Optimization of the traffic system on the airside of Amsterdam Airport Schiphol

M. Borsboom

"How safe, robust, reliable and utilized is the traffic system on the airside of Amsterdam Airport Schiphol and how can this traffic system be improved regarding safety, robustness, reliability and utilization?"

Prof. Dr. Ir. S.P. (Serge) Hoogendoorn
Professor Traffic Flow Theory, Simulation and Management (CiTG)
Dr. ir. J.H. (John) Baggen
Daily supervisor (TPM)
Dr. ir. J.W.C. (Hans) van Lint
Daily supervisor (CiTG)
Ing. C.W. (Kees) van der Leek
Supervisor Amsterdam Airport Schiphol (AAS)

M.Borsboom@student.tudelft.nl
Studentnumber 4105664
T: 06-51043995
Graduation date: 28-12-2012

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Research on the safety, robustness, reliability and utilization of the traffic system on the airside of Amsterdam Airport Schiphol

Een onderzoek naar de veiligheid, robuustheid, betrouwbaarheid en benutting van het verkeerssysteem aan de airside van de luchthaven Schiphol

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Master of Science
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Author
BSc. M. Borsboom

Supervisors
Prof. Dr. Ir. S.P. (Serge) Hoogendoorn, Delft University of Technology
Professor Traffic Flow Theory, Simulation and Management (CiTG)
Dr. ir. J.H. (John) Baggen, Delft University of Technology
Daily supervisor (TPM)
Dr. ir. J.W.C. (Hans) van Lint, Delft University of Technology
Daily supervisor (CiTG)
Ing. C.W. (Kees) van der Leek
Supervisor Amsterdam Airport Schiphol (AAS)

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The project conducts a research to the way of optimization the traffic system on the airside of Amsterdam Airport Schiphol, regarding four main aspects: safety, robustness, reliability of travel times and network utilization aspects. Also the costs aspect is taken into account with regards to the potential improvement possibilities. A total of 15 different potential improvement possibilities are designed for optimizing the specific traffic system of Schiphol airport.

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BSc. Mirjam Borsboom

Samenvatting

De toegenomen hoeveelheid vluchtbewegingen in de afgelopen jaren heeft nieuwe vraagstukken opgeworpen voor de afdeling 'Airside Operations' van de luchthaven Schiphol omtrent de veiligheid, robuustheid, betrouwbaarheid en benutting van het verkeersysteem aan de airside. Er zijn reeds veel optimalisatieonderzoeken omtrent de landings- en taxibanen uitgevoerd, echter het ondersteunde verkeerssysteem, bestaande uit de infrastructuur voor alle service verlenende voertuigen, is tot op heden nog relatief onbelicht gebleven. Om meer inzicht te krijgen in de toekomstige situatie op de luchthaven Schiphol zal in dit onderzoek eerst het huidige verkeerssysteem worden geanalyseerd. Dit verkeerssysteem bestaat uit een hoofdas, de 'Rinse-Hofstra' weg en ondersteunende wegen richting de vliegtuig opstelplaatsen. Verder is bekend dat de omgeving waarin de luchthaven Schiphol opereert, bestaat uit een complexe 'multi-actor environment', waarin veel verschillende belanghebbenden betrokken zijn. Ook de verscheidenheid in voertuigen aan de airside is zeer divers. Kortom, een duidelijk voorbeeld van een uitdagend vraagstuk in een complexe omgeving.

De vier bovengenoemde aspecten (veiligheid, robuustheid, betrouwbaarheid en benutting) van het verkeerssysteem worden in dit onderzoek per stuk nader onderzocht. Uit elk aspect zullen verschillende verbetermogelijkheden voortvloeien;

Binnen het aspect *veiligheid* zijn verschillende analyses uitgevoerd: de 'Black spot' analyse, welke zowel alle eenzijdige aanrijdingen als aanrijdingen tussen voertuigen van de afgelopen 8 jaar in kaart brengt. Uit deze analyse zullen vervolgens de kritieke punten in het systeem volgen. De gevaarlijkste locaties blijken aan het begin van de pieren te liggen, aangezien hier de meeste ongelukken gebeuren. Een volgende analyse heeft in kaart gebracht dat de gemiddelde directe kosten per aanrijding €1612,99 euro bedragen. Dit impliceert dat het verminderen van het aantal aanrijdingen direct zal resulteren in (grote) financiële besparingen. Tot slot bleek dat 'menselijke fouten' de meest voorkomende oorzaak voor een ongeluk is.

Het tweede aspect wat is onderzocht is *robuustheid* van het systeem. Gedefinieerd als volgt: "het vermogen de functie te vervullen waar het systeem voor is ontworpen, zelfs in afwijkende situaties die (zeer) afwijken van de normale omstandigheden" (Snelder, Immers, & Wilmink, 2004). Het bleek dat de viaducten over de snelweg A4, de tunnels en het begin van de pieren niet robuust zijn, wanneer deze definitie werd toegepast op het system op de luchthaven Schiphol. Het robuustheidsaspect heeft met name in infrastructurele adviezen geresulteerd, zodat het bijvoorbeeld eenvoudiger wordt om andere voertuigen te passeren in geval van een ongeluk.

De *betrouwbaarheid* van reistijden is het derde aspect waar het verkeerssysteem op onderzocht is en waarvoor de vergelijking is gemaakt tussen reistijden met en zonder gebruik van de viaducten. Wanneer je vanaf de tunnel met bestemming F-pier rijdt, maakt het qua reistijd niet uit of je wel of niet gebruik maakt van de viaducten. Echter bleken de reistijden van de routes over de viaducten wel constanter. Wanneer daarnaast de maximale snelheid over de viaducten wordt verhoogd van 30 naar 50 km/h is deze route met als bestemming de F-pier het snelst. De route met bestemming de E-pier zal nu zowel via de viaducten als via de route langs de pieren in een vergelijkbare reistijd bereikt kunnen worden. Wanneer we het verkeer adviseren om de route met de viaducten te gebruiken, zal hierdoor het verkeer om en nabij de pieren afnemen. Een verhoging van de maximum snelheid op het viaducten-traject resulteert hierdoor in een hogere *benutting*, het vierde aspect van dit onderzoek. Hiervoor zijn tevens metingen naar de verkeersintensiteit gedaan, door middel van het plaatsen van drie verschillende filmcamera's op strategische locaties aan de airside. Het bleek dat een hogere benutting van bijna 40% bereikt kan worden, door het herleiden van verkeer over de viaducten in plaats van langs de pieren.

In totaal zijn er 15 verbetermogelijkheden en oplossingen aangedragen, compleet met implementatie strategieën, waarvan vijf verbetermogelijkheden het best geschikt bleken met het oog

op kosten, effectiviteit (op het gebied van de vier genoemde aspecten) en draagvlak. Deze vijf verbetermogelijkheden kunnen als volgt worden omschreven: het herleiden van verkeer over de viaducten om een meer optimale benutting van het gehele netwerk te bereiken, het verbeteren van de samenwerking tussen bepaald betrokkenen (met name ‘airside support’ in het hoofdgebouw en de havenpolitie aan de airside), het toevoegen van een extra (veiligheid gerelateerd) trainingscomponent toe te voegen aan de platformtraining voor alle nieuwe gebruikers van het systeem om zo meer bewustzijn te creëren, het verwijderen van de huidige groene oversteekplaatsen aan het begin van de D-pier en tot slot het terugbrengen van het aantal verkeersborden om zo meer overzicht te creëren.

Summary

The increased transportation air movements in the past years has raised questions at the department of Airside Operations of Amsterdam Airport Schiphol (AAS) regarding the safety, robustness, reliability and utilization of the airside traffic system. To get more insight to this future situation, the current situation is analyzed first. Rather limited information about the current traffic system was known, besides the fact it consists of the main artery the 'Rinse-Hofstra road' and the connecting roads towards the airplane stands.

Another observation within the area of AAS is the fact that the research is performed in a complex multi-level actor environment, involving many different stakeholders. Also the variety in vehicles on the airside is very large. The four aforementioned aspects are analyzed in detail and resulted into different improvement possibility proposals.

Regarding the safety aspect, several specific analyses are performed; using the black spot methodology, all unilateral and two-sided collisions of the past 8 years are analyzed. This methodology indicated that the main problem areas regarding safety are located at the beginning of the piers. Another analysis estimated an average damage costs of €1612.99 euro per collision, which indicated the fact that a reduction of collisions will directly result in (large) financial savings. Finally, it appears that 'human errors' are the most frequent causes for collisions.

The second aspect of which the traffic system is analyzed is robustness: *"the ability to fulfill the function of which the (traffic) system is designed for, even in non-regular situations which differ (strongly) from regular user conditions"* (Snelder, Immers, & Wilmink, 2004). It appears, using this definition, that the viaducts crossing the A4 highway, the tunnels and the beginning of the piers are not very robust for several reasons; this aspect resulted in mostly infrastructural related improvement possibilities, to make it possible to overtake other vehicles more easily and being able to reroute traffic more easily in case of an accident.

The reliability of travel times is the third aspect the traffic system is assessed on, by performing travel time measurements with and without viaducts on the routes. It appears that the F-pier could be reached in the same travel time using the viaducts, coming from the tunnel, although these measurements result in slightly more constant travel times using the 'viaduct-route'. With the additional proposed improvement possibility of increasing the speed on the viaducts from 30 to 50 km/h, the F-pier can be reached faster by the 'viaducts-route' and now the E-pier can be reached in equal time by both routes. Increasing the speed on the viaducts will result in an increased use of the viaducts, which will lead to an increased utilization; this is the fourth aspect in this research. To get more insight in the number of vehicles using the viaducts and other strategic locations within the system, traffic volume measurements are performed by placing three cameras on the airside. It appears that an increased traffic volume of almost 40% of the viaducts can be realized in this way, and so reduction of the same amount on the other route, resulting in an improved utilization.

Concluding, a total of 15 different improvement possibilities, with corresponding implementation strategies, are proposed within this research, of which 5 improvement possibilities are resulted as the best improvement possibilities regarding **costs**, **effectiveness** (regarding the four aspects) and **stakeholder support**. These four improvement possibilities are: rerouting traffic over the viaducts to maximize the utilization of the network, increase the cooperation between stakeholders (mostly Airside Support and Airport Authority), add an extra (safety related) training component for new users, remove the current green pedestrian crossings and reduce the number of traffic signs to create a more clear overview.

Notation

Abbreviations

AAS	Amsterdam Airport Schiphol
AAO	Airside Authority Officer
ACC	Area Control Sector
AO	Airside Operations
CIS	'Centraal Informatie System' (central information system)
'DSL'	'Douane Scan Loods' (cargo customs)
ETS	Emission Trading System
GPU	Ground Power Unit
GSE	Ground Service Equipment
LVNL	'Lucht Verkeersleiding Nederland' (air traffic control within the Netherlands')
PMA	Process Management Airside
SDP	Schiphol Development Plan
UAC	Upper Area Control
VH	'Vertrek Hal' (departure hall)

Glossary

The Dutch translation of some definitions is placed in brackets behind the definition.

Action radius: Radius of an area within a specific vehicle mostly operates.

Aircraft stand ('Vliegtuigopstelplaats, VOP'): area where airplanes are handled.

Braking distance: the distance a vehicle needs to stand still from a specific driving speed.

Capacity: the maximum possible number of vehicles per hour per lane.

Closed Network: every node is connected with at least two other notes in the same network.

Collision one-sided: a vehicle that unintentionally physically contacts infrastructural elements within a traffic system.

Collision two-sided: two or more vehicles that unintentionally interact physically with each other within a traffic system. Possibly infrastructure is involved and/ or will be damaged.

Deceleration: the negative acceleration of a vehicle caused by braking.

Design speed: the speed at which a vehicle can follow its lane safely.

Detour: the route a vehicle has to take when his original route is blocked for any reason; most of the time extra travel time should be taken into account.

Dynamic traffic management: inform, advise, guide and control traffic and road users using real-time information, from systems within the vehicle, at home or along or above the road.

Entrances: places where users can enter the traffic system, mostly gates.

Incident: "an unexpected, undesirable and reported event (without clear causes, without necessary causing damage), (possibly) leading to loss" (The Schiphol Group, May 2012).

Infrastructure: fixed traffic facilities that carry, guide, and provide safe way for traffic units.

Lane: single road

Radial structure: ring shaped structure; the way in which the traffic system on the airside of AAS can be characterized.

Reliability: the extent to which a traveller (or user) is able to estimate the time needed to travel with a particular certainty.

Remote VOP: aircraft stand without a bridge or direction connection with the terminal**.**

Roundabout: circular road on which various lanes branches to the circle designed so that conflicting movements are minimized; traffic is moving only counterclockwise.

Response time: the time needed to transform information to actual action.

Robustness: the ability to fulfill the function of which the network is designed for, even in non-regular situations that differ (strongly) from regular conditions.

Safety: relative freedom from danger, risk, or threat of harm, injury, or loss to personnel and/or property either caused deliberately or by accident.

Slow speed traffic: traffic that is not capable enough to drive faster than 20 km/h.

Stakeholder: a single or group of individuals who have a particular interest or are active in a particular sector of transportation.

Traffic flow: number of vehicles following each other on the same path.

Traffic volume/ volume: the number of pae (passenger car equivalents) per time unit.

Traffic system (on the airside of AAS): the 'Rinse-Hofstra road' together with the supporting roads along the piers, to the airplane stands, which services all users of the system.

Trajectory speed: average speed of the traffic measured over a certain path.

Utilization: the extent to which the traffic flow is used as optimized as possible using the currently available infrastructure.

Vehicle length: the average length of all vehicles on the airside at AAS.

Weaving motion: behavior of users when joining adjacent lanes.

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1. Introduction

More and more optimization studies are performed on traffic systems nowadays. The congestion on roads in the Netherlands has decreased in the first months of 2012 partly because of the construction of new roads (Elsevier, 2012). Probably also a reduction of congestion occurred due to the economic crisis. But the statement that more roads will lead to less congestion has been questioned for years. Experts state that construction new roads will attract new users, which will not solve the problem and could even worsen the problem (Van Wee, 2010). It should be mentioned that the focus should be on the consumers' surplus, because additional roads also serve more users, so the overall effect could be different.

The public interest of congestion is clear to many; everybody who is using the roads in the Netherlands knows the disadvantage of the congested morning and evening peaks. The disadvantage of congestion can be identified in many ways: loss of time, damage, accidents, frustration etc.

Congestion is defined as: "roads and towns where there is too much traffic and movement is made difficult" (Cambridge Dictionaries Online, 2011). Later on in this research, a more specific definition will be provided to quantify several aspects and improvements. In practice it is specified as the density of vehicles on a road becoming higher than the critical density of that specific section.

Congestion occurs in many places, of which the aforementioned freeways in the Netherlands are known to be very congested. But there are more places where congestion occurs, for example at airports. These traffic systems are unique systems; special isolated traffic systems, located behind airport security, facilitate the ground handling traffic so they can fulfill their flight operations tasks, can also experience congestion problems. Congestion in this case often causes delays, damage and possibly accidents. These problems will probably worsen when even more passengers are predicted in the coming years.

This research will focus on congestion at the traffic system on the airside of the largest airport in the Netherlands, Amsterdam Airport Schiphol, located south of Amsterdam. It is the fifth largest airport in Europe regarding air transport movements, fourth regarding passenger transport (excl. transit-direct) and even third regarding cargo transport in Europe (Schiphol, 2012); an overview of these rankings is provided in Appendix E. Of the total passengers travelling by air in the Netherlands 92% travel through Amsterdam Airport Schiphol (CBS, 2012). In this kick-off document the approach of the graduation thesis at Schiphol Group will be proposed and a more detailed view and scope will be provided on the activities and planning of the coming six months.

First an introduction of Amsterdam Airport Schiphol and the assignment provided by the Schiphol Group will be discussed, followed by the main research question, sub questions, the process description and goal tree in the second section. This document will conclude with the third section containing the practical aspects as graduation committee and planning using a Gantt chart.

1.1 Amsterdam Airport Schiphol

The complete name of Schiphol airport is Amsterdam Airport Schiphol, further on in this document the abbreviation 'AAS' will be used. AAS is part of the 'Schiphol Group' company, which consists of four shareholders: the 'Stat der Nederlanden' (69.8% of all stock), Amsterdam (for 20.0% owner), Rotterdam (2.2% owner) and Aéroports de Paris (the airport company of Paris 8.0% owner). Besides Schiphol Airport, also the airports of Rotterdam, Eindhoven and Lelystad are part of the Schiphol Group.

The complete area of AAS is 2,787 hectare, which is 27,870,000 m² in total. AAS is of great importance to the Netherlands, because it provides direct employment to almost 60,000 people and indirectly (companies which thanks their existence to AAS but are located outside the direct area of AAS) even 170,000 people. Almost 550 companies are located on Schiphol Airport and provides, together with Charles de Gaulle airport in Paris, a home base for Air France-KLM and the SkyTeam Alliance.

This research will focus on the traffic system on the airside of AAS, which includes the 'Rinse Hofstraweg' and surrounding roads and facilitates the ground handling traffic by fulfilling their flight operations tasks. For example baggage, cargo and passenger handling, water refreshment, fuelling and catering services. The system also supplies the services companies, such as the Airport Authority, customs and the 'Koninklijke Marechaussee' (KMar). Figure 1.1 displays the traffic system in green. Besides this bypass, more surrounding roads are located in the area of AAS, but these roads will probably not be taken into account in this research because the expected amount of traffic flows will be minimal and will not cause any congestion problems.

