	14-7-2017 10:08	27 18R			24 18L	18L	36R		4	22	9	27	2 18L	
ACG-Air Cargo Global	B744	15-7-2017 19:17	15-7-2017 19:38 18R	***			24 18L	18L	36R		4	22	6	24	2 18L	24
ACG-Air Cargo Global	B744	16-7-2017 15:25	16-7-2017 15:49 18R	***			24 18L	18L	36R		4	22	6	24	2 18L	24
ACG-Air Cargo Global	B744	21-7-2017 16:04	21-7-2017 16:07 18R	18C	18L	***		0 -	-	-	-	-	-	0		
ACG-Air Cargo Global	B744	22-7-2017 21:04	22-7-2017 21:08 18R	***			24 ***	0 -	-	-	-	-	-	0		
ACG-Air Cargo Global	B744	24-7-2017 07:53	24-7-2017 08:15	27 ***	36L		24 18L	36R		4	22	6	24	1	24	
ACM Air Charter	F2TH	19-7-2017 12:20	19-7-2017 12:21 18R	***			24 18L	0 -	-	-	-	-	-	0		
Aer Lingus	A320	19-7-2017 17:22	19-7-2017 17:23 18R	18C			24 18L	#N	B	-	-	-	-	0		
Aeromexico	B788	20-8-2017 06:26	20-8-2017 06:45 18R	18C			24 ***	0 -	-	-	-	-	-	0		
Aeromexico	B788	20-8-2017 15:52	20-8-2017 15:58	27 18R			24 ***	0 -	-	-	-	-	-	0		
Aeromexico	B788	21-8-2017 01:08	21-8-2017 01:16 18R	***			24 ***	0 -	-	-	-	-	-	0		
Aeromexico	B788	21-8-2017 08:34	21-8-2017 08:50 18R	18C			24 18L	18L	36R		4	22	-	1 18L		
Aeromexico	B788	21-8-2017 09:18	21-8-2017 09:20 18R	18C			24 18L	0 -	-	-	-	-	-	0		
Aeromexico	B788	22-8-2017 13:40	22-8-2017 13:58 18R	18C			24 18L	18L	36R		4	22	-	1 18L		
Air Astana	A321	20-7-2017 14:21	20-7-2017 14:33 18R	***			24 18L	0 -	-	-	-	-	-	0		
Air Cairo	FA7X	20-7-2017 19:39	20-7-2017 19:40 18R	***			24 18L	0 -	-	-	-	-	-	0		
Air Canada	A333	15-7-2017 12:27	15-7-2017 12:34 18R	***			24 18L	0 -	-	-	-	-	-	0		
Air Canada	A333	5-8-2017 15:15	5-8-2017 15:21 36R	***	36L		36C	0 -	-	-	-	-	-	0		
Air Canada	A333	5-8-2017 21:08	5-8-2017 21:25 18R	***			24 ***	0 -	-	-	-	-	-	0		

Appendix XXI – Tow-movements with active runway crossings

Type of TOW	Centrum	Remote/Buffer	Vracht/Buffer	Vracht/SHLRIJK	Buffer/Hangar	Buffer 18L/36R - 04/22	Hangars	Buffer/Taxi->Rnwy	GeneralAvi
Centrum (Gates)	1	1	1	4	5	2	5	8	5
Remote/Buffer (Schiphol centre)	1	1	1	4	5	2	5	8	5
Vracht/Buffer (R-apron)	1	1	1	4	5	2	5	8	5
Vracht/SHLRIJK (S-apron)	4	4	4	1	6	7	6	11	6
Buffer/Hangar (M-apron)	5	5	5	6	1	3	1	12	1
Buffer 18L/36R - 04/22 (Between two RNW)	2	2	2	7	3	1	3	9	3
Hangars (M-apron)	5	5	5	6	1	3	1	12	1
Buffer/Taxi->Rnwy (U-apron)	8	8	8	11	12	9	12	1	12
GeneralAvi (K-apron)	5	5	5	6	1	3	1	12	1

Type of crossing	Index
No Crossing	1
Crossing 18L/36R	2
Crossing 04/22	3
Crossing 06/24	4
Crossing 18L/36R & 04/22	5
Crossing 18L/36R & 04/22 & 06/24	6
Crossing 18L/36R & 06/24	7
Movement 09/27	8
Crossing 18L/36R + Movement 09/27	9
Crossing 04/22 + Movement 09/27	10
Crossing 06/24 + Movement 09/27	11
Crossing 18L/36R & 04/22 + Movement 09/27	12