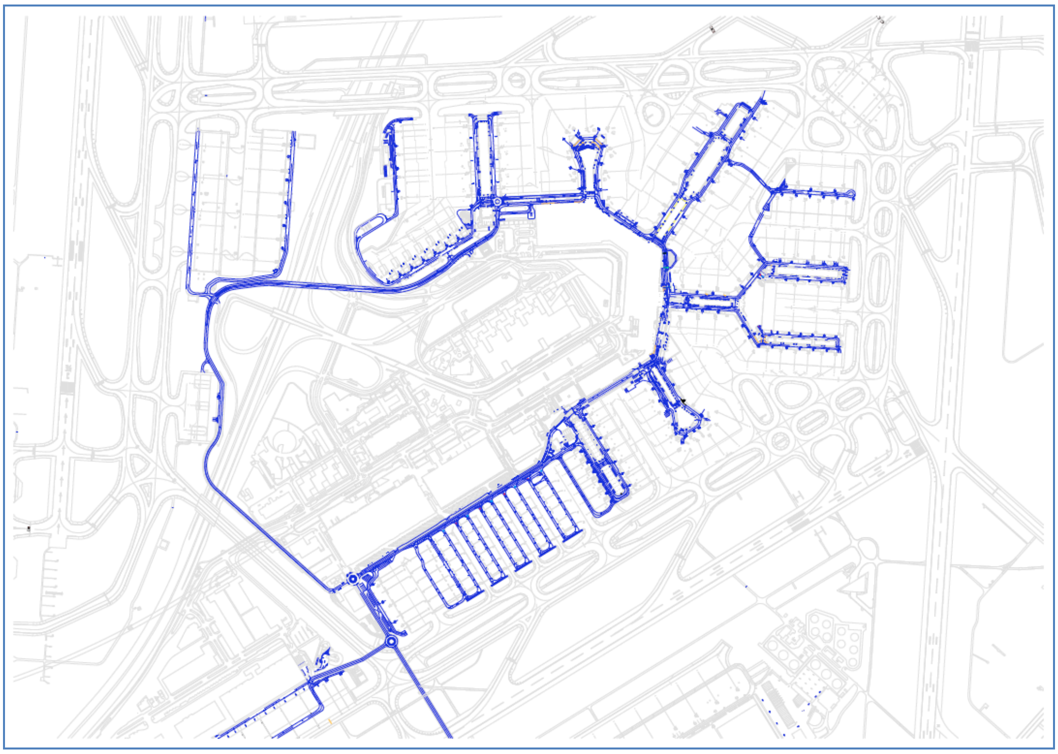

Figure 1.1; Map of the traffic system at AAS: the traffic system is displayed in green

1.2 Problem definition

Schiphol is focusing more and more on the safety on the airside, because of the rising competitive environment in the airport industry. Also the customers of AAS, for example the biggest airline at Schiphol, KLM, have their demands to the services they pay for, in this case the traffic system they use for handling their airplanes, which will be not congested at all in the most ideal situation.

The motivation for this research is the current and also predicted growth in air transportation movements, which will result in more planes at AAS, which will also generate more traffic on the airside.

Too much traffic could result into congestion, which could lead to delays; combined with the fact that the traffic system of AAS has not experienced many adjustments throughout time; this subject requires more attention within the Schiphol Group.

For all of these reasons, the problem definition is defined as follows:
"Because of the rising competition within the airport industry, fulfilling the satisfaction level and demands of customers (travellers, airlines, airplane handlers and other service companies at AAS) and the growing air transportation movements which could result in delays on the airside, the Schiphol Group is aiming to get more insight in the traffic flows and capacity of the traffic system on the airside."

A more specific assignment description from the perspective of AAS can be found in appendix A.1. Now the problem is defined, the objectives of this research could be set and will be discussed in the next section.

1.3 Objectives

Within this section the objectives of this research will be discussed. A deviation is made between practical objectives, (directly) applicable for AAS, and scientific objectives, defined for literature.

The practical objectives can be stated according the four main aspects within this research: safety, robustness, reliability and utilization. Increasing the safety level on the airside will results in less collisions, both unilateral as between vehicles, and so will results in financial savings. Improving the robustness situation on the airside will provide more flexibility within the traffic system, resulting in the ability to cope better with (un) expected events with as positive consequences less disturbances in the system. When discussed the reliability within this research it can be stated that encouraging users to choose routes with a more constant travel time, using the viaducts if applicable, will results in a higher utilization of the complete system and so less congestion at the congested locations. Finally, spreading traffic over the complete infrastructure on the airside will have the same effect as encouraging users to choose specific routes more often, namely optimizing the utilization of the complete system.

These four aspects are chosen, because of the often use in literature in comparable research, which encounters mostly safety, robustness and reliability. The utilization aspect is also analyzed within this research because of the added specific scope of traffic management within this research, performed at the faculty of Civil Engineering at the department of Transport & Planning and therefore a common and influencing aspect within this department. The utilization aspect is also taken into account because of the expected large potential on the airside of AAS. The costs aspect is mainly taken into scope because of the high level-of-importance judged by AAS, mainly experienced during interviews at AAS.

Scientific objectives could be found in the area of used methodologies. So far, little research is performed on traffic system of airports, because of the relative low need to focus on this area. In prospect of the predicated increasing air traffic movements in the future, operating with the same amount of infrastructure as is nowadays available, the focus could be split so also more attention to the capacity and usage of the service roads to achieve a optimal traffic system, capable of both the current and future air traffic movements. Including the fact that the four aspects (safety, robustness, reliability and utilization) could be very well used for these kinds of research, providing a sufficient overview of the current and future state of the traffic system at airports. In this case the airport of Amsterdam is taken as case study, but also other airports could be benefit from this methodology and optimize their traffic system using these four aspects and the applied method.

Also the more practical executed measurements could be taken as example for other airports to get more insight in their traffic system, both the traffic volume, using cameras on strategic locations to count actual traffic, as the travel time measurements, to get more insight in distances and travel times resulting in route choice and behavior.

1.4 Research questions

The previous section defined the objectives, indicating with which goals this research is performed. To get more insight in the focus of this research, the main research question and sub questions are formulated and will be elaborated on in this section.

1.4.1 Main research question

As mentioned in the previous section, research should be performed to require more insight in the current state of the traffic system on the airside of AAS regarding robustness, reliability, utilization and safety. When taking these four aspects into account, the problem, as defined into the problem definition in the previous section, could be solved. This results in the following main question:

"How safe, robust, reliable and utilized is the traffic system on the airside of Amsterdam Airport Schiphol and how can this traffic system be improved regarding safety, robustness, reliability and utilization?"

The four main aspects how to measure the state of the traffic system can be seen as overarching concepts which contain several smaller elements. Along the research these four main aspects will be defined more in detail. Besides these four main aspects, costs are also a very important aspect regarding the implementation phase of proposed improvement possibilities, even more when the fact that the current economic crisis, which is expected to endure in the near future, is taken into consideration (CPB.nl, 2012).

To answer the main question as stated above, different sub questions are formulated which together will answer the main question. In the next part the sub questions will be discussed.

1.4.2 Sub questions

For this research seven different sub questions (SQs) are defined, which together with the conclusions and recommendations will results in the nine chapters that together form the complete master thesis. After listing the sub-question, the location in this document where each sub-question will be answered will be discussed shortly. The next section will provide an overview of the research approach. For each sub question rising questions are listed, which split up the related sub-question and contributes in answering that sub-question;

SQ 1: "Which aspects should be taken into account in this research, which together will form the scope of this research?"

- How can safety, robustness, reliability and utilization effectively be defined?
- If and if yes, how are aforementioned aspects interrelated?

SQ 2: "What is the current situation of the traffic system and its traffic flows at AAS and how will this change in the future?"

- What is the current situation of the traffic system at AAS?
    - What exactly is the traffic system at AAS, what are the (physical) boundaries and where is it located?
    - What kinds of vehicles are using the traffic system?
    - Which companies and other users currently are using the traffic system?
- What are the current traffic flows within the traffic system at AAS?
    - What are the main important origins and destinations of the different vehicles?
    - How are the traffic flows operating in the traffic system regarding size and direction?

SQ 3: "What kind of problem areas can be indicated regarding the current situation and what are the main causes of these problem areas?"

- Where are the problems located in the traffic system? Are there any specific areas in the traffic system where problems arise more frequently and regarding which of the four main aspects? Is it possible to identify a main/ several problem areas(s)?
- In what way is it experienced as a problem area and by whom?
- What are the consequences if the problem area(s) is not solved?
- What is/are the **cause(s)** that this/these specific area(s) encounter more problems than other areas?
- What is/are the consequences of these problem area(s), both for the future and current situation?

SQ 4: "What will the future situation be regarding the traffic system at AAS?"

- What are the future developments of AAS?
  - How will the current situation change regarding the new masterplan (2020) at AAS, regarding the airside of AAS?
- What is the capacity of the traffic system, in terms of available roads?
- What is the demand of the traffic system, in terms of what amount of traffic is generated within a specific time frame for airport operations?

SQ 5: "How can the main problem areas be improved in the traffic system at AAS both in the current and future situation"?

- What kind of potential **improvement possibilities** or **improvement possibilities** can solve the problem areas most effective**?**
- What kind of **consequences** and **involved costs** will these improvement possibilities have and what is the attitude of **stakeholders** towards these improvement possibilities?

SQ 6: "What are the differences between the improvement possibilities regarding safety, robustness, reliability and utilization?"

- How can we compare different potential improvement possibilities in a realistic way to see if it provides a improvement possibility and what the effects are from the different scenarios?
- How are different potential improvement possibilities rated on different aspects, using a scoring-methodology?

SQ 7: "What elements should be taken into account regarding implementation of the proposed improvement possibilities?"

- What kind of implementation strategy should be followed (per potential improvement possibility)?
- What are the attitude, interest and power of related stakeholders?
- What are the financial consequences of each improvement possibility?

The objectives within the previous section provided more insight in the reasons for using specifically these four main aspects in this research while chapter 2 will limit the scope of the research describing general information about AAS. Both elements will answer together sub-question 1 (SQ 1). An analysis of the current situation (SQ 2), together with a description of the main problems areas (SQ 3) is covered in chapter 3, 4, 5 and 6; all related to one of the four individual mentioned aspects. A side step is made regarding the future masterplan of AAS in the end of chapter 6. Next, the identified problem areas can be solved or at least reduced by the improvement possibilities proposed in chapter 7 (SQ 5). Within this chapter, also a scoring methodology will be used to score the individual improvement possibilities regarding their consequences and costs (SQ 6). Also the attitude, interest and power of stakeholders regarding the individual improvement possibilities are discussed here.

Finally, chapter 8 (SQ 7) will contain the implementation strategy for the proposed improvement possibilities. This thesis report will end with conclusions and recommendations of the complete research described in this report. Now first an overview is provided of the approach of the complete research in the following section.

1.5 Research approach overview

The approach of this graduation thesis is visualized in figure 1.2, including the related chapter numbers. Different processes will fulfill different sub goals, which eventually will result in fulfilling the main goal. The complete process consists of three main blocks: the context of the airside transportation system of AAS, the analyses phase and finally all improvement possibilities designs and conclusions.

This master thesis will have an interdisciplinary character, because both the perspective of Civil Engineering, Geosciences and of Technology (CiTG), Policy and Management (TPM) will be taken into account during the execution of this research.

Within the context of the airside transportation system of AAS an overview will be provided of the following subjects: economic activities, transport services, traffic services and transport and traffic markets; all sections are related to the TRAIL-layer model. Besides the practical implementation of the TRAIL-layer model, also literature study is performed within chapter 2 to get more reliable analyses because of more accurate definitions for the adopted aspects (robustness, reliability, safety and costs).

The next phase is the analyses phase, in which four different analyses are executed regarding four pre-defined aspects: safety, robustness, reliability and utilization. Within each analysis phase different subsection can be distinguished, which will be introduced in the beginning of each chapter.

The final phase will consist of three parts: a description of all formulated potential improvement possibilities resulted out of the analyses phase including a scoring method to get more insight in differences between improvement possibilities, an advised implementation strategy and finally conclusions and recommendations.

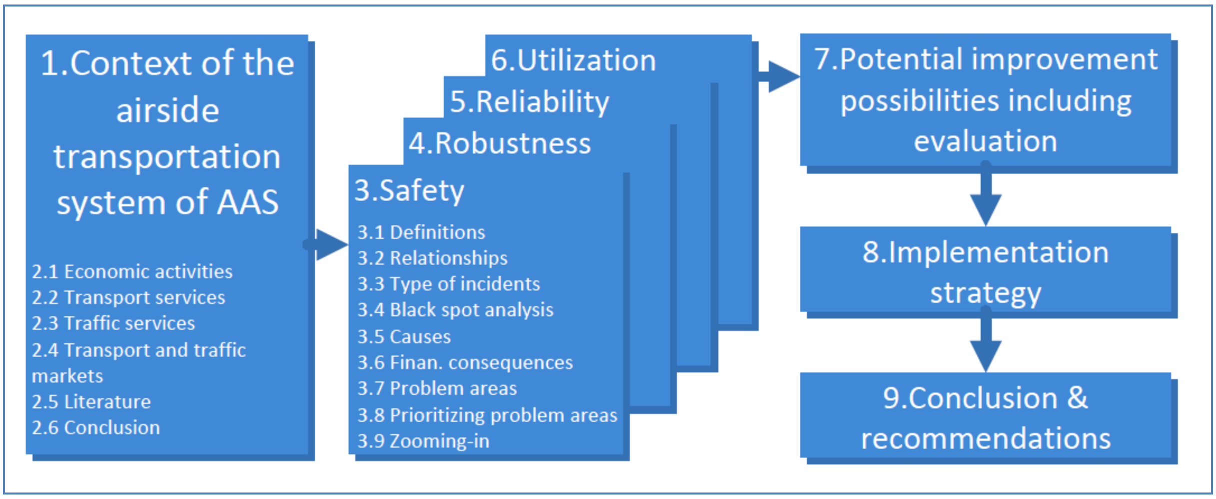

Figure 1.2; Process description of this research, including related chapter numbers

1.5.1 Gantt chart

Besides the process description also a Gantt chart is constructed to get more insight in the process approach time-wise, which can be seen in appendix A.2. Sequential tasks can be identified more clearly this way. The four obligatory meeting moments, mentioned earlier in the beginning of this section, are also indicated clearly in the Gantt chart; this way a transparent execution of the master thesis is reached and everyone knows what to expect on the collective meetings. Also the demarcated phases are indicated on top in the chart.

1.5.2 Goal tree

Table A.1 in appendix A.3 displays the goal tree of this research, split up in different sub goals. Each sub goal can be specified into different activities, which all have their own deliverable and related deadline. These goals are clustered in the same eight chapters as the report. Also the sub questions (SQ) are displayed in the 'Goal column' in which phase they will be answered.

1.5.3 Methodology

Different frameworks and methodologies are used in this research, with each having different goals. For this and other reasons it is chosen to elaborate more on the methodology when it is actual used. Within this section only the scientific methodologies from literature that are used in this research will be listed, why the methodology is used in this research and the corresponding location in this report where the methodology is used and so also elaborated on;

- The TRAIL-layer framework (Schoemaker et al., 1999): used to structure chapter 2, the context of the airside transportation system of AAS.

- The Black spot analysis (Geurts & Wets, 2003): used in section 3.4 within the safety analysis of the traffic system to indicate the location of the collisions occurred in the past at airside of AAS.

- Road capacity calculation methodology (De Jong, 2004): used in section 6.3, road capacity, to provide insight in the road capacities at airside of AAS and predict future road capacities regarding the new masterplan.

- GGB+ methodology (in Dutch "Gebieds Gericht Benutten Plus") (Van Kooten & Adams, 2011): a suitable design framework, used through the complete research, for instance section 2.3.4 to label different type of roads and their functions and section 7.1 and 7.2 regarding potential improvement possibilities. The methodology is designed by Rijkswaterstaat, from the Dutch Ministry of Infrastructure, to analyse transportation system and provide improvement possibility directions to improve this system.

- Different stakeholder coopertion labels (Hillson & Simon, 2007): used in section 8.2, stakeholder cooperation, to label the different stakeholders in sense of their power and interest towards new potential improvement possibilities.

Section 7.2 qualifies all different methodologies into qualitative or quantitative analyses, in which also more general methodologies, for instance interviews, are taken into account.

2. Context of the airside transportation system of AAS

Before going into more in depth on the four aforementioned aspects on which the traffic system on the airside at AAS will be assessed, first a general description is provided in this chapter to get more insight in the context in which the research is held and in the complete transportation system itself, before it is analyzed more in depth. To structure all information related to the transportation system on the airside of AAS, a scientific model is used, called the Trail Layer model (Schoemaker et al., 1999). This framework is visualized in figure 2.1 and is often used in literature to analyze a transportation system and provide a clear overview of this system. Transportation system contains different elements with interconnected relations and similarities. The TRAIL-layer framework provides a generic framework and so a proper understanding of all these phenomena. The framework consists of three layers, Economic activities, Transport services and Traffic services, and two markets between them: Transport market and Traffic market. The three layers will be discussed separately in section 2.1, 2.2 and 2.3 respectively, while the two markets will be discussed together in section 2.4.

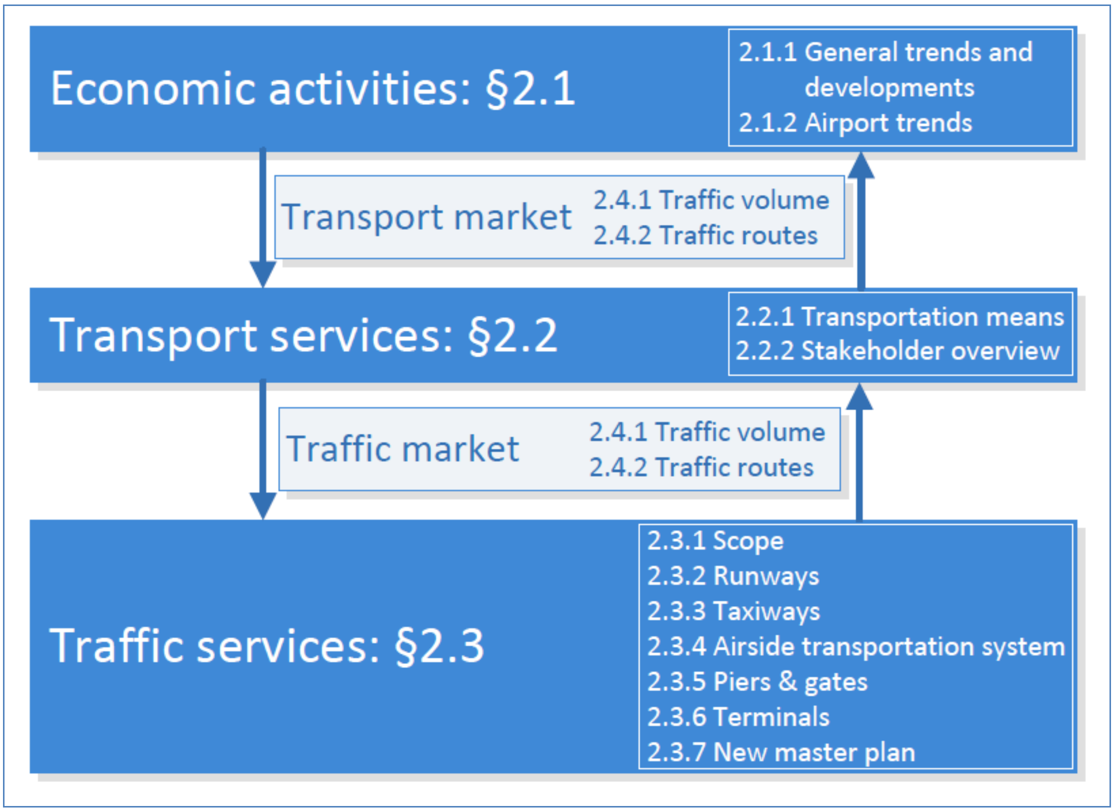

Figure 2.1; TRAIL framework applied to chapter 2 (Schoemaker et al., 1999)

Economic activities contain general aviation and airport trends and related developments. Section 2.2 elaborates on transport services, split in discussing transportation means and a providing a stakeholder overview. Traffic services can be seen as the infrastructural elements of the research areas. They will be discussed in section 2.3 and consists of seven different elements: scope, runways, taxiways, the airside transportation system, piers & gates, terminals and an insight in the newly developed masterplan. The final elements of the TRAIL-layer model are the transport and traffic market, functioning as relations between the three main layers. These two markets will be discussed together in section 2.4.

This chapter closes with a separate section about traffic flow theory and traffic management, section 2.5, providing more insight in literature regarding traffic, which together with the information from the Trail Layer framework will be used as background information in this research. Section 2.6 will provide a short conclusion of this chapter.

Within this chapter sub question 2 will be answered: *"How does the current situation and traffic flows of the traffic system at AAS looks like at the moment and how will this change in the future?"* At the of this chapter more information is gathered in the context of this research and in the next chapter 3, 4, 5 and 6 each of the four mentioned aspects (safety, robustness, reliability and utilization) will be analyzed separately.

2.1 Economic activities

The first layer of the TRAIL-layer model describes economic activities, both present activities as future economic activities. This broad layer is split into two sections: general aviation trends and developments and more specific airport trends. The latter can be distinguished into two subsections: the total growing amount of air traffic movements in general and three scenarios of (aviation) market expectations.

2.1.1 General aviation trends

In every sector different trends dominate at some point the market. Three main aviation trends will be discussed in this subsection; first, the mergers and acquisitions of airlines are a general trend that arose in the last few years and can be seen as a growing trend nowadays in several counties across the globe. These highly strategic decisions are influencing the customer composition of AAS and will have consequences in stakeholder policies (Finance maps of World, 2012). Another general trend is the growing extensive internationalization, which creates more collaboration, for example by setting up cooperation with another airport in the world. These collaboration initiatives can be used for sharing best practices for example (Anna.Aero, 2012). A third trend that will is seen within the market is a trend watched in 2012 within the spending of different airports. Next to the traffic recovery seen in 2010, airports increased their IT and telecommunications (IT&T) spending as a percentage of overall revenues. It also shows that while the economic recovery remains uncertain, airports expect their IT spend to increase in 2012 (Sita Aero, 2012).

2.1.2 Airport trends

Now three general aviation trends are discussed in the previous section, two more specific airport trends will be discussed now: the growing amount of air traffic movements and three different scenarios of market expectations, developed by AAS to get more insight in airport trends.

Growing amount of traffic

The growing amount of traffic is characterized by the amount of air traffic movements. The amount of traffic is decreased because of the economic crisis in 2008 but is now increasing again, which one can see in table 2.1 and figure 2.2. On long term the amount of passengers is predicted to grow even further: "annual and peak-volumes will increase until 2025 with about 40% and 25% respectively" (Schiphol Development Plan 2013-2017, 2012).

Table 2.1; Yearly Passenger, cargo volume and air transport movements (Annual report Schiphol Group, 2009 and 2011)

Year	Yearly Passengers transport (mln)	OD-passengers (mln)	Transfer-passengers (mln)	Yearly Cargo transport (tonnes)	Yearly air transport movements
2008	47.4	27.1	20.4	1,566,000	410,500
2009	43.6	24.7	18.9	1,286,000	377,700
2010	45.2	26.4	18.7	1,512,256	386,316
2011	49.8	29.5	20.2	1,524,806	420,249

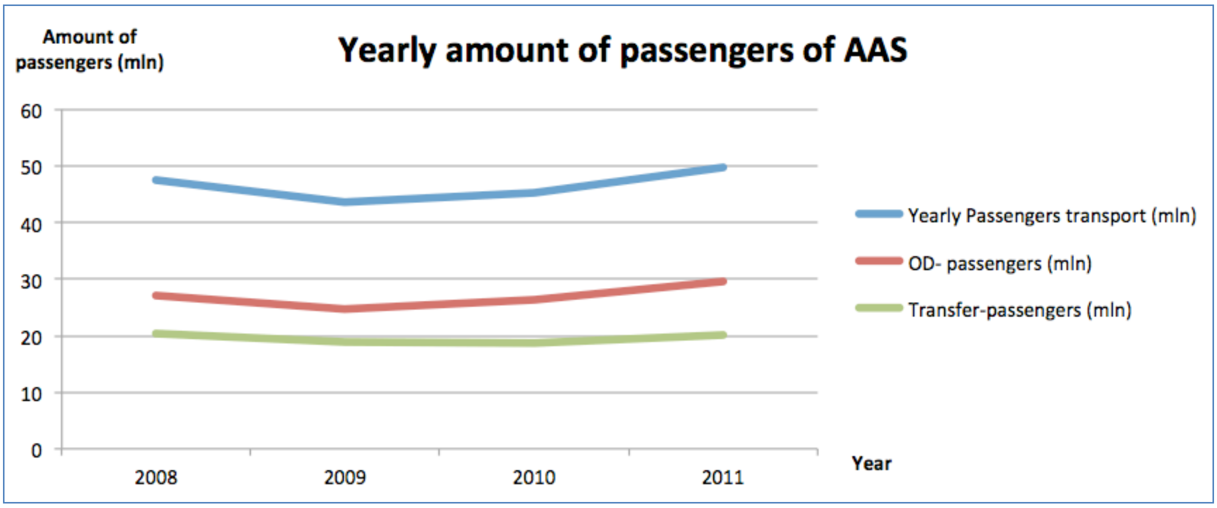

Figure 2.2; total yearly amount of passenger of AAS, split in OD- and transfer-passenger (mln passengers)

Eurocontrol predicts a medium-term average growth of 1.9% per year for the period of 2012-2018 (Eurocontrol, September 2012). This medium-term prediction will be taken to forecast the developments on the airside regarding the current traffic volume related to the capacity. More in-depth information can be found in appendix E.3.

Three scenarios of market expectations

There can be three different scenarios assumed about future market expectations:

- **High**: slightly increasing economic growth in the next five years of developed countries. The price of oil will also increase slightly, because of (geo-) political stability and investments in new fields while the effects of Emission Trading System (ETS) will be limited, these factors combined will results in a growth of AAS.

- **Medium**: also a slightly increase of economic growth in the next five year of developed countries. The price of oil will increase even more because of the continuous demand of growing economies, which will results in a slight growth of AAS, also again because of a limited effect of ETS.

- **Low**: in this scenario almost no growth of developed economies is expected in the coming five year. The price of oil will rise less than before because of the decreasing demand and again a limited effect of ETS (Schiphol Development Plan 2013-2017, 2012).

2.2 Transport services

The second layer of the TRAIL-layer framework are the transport services, discussed by the different means of transportation on the airside of AAS and providing a stakeholder overview of all involved parties.

2.2.1 Means of transportation on the airside of AAS

Per service different type of vehicles can be indicated, divided into three different categories: "Slow speed vehicles", "Normal speed vehicles" and "Aircraft stand vehicles". Vehicles driving most of the time less than 20 km/h are categorized as "slow", and vehicles able of driving faster than 20 km/h as "normal". This driving speed is estimated on personal experience of the driving behavior of different vehicles and checked by experts of AAS. All three categories will be discussed shortly.

"Slow speed vehicles"

The following vehicles are indicated as "slow" vehicles: animal transport (figure 2.3), pushback vehicles (figure 2.4), cargo and/or baggage vehicles with three or more dolly's/ trolleys (figure 2.5), forklifts (figure 2.6), palletizers (figure 2.7) and fuelling trucks (figure 2.8). All photos are taken on the 7th of November 2012.Also other vehicles not able to drive harder than 20 km/h are indicated as "slow speed vehicles", for example heavy construction vehicles, although not photo is provided.

Figure 2.3;Animal transport

Figure 2.4; Push-back truck

Figure 2.5; Cargo dolleys

Figure 2.6; Forklift truck

Figure 2.7; Palletizer

Figure 2.8; Fuelling truck

"Normal speed vehicles"

All vehicles able to drive more than 20 km/h on the airside are labeled as "normal speed vehicles". Six examples are provided: Baggage / cargo trucks (figure 2.9), catering trucks (figure 2.10), passenger busses (figure 2.11), airside authority vehicles (figure 2.12), dispensers (figure 2.13) and passenger vans / cars (figure 2.14). All photos are taken on the 7th of November 2012.

Figure 2.9; Baggage/cargo truck

Figure 2.10; Catering truck

Figure 2.11; Passenger bus

Figure 2.12; Airside authority vehicle

Figure 2.13; Dispenser

Figure 2.14; KLM passenger van

"Aircraft stand vehicles"

Two examples of aircraft stand vehicles are displayed in figure 2.15 and 2.16. The Ground Power Unit (GPU) is fixed available on the aircraft stands, while the stairs could possibly moved to a stand nearby, but in practice this happens rarely. The list with all different types of vehicles on the airside is displayed in appendix B.3.

Figure 2.15; Stairs

Figure 2.16; Ground Power Unit (GPU), fixed on large aircraft stands

2.2.2 Stakeholders overview

The second part of the transport services layer of the TRAIL framework will be discussed by providing a stakeholder overview. As mentioned before, the Schiphol Group is characterized as a complex multi-stakeholder environment, because of the large variety of stakeholders. This create a complex and at the same time interesting environment for executing this project. Within this section, the division is made between organizational stakeholders, focusing on management-related topics, and operational stakeholders, which are the every day users of the traffic system. Within the operational stakeholders, the different services available on the airside and the actual companies operating on the airside are discussed. This section concludes with providing a clear overview of all stakeholders, their power and interest regarding this research, by using a power versus interest grid.

Organizational stakeholders within the company of AAS

Within the organizational structure, displayed in figure 2.17, the government of the Netherlands is also included, although it is not part of the Schiphol Group, because of the large economic impact of the Schiphol Group to the Dutch economy. Handling companies are also included within the structure, because of the fact that these companies are the largest companies on the airside, therefore have a large stake and are directly involved in this research. The Schiphol Group is split in three different locations: AAS, Lelystad Airport and Brisbane Airport. The focus of this research will be on AAS only and so ‘the Schiphol Group’ will be further referred to as ‘AAS’. Different department form together AAS, of which the focus in this research will be on Operations and Security and not on for example the Real Estate and Asset Management departments. This research is requested by the department of Airside Operations, which is split in Airport Support (AS) and Airport Authority (AA). These two departments consist of different smaller departments, which are visualized in figure 2.17. In the next sub-section the operational stakeholders will be discussed.

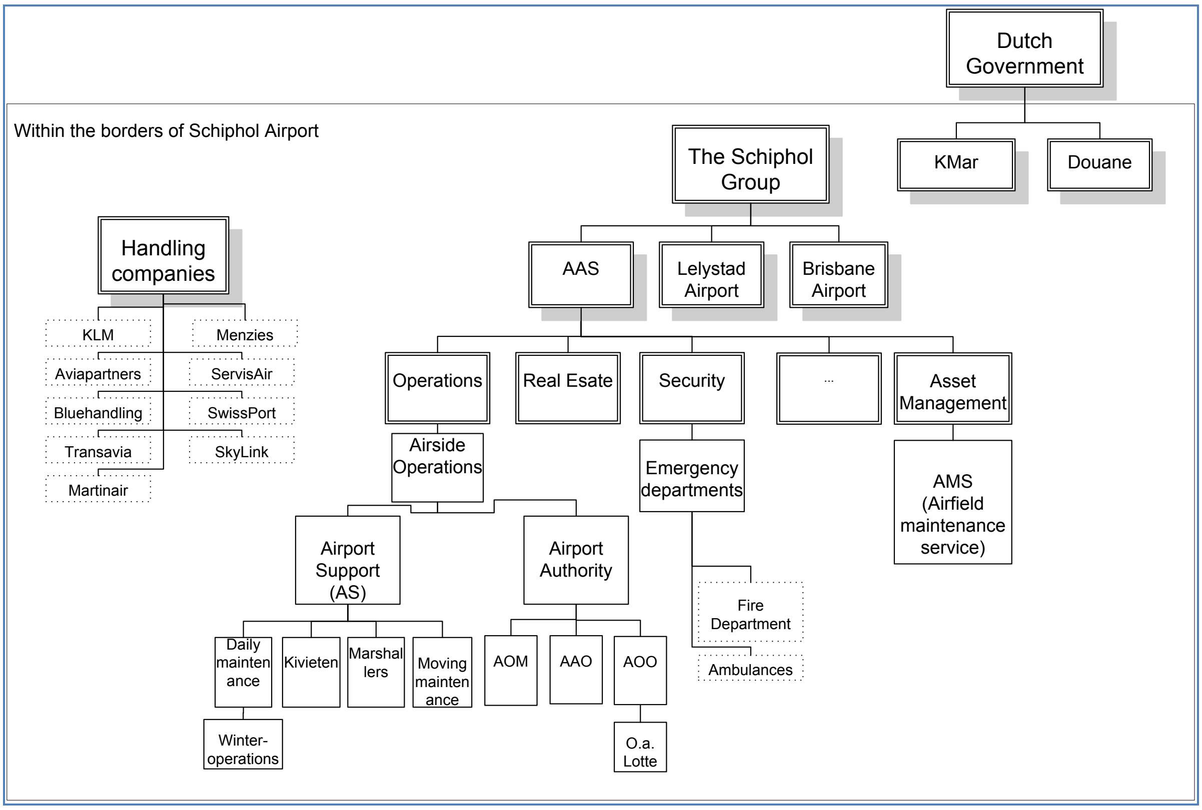

Figure 2.17; The organizational structure of AAS

Operational stakeholders on the airside of AAS

Besides organizational stakeholders, which are commonly used in stakeholder overviews, the users of the traffic system are in this case also seen as 'stakeholders' because they are operating on the airside, make use of the roads on the airside and so all have their own 'stake' into this research. Different services are supplied at AAS of which are operated by different companies. Each service requires different type of vehicles, which already discussed in sub-section 2.2.1. In the end of this section it should be clear who are involved in this research by providing a complete stakeholder overview, including the power and interest of the main stakeholders.

The top 5 most registered vehicles, and so companies, is provided in figure 2.18. It can be seen that KLM is by far the largest customer of AAS and therefore has a large stake and interest in developments on the airside.

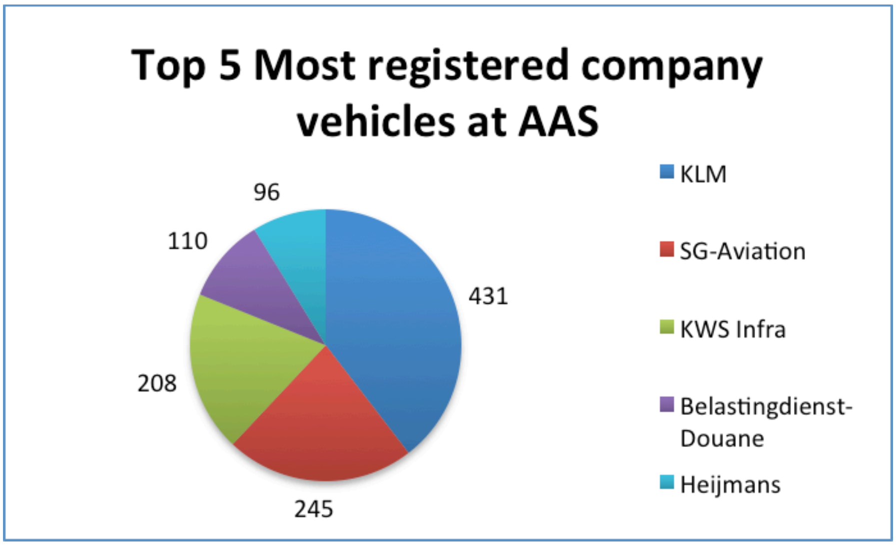

Figure 2.18; The top 5 amounts of most registered vehicles per company at AAS

Type of services on the airside of AAS

The main function of AAS is supplying the airlines with all the facilities to be able to operate their airplanes. For this functioning several services are available for the airlines on AAS, which are displayed in table 2.2, with corresponding type of companies and related type of vehicles (AirlineUpdate.com, 2012). The type of vehicles is already discussed in sub-section 2.2.1.

Table 2.2; Different type of vehicles per company and per service (AirlineUpdate.com, 2012).

Type of service	Type of company	Type of vehicles
Scheduled passenger handling	Ground handling companies	Baggage trucks, conveyor trucks, dolly's
Cargo handling	Ground handling companies	Cargo trucks, pallet loading trucks, dolly's
Aircraft stand handling	Ground handling companies	Catering, fuelling, water supply, stair trucks and push-backs
Airfield maintenance	AAS	
VIP handling	Government	Passenger cars and vans
Load control and support	Ground handling companies	Palletizers
Representation and admin		Passenger cars
Security	e.g. Airport authority, Securitas, Triport	
Aircraft fuel supply	Fuelling companies	Fuelling trucks and dispensers
Corporate/ non-schedules flight support		Passenger cars

Companies on the airside of AAS

On the airside of AAS different companies operating the same services. The larger airlines provide their own services, while the smaller companies are using the services of larger airlines. An overview is given of the different Airlines flying from and to AAS;

- **Airlines**: Air France-KLM (with the following major holdings: Air France, Regional, Brit Air, KLM, KLM Cityhopper, Martinair Transavia.com, CityJet and VLM Airlines), Air India Limited, Avia Improvement possibilities Group, AviancaTaca Holding, Azul Trip, Celestair, Eimskipafelag Islands, Icelandair Group, International Airlines Group, LAN Airlines, LATAM Airlines Group, Lufthansa, MatlinPatterson Global Advisors, Orange Star, Regional Express Holdings, SAS Group, Sun Group, Tiger Airways Holdings, Virgin Australia Holdings and Virgin Group.

Table 2.3 displays the **ground handling companies** in the Netherlands, including the service(s) they perform (AirlineUpdate.com, 2012), because these are the largest companies operating on the airside and thus will have a large impact (power) in this project of all companies operating on the airside.

Table 2.3; The ground handling companies in the Netherlands (AirlineUpdate.com, 2012)

• **Pax** Scheduled Passenger Handling • **Crg** Cargo handling • **Rmp** Aircraft ramp handling • **VIP** VIP handling • **Ldc** Load control & support • **Rep** Representation & admin • **Sec** Security • **Fuel** Aircraft fuel supply • **Corp** Corporate / Non-scheduled flight support	Pax	Crg	Rmp	VIP	Ldc	Rep	Sec	Fuel	Corp
Aero Groundservices B.V.									
Amsterdam Airport Schiphol	✓		✓				✓		
Bluehandling									
Aviapartners Netherlands	✓	✓	✓	✓	✓	✓			
IHD Airport Services BV									
KLM Royal Dutch Airlines	✓		✓						
Menzies Aviation (Netherlands)	✓	✓	✓	✓	✓				
Servisair Netherlands	✓		✓						
Swissport Cargo Services		✓							

Power versus interest grid with all stakeholders

All aforementioned (mostly operational) stakeholders are set in the power versus interest grid displayed in figure 2.19. Using this figure, the different levels of interest and power are made clear for AAS. It can be seen that safety & security departments will have both the most power and interest within this research. Fuelling companies and airplane maintenance score relatively high on power because of the consequences if anything happens to these vehicles on the airside. Finally, cleaning, waste, vehicle maintenance and special service companies score relatively low on power and moderate on impact, because of the supporting service they are fulfilling at AAS. Hardly any stakeholders with less interest are defined, because they are relatively too small for this overview and let out of scope.

The companies within the square of high power and high interest are labeled as “savior”, within high power and less interest as “sleeping giant”, within low power and high interest as “friend” and within the square with low power and low interest as “acquaintance” (Hillson & Simon, 2007). These stakeholders labels with be further explained and used in the final chapter, implementation (section 8.2 stakeholder cooperation).

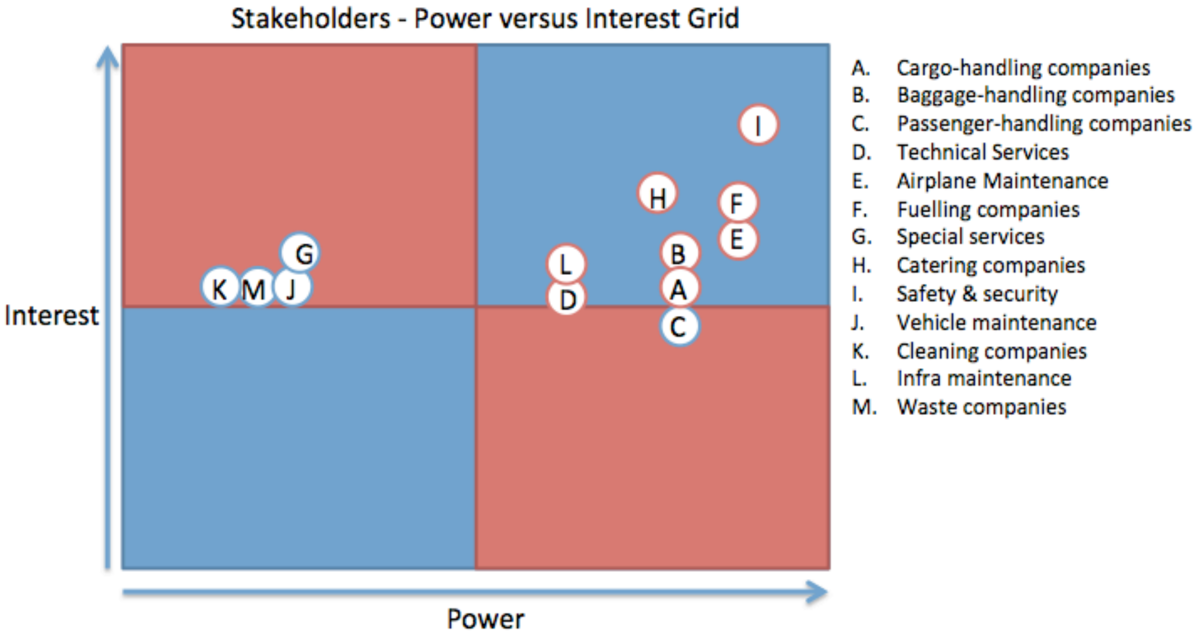

Figure 2.19; Power versus Interest Grid of all relevant service-providing companies on the airside of AAS

2.3 Traffic services: the transportation system

The third layer of the TRAIL-framework is consisting of the traffic services; within the area on the airside of AAS the traffic services can be seen as the complete transportation system, consisting of runways, taxiways, the traffic system, piers & gates and terminals. All of these elements will be discussed in this section individually. To provide a clear overview of what is taken into account within this research regarding the transportation system, before discussed the separate elements, first the scope will be discussed shortly. At the end of this section also the future perspective of AAS regarding the airside will be discussed, providing more insight in the construction plans until 2030.

2.3.1 Scope of the transportation system

The following areas are not taken into account within this research and are left out of scope: the cargo-terminals in the southern area, Schiphol East, the VIP airplane area in the northern part of AAS and the outside ring road outside the runways. Although the focus of this research will be on the traffic system, also the other aspects of the transportation system will be discussed.

The current transportation system contains the runways, taxiways, the transportation system, piers & gates and the terminal, which will be discussed individually in the next sections.

2.3.2 Runways

Because Schiphol is located close to the sea, al lot of different wind directions and strength can occur. For this reason, together with noise aspects, AAS is designed with a ‘tangential’ runway system: five different runways in different directions with the terminal located in the middle of all runways, being a unique concept for that period of time (www.Schiphol.nl, 2012). Figure 2.20 displays the five different runways, including their names and runway codes. Figure 2.21 will be discussed in the following section.

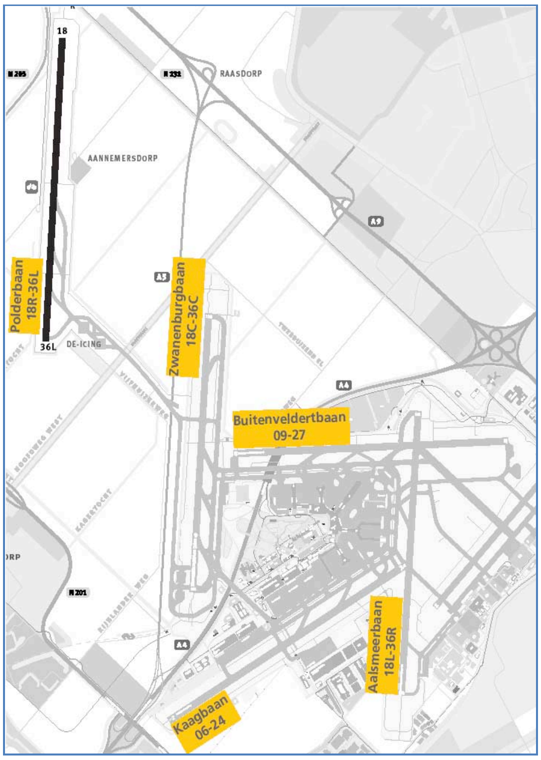

Figure 2.20; Runways of AAS (www.luchtverkeersleiding.nl, 2012)

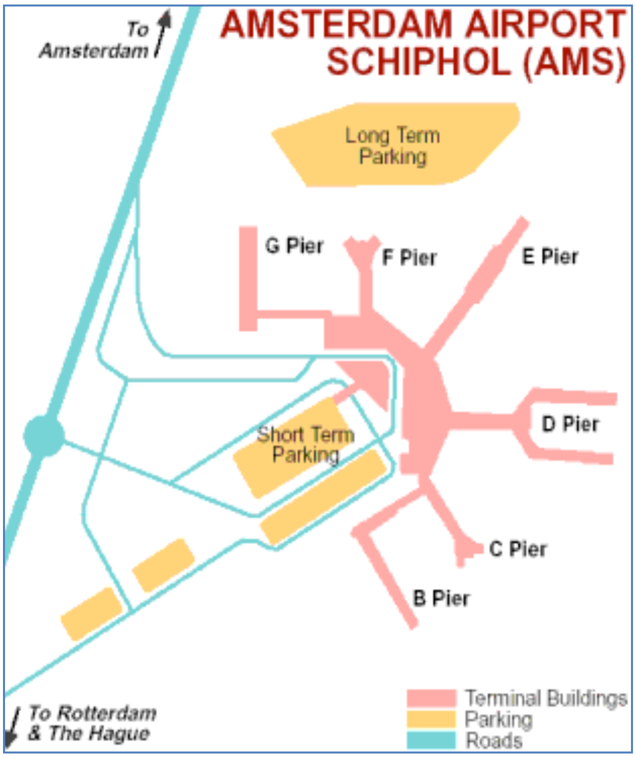

Figure 2.21; Map of AAS (Cheapflights.com)

2.3.3 Taxiways

Another SIM student, from the faculty of Aerospace Engineering, has performed a research to the optimization of the taxiways at AAS. She performed a simulation study to see if and if so, where the taxiways could be optimized regarding to the volume, location and direction of taxiways. During this research contact with her for sharing experiences and knowledge has been conducted.

2.3.4 The airside traffic system

The traffic system on the airside of AAS is composed of the main artery the Rinse-Hofstra road (RH-road) together with the connected roads to the aircraft stand ('Vliegtuigopstelplaats' in Dutch) where the airplanes are handled (Ashford, Mumayiz, & Wright, 2011). Because the traffic system is the main focus of this research, this section is used to discuss the traffic airside more in depth. A traffic system is always composed of different elements (Schoemaker, 2002):

- The **entrances and exits**, where users can enter of leave the system,
- **Links**, used to connect entrances/exits with each other,
- **Junctions,** locations where three or more links join each other and
- **Buffer/ parking** facilities, where users can store their vehicles.

Now first the rules and regulations within the area of AAS will be discussed, followed by the different elements of the airside traffic system of AAS: entrances and exits of the complete system, road categories and their functions, traffic system functions and the entrances and exits of the baggage halls and basements within the system at AAS.

Rules and regulations

Vehicles driving on the airside are allowed to drive maximum 30 km/h; when going down at ‘Rinse Hofstraweg’, ‘Kaagbaantunnel’ and ‘tunnel R-platform’ a restriction to the maximum speed is applied for baggage and fuelling trucks to 15 km/h.

Airside authority officers (AAO’s) are responsible for the daily enforcement and monitoring of the traffic on the airside. Measures to deal with exceeding the traffic speed are displayed in table 2.4 and resulted from an interview with one of the authority officers, which could be seen as the ‘police’ on the airside (appendix G.9 minutes interview Paul van der Lans).

Table 2.4; Official measures as consequences of exceeding the maximum speed on the airside, enforced by airport authority officers

Driving speed (while 30 km/h is allowed)	Consequences
30- 50 km/h	Official warning, also reported to manager of the driver
50 – 60 km/h	Two official warnings, also reported to the manager of the driver and the platform test should be retaken.
> 60 km/h	Withdrawal of ‘Schiphol pass’, so working on the airside is not longer possible

One of the most important rules is the fact that vehicles are not allowed to cross the broad red line at the end of the aircraft stand. This is called the ‘(broad red) clearance line’ and marks the boundary between the area where aircraft rides and where they stand still (on a aircraft stand). No one may cross the line without permission of the ‘Luchtverkeersleiding Nederland’ (LVNL), unless work-related duties. The edges of the stand are marked with a narrow red line that indicates the ‘Vliegtuigklaringslijn’ (www.Schiphol.nl, 2012).

Entrances and exits of the traffic system

The traffic system can be seen as an isolated system, operating separate from the public road. As described earlier in this section, this has consequences for the rules and regulations on the operating system. Vehicles on the airside first have to be registered at the Schiphol vehicle registration before they are allowed to entering the traffic system. Figure 2.22 describes all entering and exit gates at AAS, of which the last three exits are out of scope (gate 40, 43 and 2). To enter the isolated system of the airside of AAS, several accesses are constructed, on which every vehicle and pedestrians have to pass a security check;

- ‘G-passage (gate 60)’
- ‘X-passage’
- ‘EF-passage’
- ‘S-passage’
- ‘I-passage’
- ‘Tunnelpassage (gate 54)’
- ‘Kokspassage (gate 56)’
- ‘Transview (gate 58)’
- ‘Schiphol-ZO (gate 90)’
- ‘AFS only’ and
- ‘Post Sloten (gate 77)’

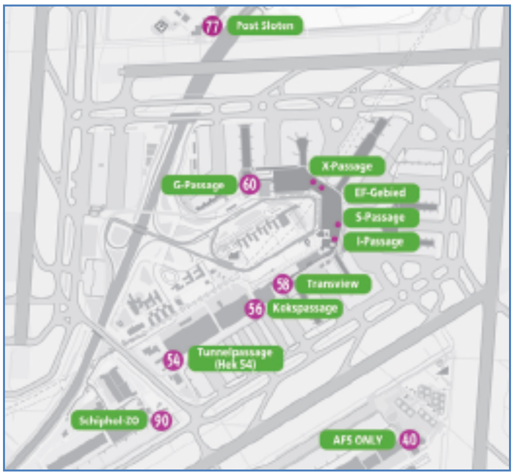

Figure 2.22; Entrances and exits of the traffic system

Road categories and their function(s) the traffic system

Before going more in detail about road categories, first a specific methodology will be discussed; 'Gebiedsgericht Benutten plus' (Region Orientated Utilization plus), in short GGB+, is one of the latest general applicable frameworks that addresses traffic management by the executing ministry of Infrastructure within the Netherland. GGB+ benefits from all the resources of ITS development all over the world (Van Kooten & Adams, August 2011).

The methodology of GGB+ distinguishes six different road functions in public spaces: main highways, connecting urban roads, regional connecting roads, urban axes, supporting roads and protected roads. The complete traffic system of the Netherlands can be mapped into these six different road categories. Each category has one or more functions, of which three different types can be identified: service the main traffic flow, connecting the main flow to lower level roads and distributing the traffic. Table 2.5 displays an overview of the six road categories identified by GGB+ with their related functions.

Table 2.5; The six different road categories identified by the GGB+ methodology (Van Kooten & Adams, August 2011)

Function / Road category	Service the traffic flow (arterial function)	Distribution of traffic (from main axes to distributing roads)	Residential function (to final destination)
Main highways	X		
Connecting urban roads	X	X	
Regional connecting roads	X	X	
Urban axes		X	
Supporting roads		X	X
Protected roads		X	X

The focus of this research, the traffic system of the airside of AAS, can be categorized into two different road categories, related to two GGB+ road functions, namely main axes and distributing roads. The main axes are composed from 'connecting urban roads', 'regional connecting roads' and even 'urban axes' in a minor form. Mostly the function of the first two types is adopted, namely service the main traffic flow, but also the function of distributing the traffic is applied at the main axes: mostly around the beginning of the piers. The distributing roads have the same function as the GGB+ function describes, namely distributing the traffic to their final destination. Figure 2.23 displays which roads on the airside comply with which of the two road categories.

Figure 2.23; Road function categorization: main axes and distributing roads

Traffic system function(s)

Now the individual road functions are described in the previous section, the main function(s) of the complete network can be discussed as well. Because the traffic system on the airside of AAS consists of mostly main axes and distributing roads, the main functions of the complete system can be identified two-sided: **service the main traffic flow** and **distributing the traffic to its destination**.

Entrances and exits of the baggage halls at AAS

All entrances and exits of the baggage halls and basements within the system at AAS are mapped and it could be stated that many entrances and exits are closely related to the main road (with as main function serve the main traffic flow as is discussed before in this section). The map with all entrances and exits can be found in appendix B.1 (figure B.1),

2.3.5 Piers & gates

AAS consists of six major piers at the moment; named from B to G. Pier A will be constructed as part of the new masterplan. Figure 2.21 displays the different piers and including gates and table 2.6 contains the categorizations and time aspects per gate.

Each pier contains more gates, in which the distinction can be made between Widebody (WB) and Narrowbody aircrafts (NB). Both wide and narrow body gates are present at AAS. Table B.1 in appendix B.1 displays the type of gate for each gate number on AAS.

Table 2.6; Categorization and drag standards per gate (Arr. = Arrivals and Dep. = Departures)

Different type of gates	Categorization	Airplane drag standards
Widebody gates	Airplanes of CAT 5 and larger	- Widebody aircraft (WB) KL > 270 min (gate time Arr. 75 min, Dep. 85 min.) - Widebody aircrafts(WB) non-KL > 210 min (gate time Arr. 75 min, Dep. 85 min.)
Narrowbody gates	Airplanes of CAT 4 and smaller (non-regionals)	- Narrowbody (NB) > 170 min (gate time Arr. 55 min, Dep. 65 min.)
Regionals	Airplanes <70 pax. + KLM F70/E90	

2.3.6 Terminals

AAS consists of a one-terminal concept, because all halls are interconnected with each other. There are three different arrival and departure halls at AAS, numbered from 1 to 3. Within the terminals the check-in desk, baggage drop desks, shopping areas are located both before and after customs. Behind customs the waiting areas and lounges are located. Because the terminal is not part of the traffic system and only passengers and employees have access to the terminal and not vehicles, the terminal will be further left out of scope of this research.

2.3.7 The new master plan of AAS

Different new ideas and plans are already developed within the Schiphol Group and can be split up into three areas: airside, terminal and landside. These developments and plans are based on current insights, strategies and market expectations (Schiphol Development Plan 2013-2017, 2012).

The new masterplan regarding the airside at AAS

An extension of the piers will be developed in the south direction next to the B-pier another pier will be constructed named the ‘A-pier’, developed for ‘other carriers’ (than KLM). KLM SkyTeam will have more opportunities to grow at the G-pier. To realize this plan, the ‘Bravo-platform’, cargo-stations and KLM catering will be moved elsewhere.

The new masterplan regarding terminals at AAS

A new terminal will be developed, located at the southern side of the terminal (on the old Martinair-location) for other carriers than KLM, so SkyTeam and Transavia can stay located completely at departures 1. In the new terminal an extension of the departure and lounge capacity will be realized, together with new baggage-facilities for ‘other-carriers’. In this way Departures 1 and 2 can be dedicated to KLM SkyTeam and Departures 3 for SkyTeam and the other carriers. Two draft designs, for both 2018-2020 and 2025-2030 are displayed in figure 2.25 and 2.26, compared to the current situation (figure 2.24) (Schiphol Group, 2012).

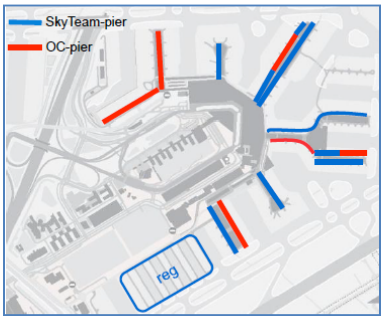

Figure 2.24; Current deviation SkyTeam and other carriers at Schiphol with SkyTeam central located and other carriers on both the sides (north and south)

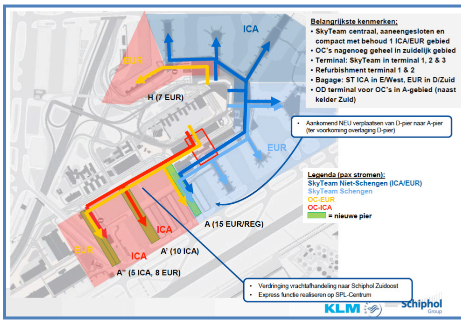

Figure 2.25; Masterplan Schiphol 2018-2022 with SkyTeam central located and other carriers on both the sides (north and south)

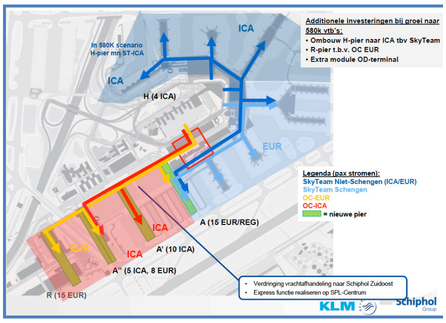

Figure 2.26; Masterplan Schiphol 2025-2030 with SkyTeam central located, including G- and H-piers and the other carriers in the south

The new masterplan regarding the landside at AAS

Due to all aforementioned changes, up scaling should take space on landside to cope with all these changes. Wider and lengthened roads will be realized and an improved traffic flow will be aimed for. Also an extra entrance to the train stations will be realized and other comparable improvement possibilities to increase the connectivity between public transport and AAS.

2.4 Transport and traffic markets: traffic flows

This sub-section is divided into two categories, namely first the volume of the traffic on the airside of AAS will be discussed, using the number of registered vehicles allowed to enter the airside, followed by the routes taken by the traffic flows, including the possible origins and destinations of different services.

2.4.1 Volume of the traffic on the airside of AAS

The size of the traffic flows depends on the amount of vehicles driving on the traffic system on the airside, together with the amount of total kilometers each vehicle drives. In the aforementioned vehicle registration all vehicles are registered which both drive on the landside and the airside. It is researched that the Schiphol Group has 505 vehicles in their own registration, while only less than half (45%) is officially registered at AAS and so are allowed to leave the airside (figure 2.27); the non-registered vehicles are not allowed to leave the airside. Of these 505 Schiphol Group vehicles, there are 217 vehicles that are indicated as equipment vehicles, representing 43% of the total amount of Schiphol Group vehicles on the airside. Equipment vehicles are vehicles needed to handle airplanes.

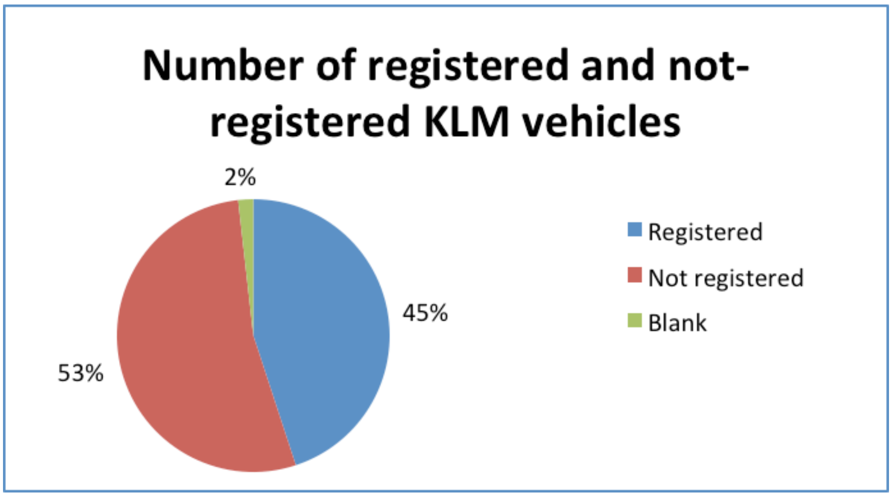

Figure 2.27; The percentage of registered and not-registered vehicles

The registration of AAS counts total 3962 registered vehicles. This only concerns the *registered* vehicles and excludes the vehicles which are not registered (figure 2.27), but are driving around on the airside, as is discussed earlier. Because only the vehicle data of the Schiphol Group is available for this research, the percentage of registration of the Schiphol Group is extrapolated for all vehicles on the airside.

The total amount of vehicles on the airside can be roughly estimated at 8804 vehicles, of which 3962 vehicles are registered (45%), 4666 vehicles are estimated as not registered (53%) and of an estimated 176 vehicles (2%) it is unknown if they are registered or not (figure 2.28). In this calculation both the percentage of registered vehicles of KLM and the total registered vehicles at AAS is taken into account.

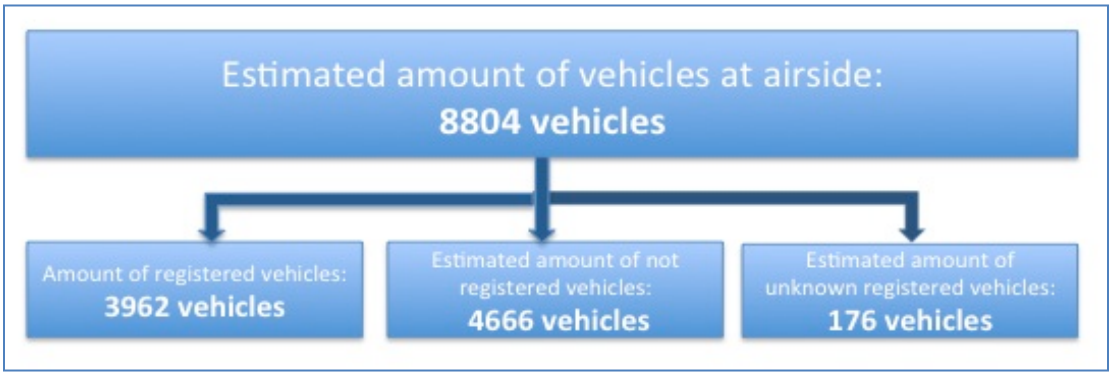

Figure 2.28; Number of registered, not registered and unknown if registered vehicles on the airside of AAS

2.4.2 Routes of traffic regarding origins and destinations

The previous section discussed the total number of vehicles (allowed) driving on the airside of AAS, which is analyzed to be 8804 vehicles in total. Each vehicle on the airside has its own origin and destination, and thus specific route. The same type of vehicles from the same company, for example catering trucks from KLM, will probably have the same origin, namely the catering building of KLM, but will have continue different destinations, namely different airplanes on different locations on the airside. It is experienced that all type of vehicles will drive everywhere, while busses and fuelling trucks are mostly used for gates further away from the central terminals; in this case the H-platform of Easyjet in the north and the B-buffer in the south of the traffic system. Table 2.7 displays the origins and destinations per type of service; it should be mentioned that these services are the most common services, but also other services are driving around on the airside, for example KLM or AAS passenger cars.

Table 2.7; Origins and destinations of different type of services (OD-matrix)

Service type	Origin	Destination	Loaded/ empty
Baggage handling	Baggage basement/ hall	Aircraft stands	Loaded
	Aircraft stands	Baggage hall	Empty
Cargo handling	Cargo hall (KLM)	Aircraft stands	Loaded
	Aircraft stands	Cargo hall (KLM)	Empty
	Cargo hall (KLM)	Customs ('DSL')	Loaded
	Customs ('DSL')	Aircraft stands	Loaded
Catering	Catering hall	Aircraft stands	Loaded
	Aircraft stands	Catering hall	Empty
Busses	Bus platform	Aircraft stands	Empty
	Aircraft stands	Terminal	Loaded
	Terminal	Aircraft stands	Empty
	Terminal	Bus platform	Loaded
Fuelling	Fuel station airside	Aircraft stands	Loaded
	Aircraft stands	Fuel station airside	Empty
	Parking fuel trucks	Fuel station airside	Empty
Airport authority, security and customs	Everywhere	Everywhere	-
Service vehicles	Maintenance hall	Aircraft stands	-
Cleaning vehicles	Cleaning buffer	Aircraft stands	-

2.5 Literature on traffic theory

Now the current general situation on the airside of AAS is discussed, only more insight in traffic theory should be discussed, before starting with analyzing the four aspects separately. Both traffic flow theory, as traffic management will be discussed in this section, starting with a short discussion on the phenomenon called congestion and its way of measuring this phenomenon. This phenomenon requires attention first, because when researching possibilities to reduce congestion, as is stated in the objective in the beginning of this thesis, a strict definition of both congestion as well as the measurement of a reduction in congestion is vital.

2.5.1 Measuring congestion

There are a lot of different ways to define congestion, of which a selection is made for this research. Now two ways to measure the amount of congestion will be discussed;

Two other definitions that could be used of measuring the amount of congestion are measuring speed reduction and/or measure the lost vehicle hours (lost hours multiplied by the number of vehicles experiencing a time loss). Both numbers should go down if congestion is reduced in a section. Both may give insight on a link level, but the first one is more applicable when analyzing the network as a whole. Because within this research the current and future situation is researched, the level of congestion is of less importance; at first the number of vehicles should be mapped, for example by using the **traffic volumes**. The traffic volume is defined as "the number of vehicles passing by per time frame". When the traffic volume is related to road capacity: "the numbers of vehicles that can be processed per time frame", the I/C-ratio (Intensity/Capacity per lane) can be calculated of different locations, which provides us a lot of information about the situation within the system. This analysis is performed in chapter 6, the utilization analysis.

Meurs & Van Wee stated that less attention should be paid to classical accessibility definitions, for example measuring congestion and vehicle loss hours, and more to **problem junctions** and the **reliability of travel time** (Meurs & Van Wee, 2012). Now, a small introduction into traffic flow theory is provided to get more insight in the theoretical literature behind this research.

2.5.2 Traffic flow theory

The theoretical base of congestion, and thus of traffic flows, is based upon a simple demand-supply characterization. The demand represents the number of vehicles that would like to be served; supply represents the maximum number of units that can be served. If the demand exceeds supply congestion will occur.

Traffic flow theory is based upon three main variables (when taking a macroscopic perspective, see chapter 5.1.1): the flow rate (q), the density (k) and the speed (u). These three variables are related in what is called the *'continuity equation'* (Greenshield, 1934): **$q = k*u$.**

The actual values of these diagrams are depending on several conditions, such as for example the weather, regulations, vehicle composition and other conditions. The principles and basic shape however remain unchanged (Hoogendoorn, 2010). It should be noted that the merging of non-homogenous traffic flows lowers the efficiency of the road usage, thus lowering the curve of the fundamental diagram.

When congestion occurs the situation becomes unstable: the flow-speed-density states change over time. When such a change of flow-speed-density occurs, the boundary between the states moves both in space and time. Such boundary is called a ***shockwave*** and causes congestion to move away from the location it originated at certain densities (Hoogendoorn, 2010).

Last, but not least, a congested situation may rapidly escalate due to ***spillback***. If a queue on the road would spillback to for example an off-ramp, the exit of the road will be blocked and the congestion will grow even more rapidly. If an on-road is blocked, the connection from another road section to the congested road is blocked, and the other road will start to suffer from congestion as well. Therefore the congestion thus might spread (Hoogendoorn, 2010).

2.5.3 Traffic management

The insight into the mechanics of traffic and congestion allows the traffic not only to be monitored, but also to be influenced and even controlled. This is called ***traffic Management***. While traditionally the reaction to congestion problems was through expensive infrastructural project (as mentioned in the introduction), traffic management focuses on the efficient use of existing infrastructure (Weng, 2010).

Main techniques in traffic management are reducing the density to ensure maximum flow (for example by reducing the inflow on a road section), unraveling flows, or prevention of spillback problems. Further on, measures to achieve this are described.

Thanks to the development of IT traffic management has become more intelligent. Using continuous streams of data and the knowledge on macro- and microscopic traffic behavior traffic flows can be predicted and optimized (Hoogendoorn, 2010). These measures however still work locally.

2.6 Conclusion of the airside transportation system of AAS

This chapter provided a complete overview of the transportation system on the airside of AAS, using the TRAIL-layer framework as general methodology to structure all separate elements. The first layer, economic activities, discussed both general aviation trends as more specific airport trends. The second layer consisted of two sections, the different means of transportation and a complete stakeholders overview, which together form the transport services layer. The third layer is explained quite extensive, because of the focus of this research to the traffic system, which is part of the traffic services layer. Other discussed elements are the runways, taxiways, piers & gates and the terminals on the airside of AAS. Also the scope and a future perspective regarding the future masterplan of AAS are provided within this section. The two in between markets within the TRAIL-layer methodology, transport and traffic markets, are combined in the fourth section in this chapter, discussed the total volume of traffic driving on the airside of AAS and their routes regarding origins and destinations. All of these elements of the TRAIL-framework will be used later on in the report or is used as common knowledge and / or background.

Besides the TRAIL-layer framework, also more theoretical insight is provided by discussed shortly the way of measuring congestion, traffic flow theory and traffic management in section 2.5 of this chapter. This insight will be used as general understanding in the rest of this research.

The methodology is completely adjusted to the situation on the airside of AAS and all separate discussed elements will be used in the following four chapters: the safety, robustness, reliability of the travel times and utilization analysis.

3. Safety analysis of the traffic system

This section is the first of the four analyses chapters; each discussed one of the four aspects. Both sub question 2 and 3 will be answered: SQ 2 by analyzing first the current situation regarding safety and SQ 3 by indicating the problems areas where improvements are possible.

In this chapter, the safety of the traffic system on the airside of AAS is described and analyzed. The relationship between safety and incidents will be discussed, after defining safety, incidents and collisions, even as the different types of incidents followed by a black spot analysis, indicating the locations of specific types of incidents on the airside between 2005 and June 2012. Furthermore, the most common causes and consequences of incidents are described, which will provide more insight in solving which areas, which will be called 'the problem areas'. In this way, a prioritization could be made between all bottlenecks on the airside where accidents are happening; including which the highest prioritized bottleneck is and so should be addressed first. This chapter ends with a zoomed in analysis of the area with the most accidents: the D-pier.

3.1 Definition of safety, incidents and collisions

Before starting with the relationship between safety and incidents, first the definitions of safety, incidents and collisions are provided. Safety is approached in this research as traffic safety, which is be defined as follows: *"the methods and measures for reducing the risk of a person using the road network being killed or seriously injured".* An incident is a more general term for unexpected events, while collisions can be seen as a specific type of incident, namely when actual contact is made to a building, person or something else, while incidents could be anything. The box below provides the definitions of both incident and collision.

Safety: "the methods and measures for reducing the risk of a person using the road network being killed or seriously injured" (International Transport Forum, 2008).

Incident: "an unexpected, undesirable and reported event (without clear causes, without necessary causing damage), (possibly) leading to loss" (The Schiphol Group, May 2012).

Collision: "a vehicle that will get in contact with infrastructural elements or other vehicles within the traffic system" (The Schiphol Group, May 2012).

3.2 The relationship between safety and incidents

As stated earlier in section 2.6.1, safety can be defined as follows*: "Relative freedom from danger, risk, or threat of harm, injury, or loss to personnel and/or property, whether caused deliberately or by* ***accident****"* (Business dictionary, 2012). This definition indicates that accidents are an underlying aspect of safety. The Airside Operations department of AAS has set as safety goal to reduce incidents as much as possible and even more specific: "Avoid collisions on the airside" (Leek, 2012). For this reason the statement is adopted that 'reducing incidents will lead to more safety on the airside of AAS'. This answers partly, at least for the safety aspect at the moment, sub question 3 of this research: "What is the ideal/preferred situation regarding the traffic system at AAS?".

To be able to get more insight in how to reduce the aforementioned incidents, first the different types of incidents will be discussed in section 3.3.

3.3 Types of incidents

The aforementioned department 'airside operations' of AAS has adopted safety objectives regarding the environment on the airside. These safety objectives use six different types of incidents, namely:

- Avoid **collisions on the airside**,
- Avoid serious **pollution of surface water,**
- Avoid **dangerous situations during construction works,**
- Reduce the number of **runway incursions,**
- Reduce the number of **foreign object damage (FODs),**
- Avoid the number of **bird strikes.**

Within these safety objectives, six different types of incidents can be recognized, which are printed **bold** in the enumeration. Because this research is focusing on the traffic system on the airside, only the first aspect within the enumeration listed above will be taken further into account: 'collisions on the airside'.

Within this one category of incidents, six types of collisions are distinguished at AAS, which are also used within this research to create consistency with the Schiphol Group (The Schiphol Group, May 2012). The five types are:

- Collisions between vehicles (*'Aanrijding tussen voertuigen')*,
- Unilateral collisions (*'Aanrijding eenzijdig'),*
- Other types of collisions (*'Aanrijding overig met mens en/of dier)'*.
- Collisions with a plane (*'Aanrijding tegen vliegtuig'),*
- Collisions caused by a plane (*'Aanrijding veroorzaakt door vliegtuig')* and
- Collisions by the passenger bridge (*'Aanrijding door passagiersbrug')*.

An overview of the different types of incidents and different types of collisions are summarized in figure 3.1.

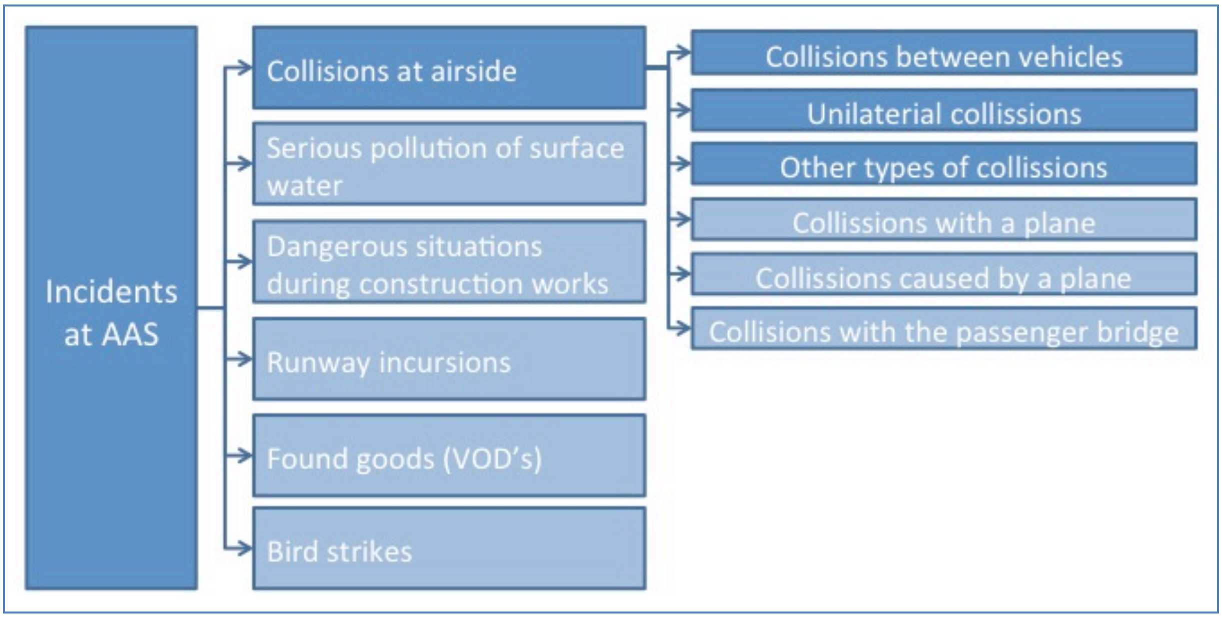

Figure 3.1; The proportion of incidents and collisions

For further analysis, the latter three types of collisions, 'collisions with a plane', 'collisions caused by a plane' and 'collisions with the passenger bridge' are considered not relevant enough to take further into account because the research is focusing on the traffic system. Collisions involving planes and involving the passenger bridge (on the VOP) both does not occur directly on the traffic system of AAS. Even after removing these types of collisions, there are still collisions in the data set, which happened on a VOP within the three types of collisions that *are* taken into account ('collisions between vehicles', 'unilateral collisions' and 'other types of collisions'). These collisions are manually deleted from the data set, which reduced the number of collisions in the data set from 1626 to 1067 collisions; a reduction of collisions of 36%.

The number of incidents per year, after removing three types of collisions and collisions that took place on a VOP/ outside the traffic system from the original data set provided by AAS, can be seen in table 3.1. The financial impact will be discussed later on in section 3.6.

Table 3.1; The number of collisions per year divided into the five collision types

Numbers	2005	2006	2007	2008	2009	2010	2011	2012 (half a year)	Total
Collisions between vehicles	112	132	108	114	88	69	73	27	**723**
Unilateral collisions	64	51	57	55	41	33	30	9	**340**
Other types collisions	0	0	0	2	0	1	0	1	**4**
Total	**176**	**183**	**165**	**171**	**129**	**103**	**103**	**37**	**1067**

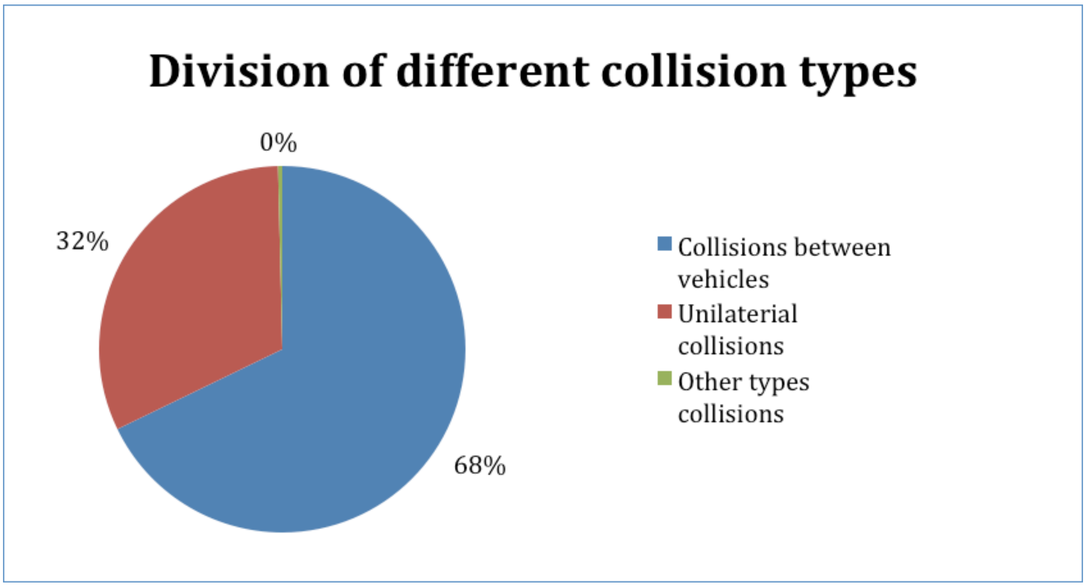

Figure 3.2; Pie chart with the deviation per collision type in percentages

The pie chart, displayed in figure 3.2, shows us the deviation of collisions between vehicles, unilateral collisions and other types of collisions. It can be seen that by far, 68%, the most occurring collisions are those between vehicles.

To detect possible seasonal trends and/ or developments, also the number of collisions per month is set out in a line chart (figure 3.3); including a trend line into the chart (the red line). A slight yearly peak can be seen in figure 3.3 during the summer period (June, July and August), which sounds reasonable because of the generally defined holiday period within the Netherlands in this period. Both a lot of Dutch people use AAS as their departure airport for summer holidays, as AAS also is functioning as arrival location for many tourists. Furthermore AAS is one of the largest transfer hubs of Europe, which results in large numbers of transferring travellers.

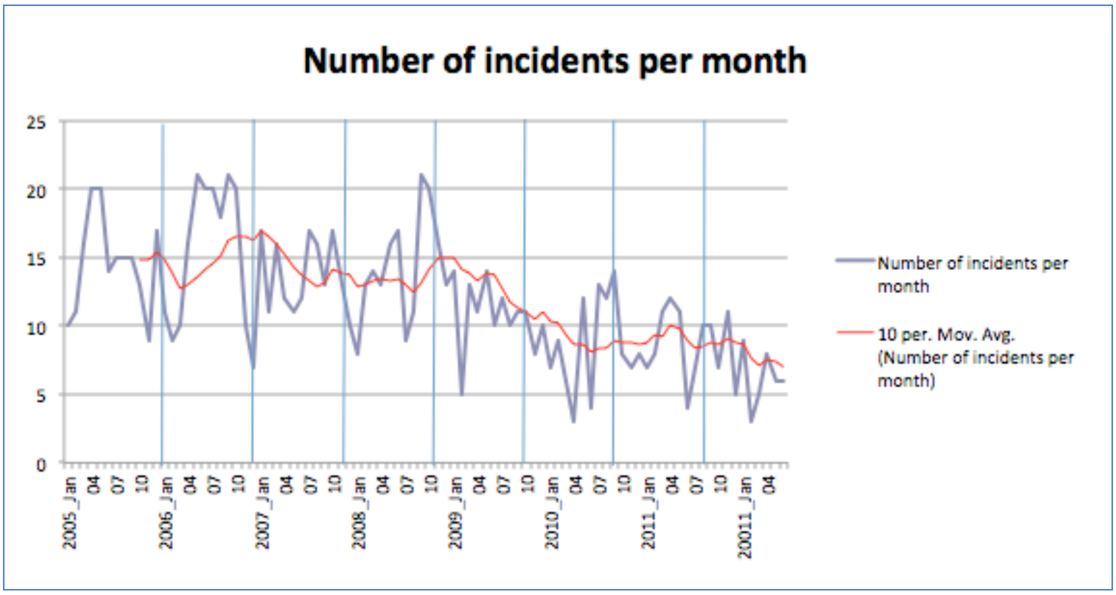

Figure 3.3; Line chart with the number of incidents from 2005 until 2012 per month, including the average trend line

3.4 Black spot analysis

To continue with this research, sub question 4 should be answered: "what kind of problem areas can be indicated comparing the current situation and the future situation to the frame of reference and what are the main causes of these bottlenecks?" For answering this sub question, five different stages are used; first the location of incidents should be identified, which will be done in this section. Then the causes and (financial) consequences should be researched, section 3.5 and 3.6 respectively. Next, the locations of incidents will be clustered and specific 'problem areas' will be identified in section 3.7, which are characterized by high density of incidents; thus many incidents per m². Five problem areas are resulting from this analysis and will be prioritized in the section 3.8, which will results in one major problem area. This specific problem area is also chosen as model for the rest of the problem areas; solving problems in this area can be generalized to other areas on the airside. Section 3.9 contains the zooming in into the major problem area, which later on, in chapter 7, will result in improvement possibility directions for this area, and so for more identified problem areas.

AAS started with gathering data from incidents in 2005. From this year, incidents are reported and documented at the incident registration of Schiphol. From this registration department, data is collected until now, in which the distinction is made between the aforementioned five different types of incidents. Each incident is labeled, using a reference number, and several characteristics of the incidents are known; year, month, date, time, process phase, activity, location, detailed location, weather conditions and description of incidents.

The incidents are made graphically for each year separately, using the Black spot analysis (Geurts & Wets, 2003), which resolve in areas with more incidents than others. This element will be taken into further analyses in the next sub-section. The red dots represent 'collisions between vehicles', the blue dots 'unilateral collisions' and the green dots the 'other collisions' type. The maps of 2005 until 2008 are seen in figure 3.4 until 3.7 respectively and the maps of 2009 until 2012 in figure 3.8 until 3.11. A complete overview of all collisions happened between 2005 and June 2012 is visualized in figure 3.12. The next section continues with the different causes of the collisions.

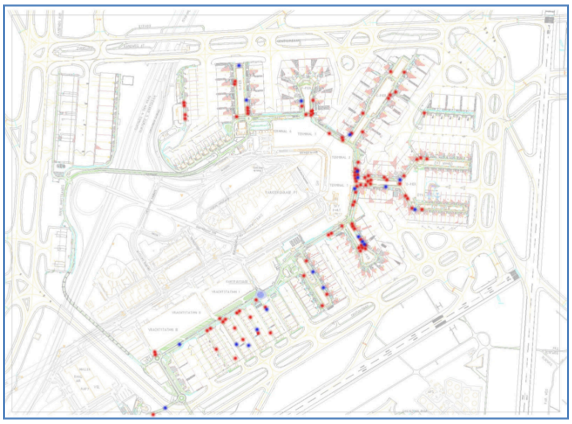

Figure 3.4 Map of all accidents occurred in 2005

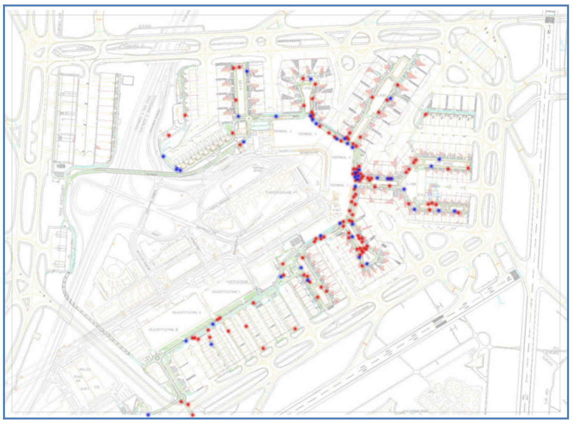

Figure 3.5; Map of all accidents occurred in 2006

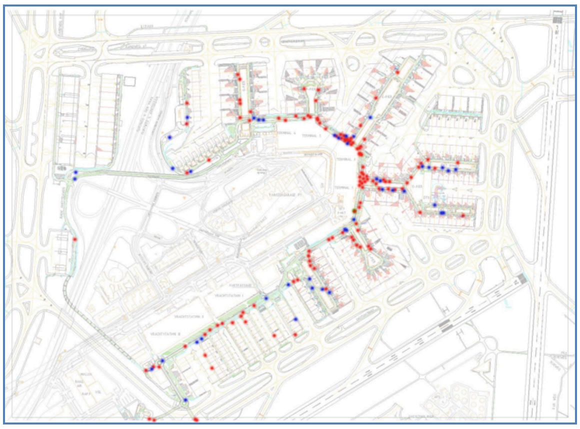

Figure 3.6; Map of all accidents occurred in 2007

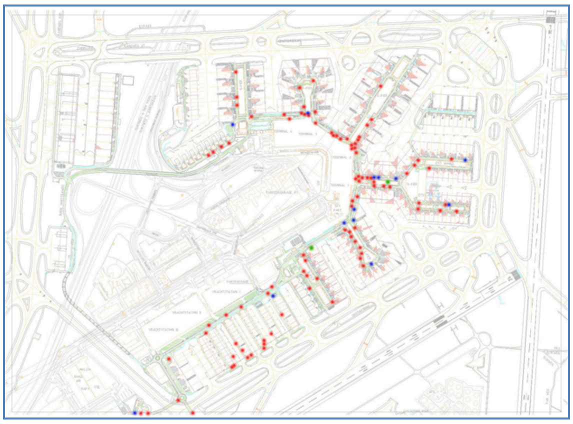

Figure 3.7; Map of all accidents occurred in 2008

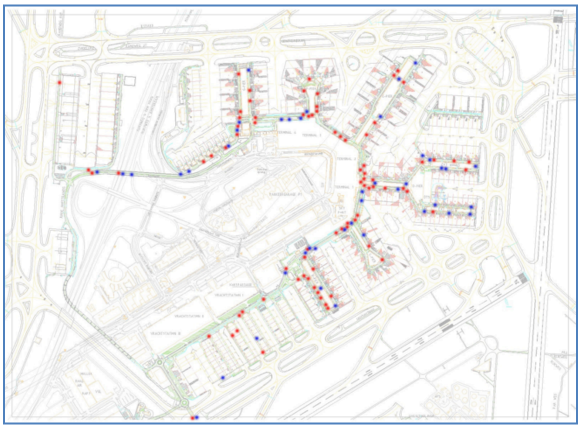

Figure 3.8; Map of all accidents occurred in 2009

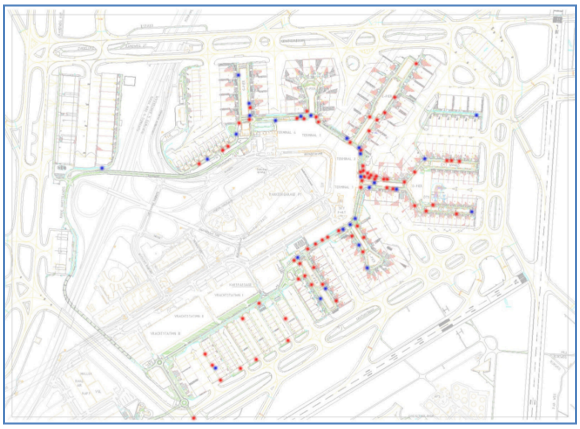

Figure 3.9; Map of all accidents occurred in 2010

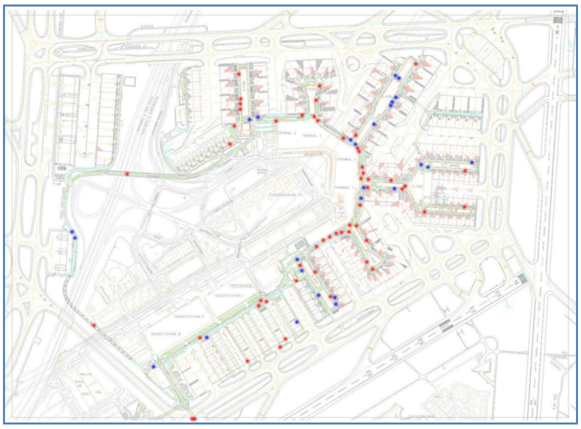

Figure 3.10; Map of all accidents occurred in 2011

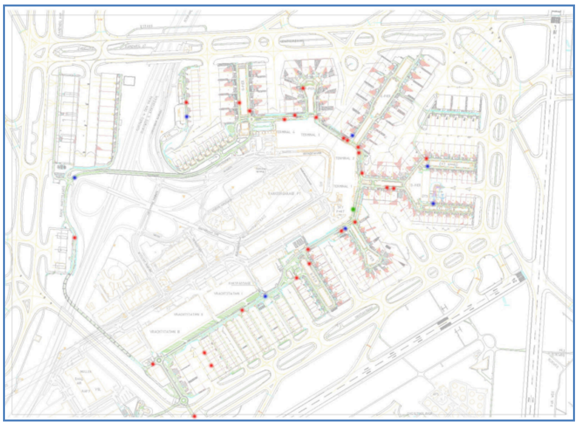

Figure 3.11; Map of all accidents occurred in the first half year of 2012

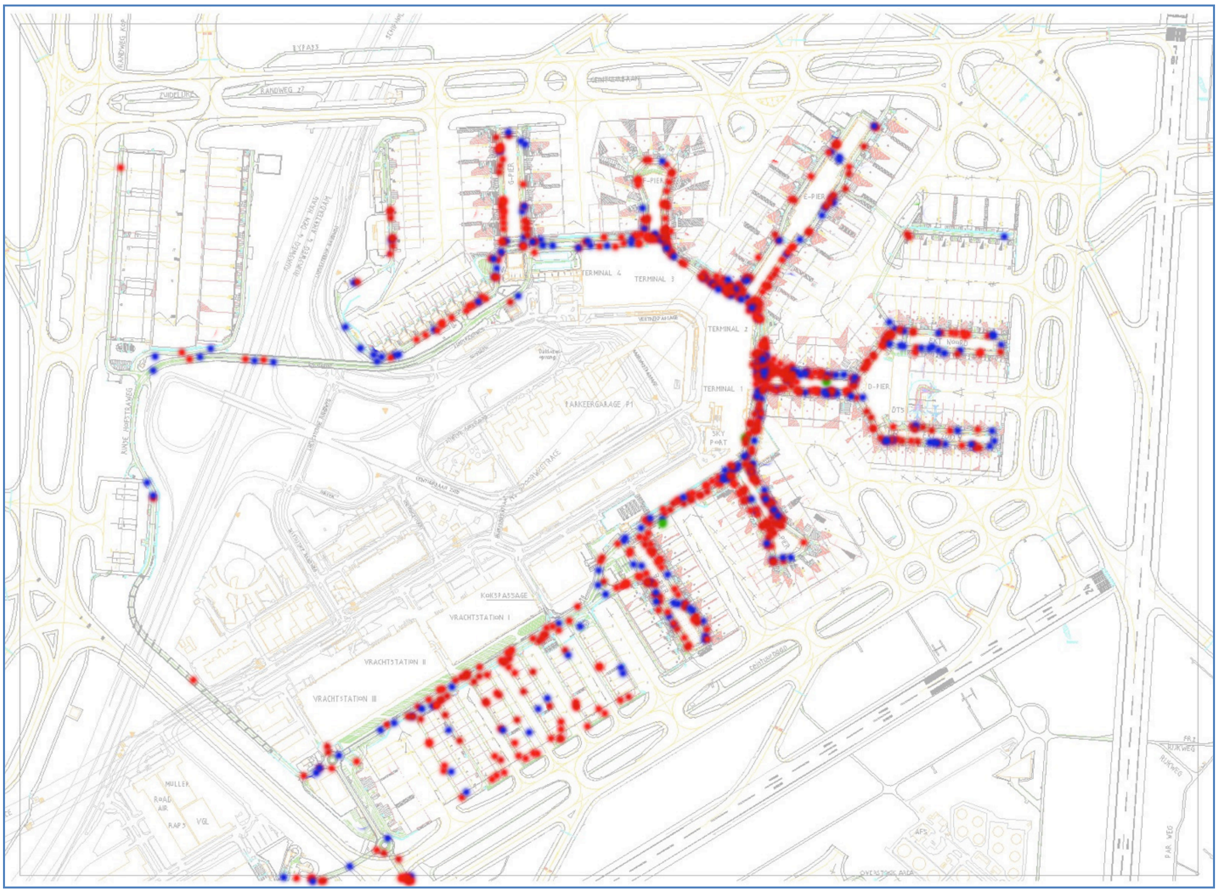

Figure 3.12; Map of accidents occurred between 2005 and 2012

3.5 Causes of collisions

The locations of all collisions of 8 years of data are known due to the executed black spot analysis. Within this section more insight will be provided in the causes of these collisions. The cause of an incident depends on several aspects. For example, the current infrastructure is of importance and also the type of vehicle is of interest when analyzing causes of incidents. These two elements can be seen as primary aspects that are related to the causes of incidents. Also human influences and behavior can be seen as a primary aspects in this case, because of the large influence this aspect have on the number of incidents. It could be that there are also secondary aspects influencing the causes of incidents, such as weather conditions and other causes. Figure 3.13 displays an Ishikawa-diagram in which all causes are summarized, both primary as secondary causes of incidents. This segmentation is based on the percentages of causes of incidents; primary causes are for between 5 and 25% responsible for causes, while secondary causes are less than 5% responsible for incidents. These numbers are also displayed in the diagram. The diagram contains five different branches, with on the top the cause species and along the branches several causes types per species.

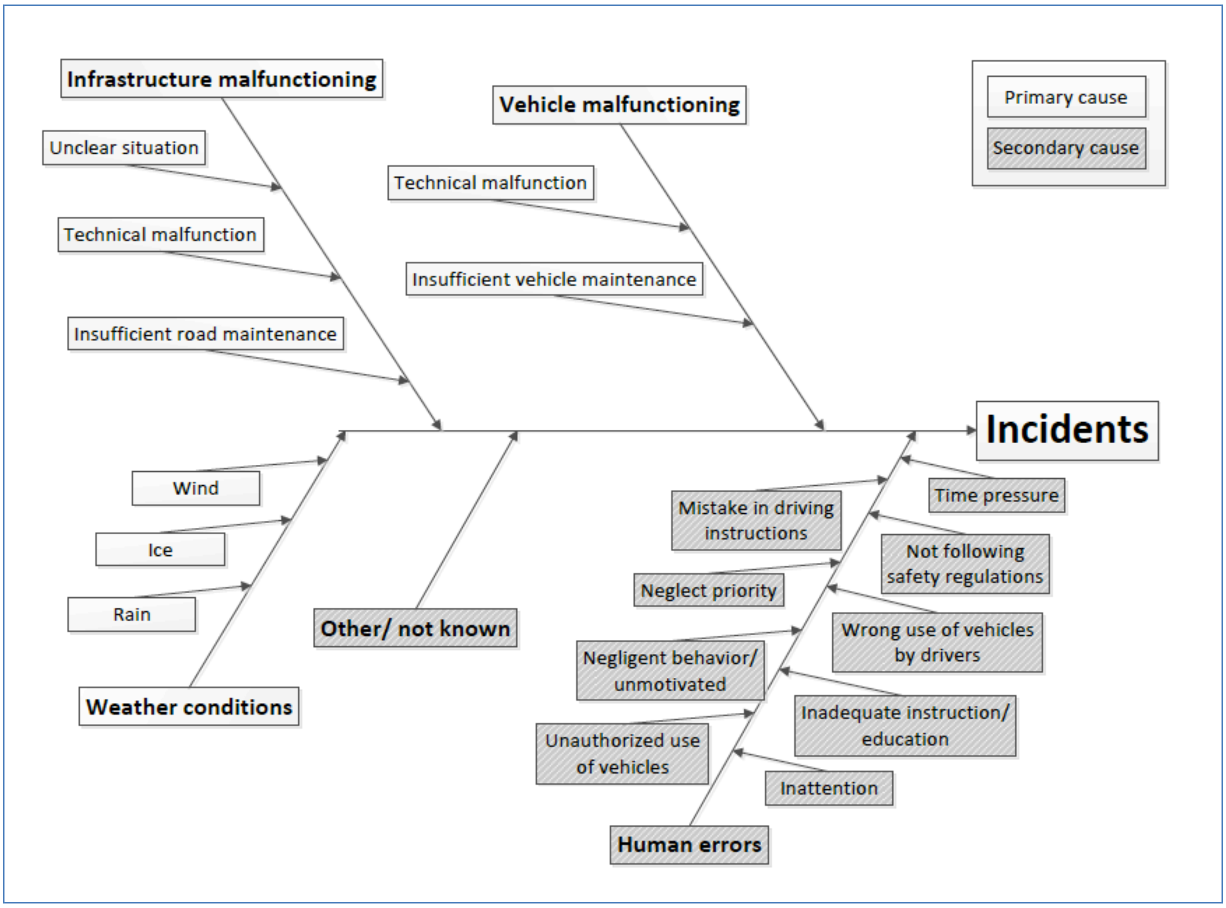

Figure 3.13; Causes diagram of collisions at AAS

Figure 3.14 until 3.17 display the top 5 most involved in collisions regarding related companies; the type of vehicles, general type of causes and specific causes on the airside of AAS between 2005 and June 2012. KLM is the company most involved in collisions, which could be explained easily because KLM also has the largest amount of registered vehicles on the airside. The exact number of vehicles of each company is lacking, so unfortunately it was not possible to research the number of collisions per vehicle. Another interesting aspect is the remarkable fact that many passenger cars are involved in collisions, instead of equipment used for handling planes. Regarding figure 3.16, it can be said that most causes can be found in the knowledge and behavior of users, combined with safety causes. To be more specific, figure 3.17 displays the fact that most specific causes appear to result from human errors, neglecting priority and parked vehicles. The details of the discussed four figures can be found in appendix C.1 until C.4 respectively.

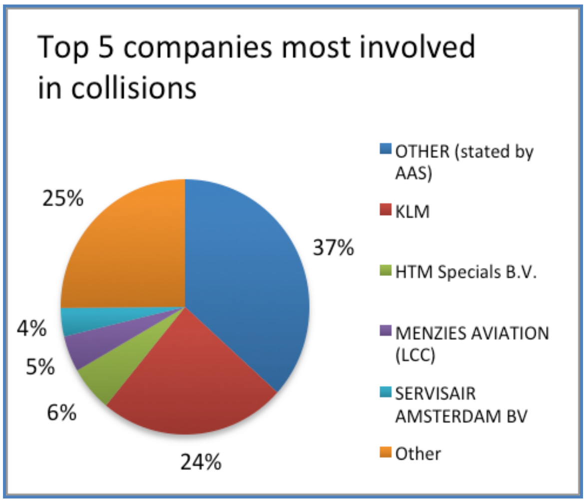

Figure 3.14; Top 5 companies most involved in collisions

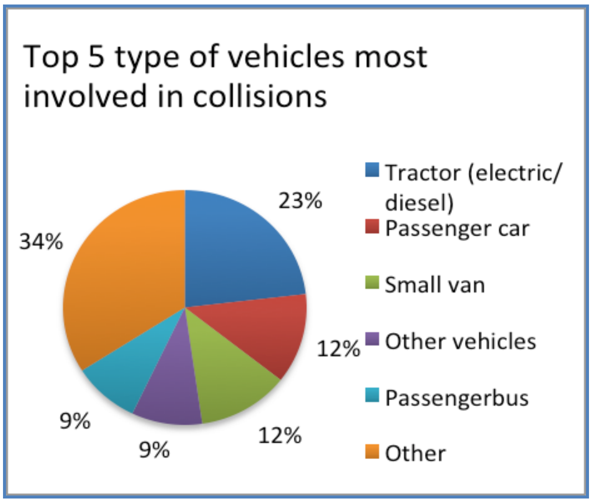

Figure 3.15; Top 5 of vehicles most involved in collisions

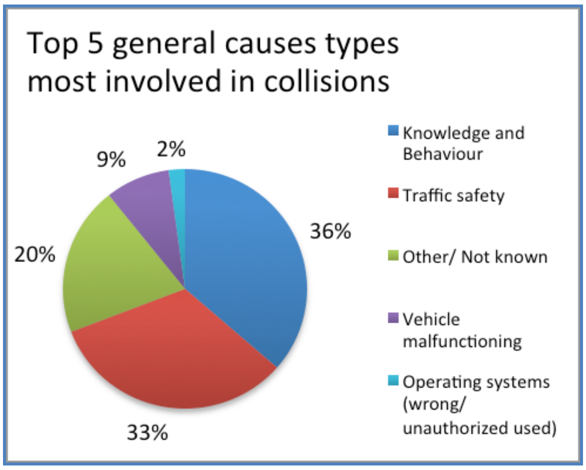

Figure 3.16; Top 5 general causes types most involved in collisions

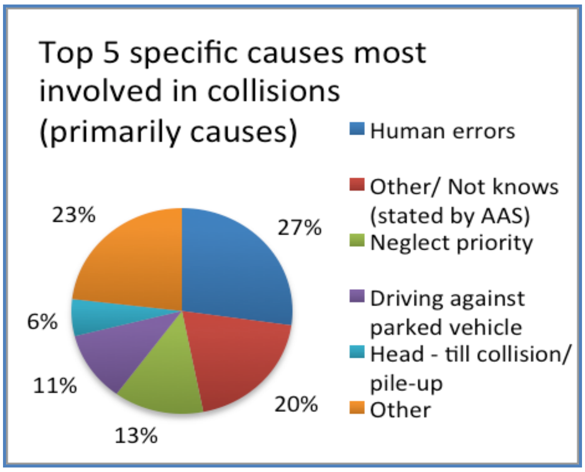

Figure 3.17; Top 5 specific causes most involved in collisions

3.6 Financial consequences of incidents

Within the previous sections, the different definitions, locations and causes of the occurred collisions at the airside of AAS are discussed; it should now be defined what are the financial consequences of these collisions. The consequences of incidents can be split into three main categories: costs, time and impact. The latter two aspects can also be translated into costs, which will therefore result in costs as the main criterion to indicate the severeness of consequences, although it is often not known how much these costs are. From damage reports of AAS different collisions resulted in different damages. Table 3.2 displays an overview of the financial consequences of the vehicle damages of AAS between 01-01-2012 and 12-10-2012. It can be seen that a collision will cost on average €886.67 euro. The maximum vehicle damage within the data is €8374,- euro, while the lowest repaired damage is €28,- euro. The data of AAS is taken an example of the costs of vehicle damage on the airside, because of time and added value constraints only the damages of AAS are used and not all other companies driving on the airside.

Table 3.2; Costs of average vehicle damage of AAS, based on data between 01-01-2012 and 12-10-2012.

Type of damage	Average amount of damage and number of damages of AAS
Average damage for all 171 damages	**€886.67**
Average damage for repaired 94 damages	**€1,612.99**
Number of damages	171
Number of repaired damages	94
Number of non-repaired damages	77

The executed quick scan of AAS delivers more insight in the financial consequences, although not all damages are repaired. As is discussed earlier, the average costs of damaging vehicles is €886.67 euro, with a maximum of €8374,- euro and a minimum of €0,- euro. It should be said that the average of €886.67 euro also includes all damages, which explains the minimum damage of €0,- euro, but these cases were not that serious that they had to be repaired. If these cases are filtered out, the average damage will be €1,612.99 euro, with a minimum of €28,- euro.

3.7 Problem areas

Above discussed information provides more insight in consequences of collisions, but it is still questioned where in the traffic system the most locations occur. For that reason, the term 'problem area' is conducted: when the number of incidents on specific areas is relatively high, it can be indicated as a 'Problem area'. The data from 2005 until June 2012 is merged into one figure, figure 3.12 (previous section). In this figure the problem areas are indicated which resulted from at least 6 out of the 8 years. So is for example the D-pier in all years indicated as bottleneck, and so will also be seen as a bottleneck in the final figure, figure 3.20. In between figure 3.18 and 3.19 show the problem areas of unilateral collisions and collisions between vehicles respectively. In the next section, a prioritization will be made between the different problem areas.

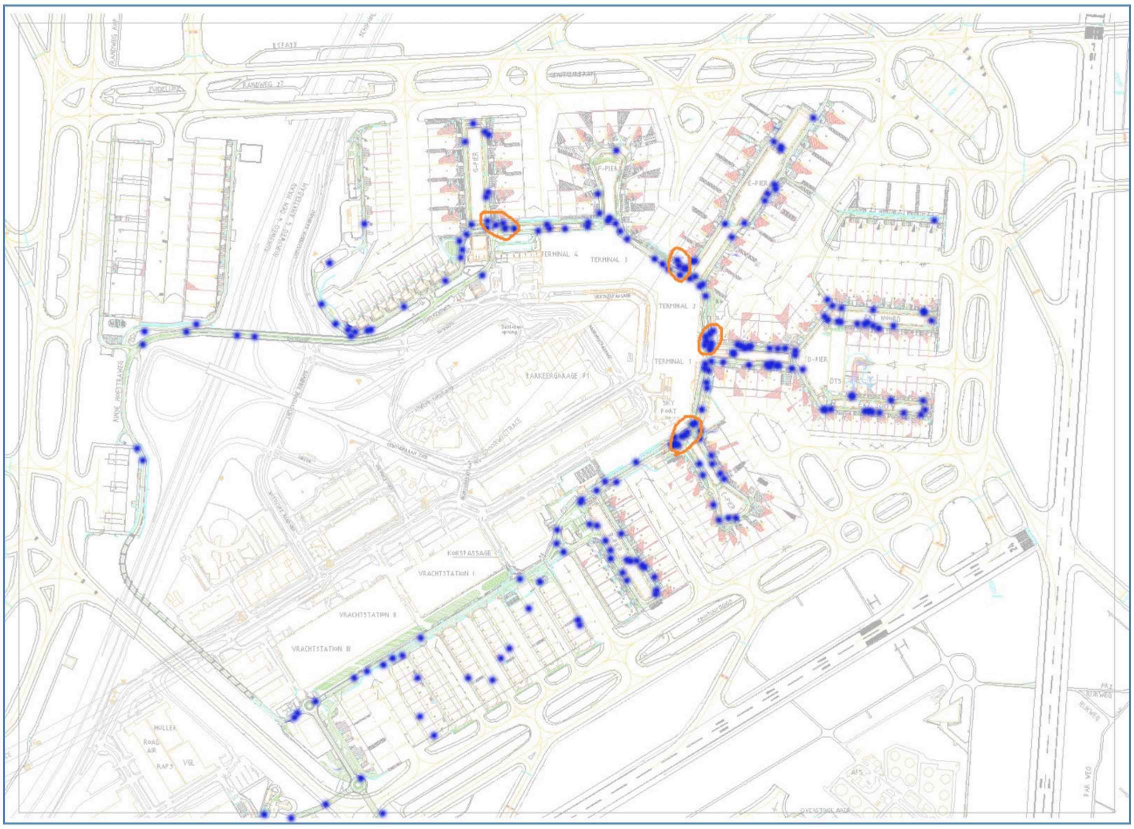

Figure 3.18; Problem areas of unilateral collisions

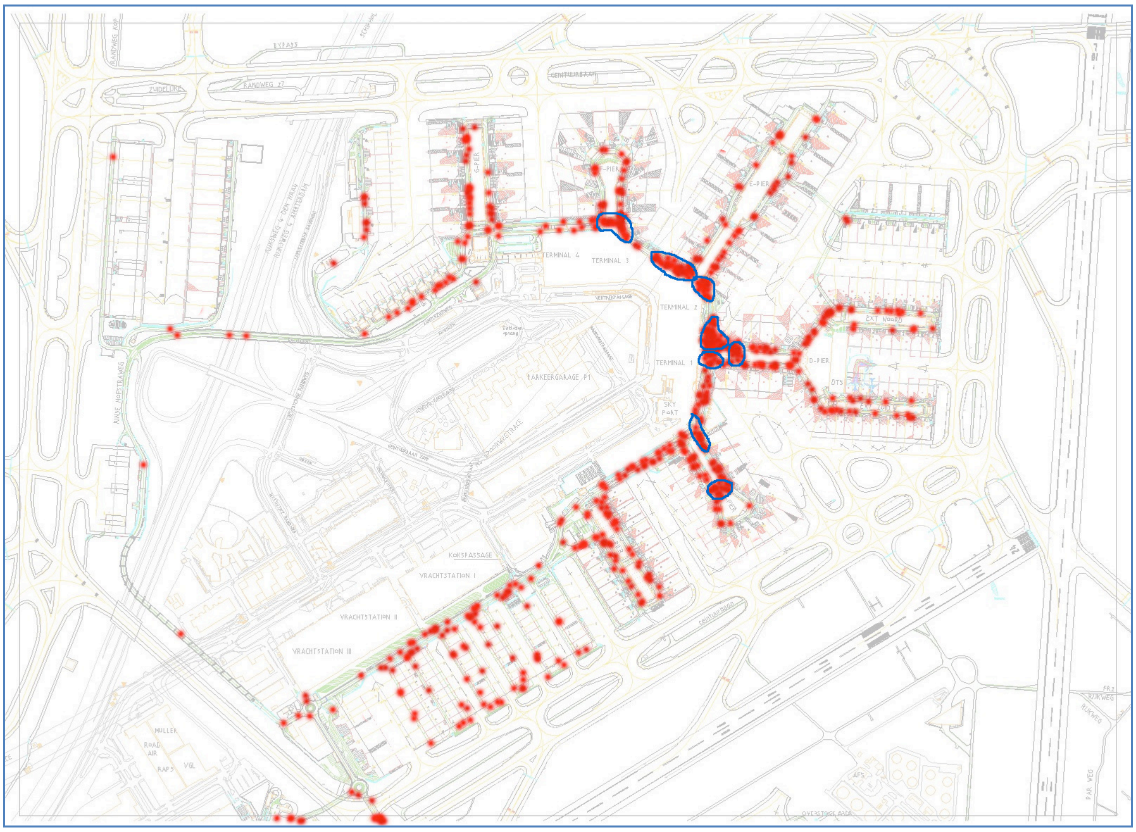

Figure 3.19; Problem areas of collisions between vehicles

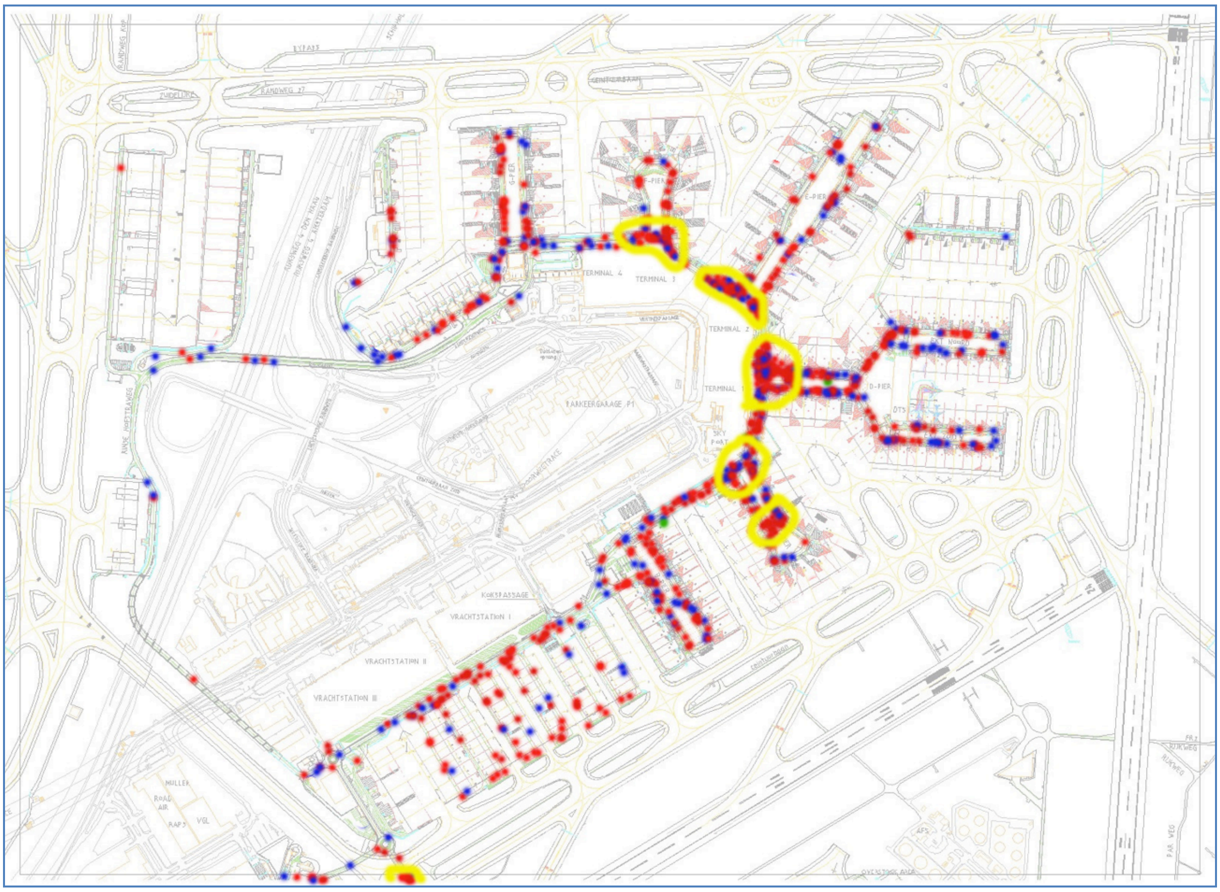

Figure 3.20; Problem areas overall

3.8 Prioritizing the problem areas

Now the types, locations, causes and consequences are known of the collisions on the airside between 2005 and June 2012, a prioritization of the problem areas should be made to indicate the most important areas where collisions occur.

A prioritization method is used, comparable with a Belgium traffic research (Design mobility plan Flanders, 2001) and which can be seen as a linear regression type of method. First five specific areas are already indicated in the previous section (figure 3.20, problem areas overall in the previous section), which experience a lot of collisions in the past eight years. These five areas are analyzed more in detail and can be seen in figure 3.21 until 3.25.

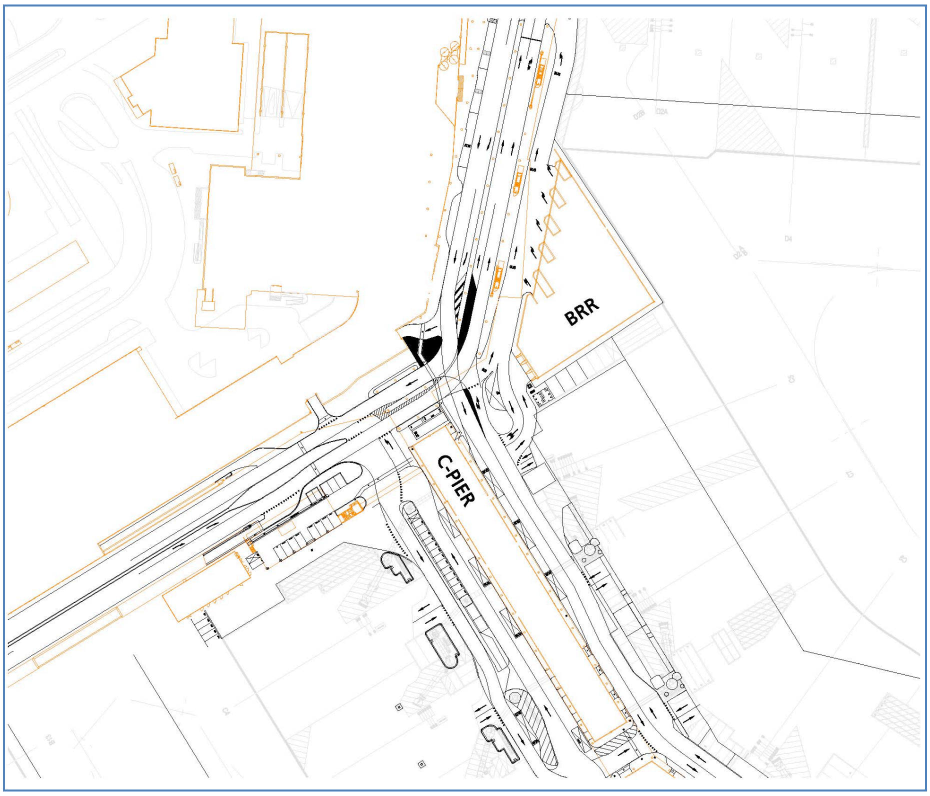

Figure 3.21; Zoomed-in area of the beginning of the C-pier

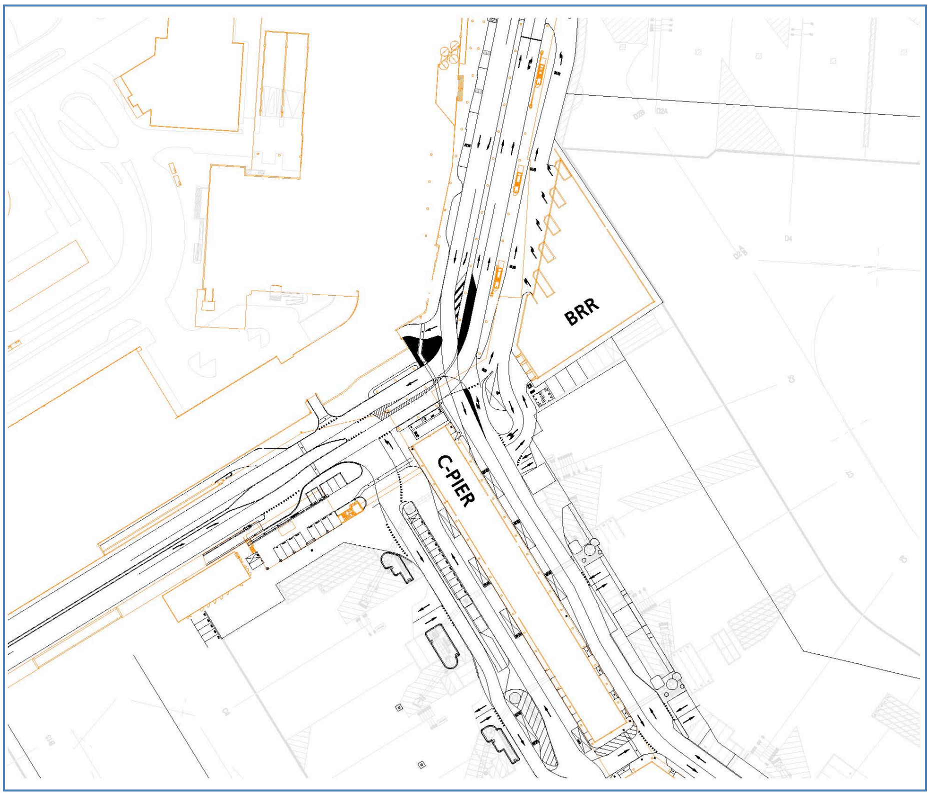

Figure 3.22; Zoomed-in area of the middle of the C-pier

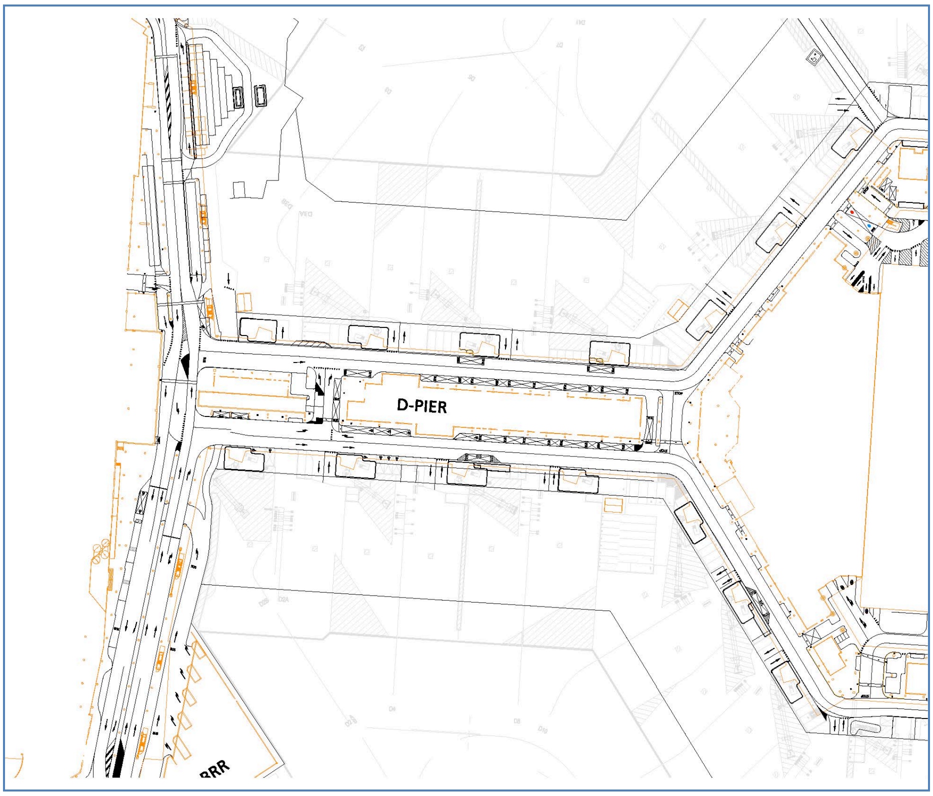

Figure 3.23; Zoomed-in area of the beginning of the D-pier

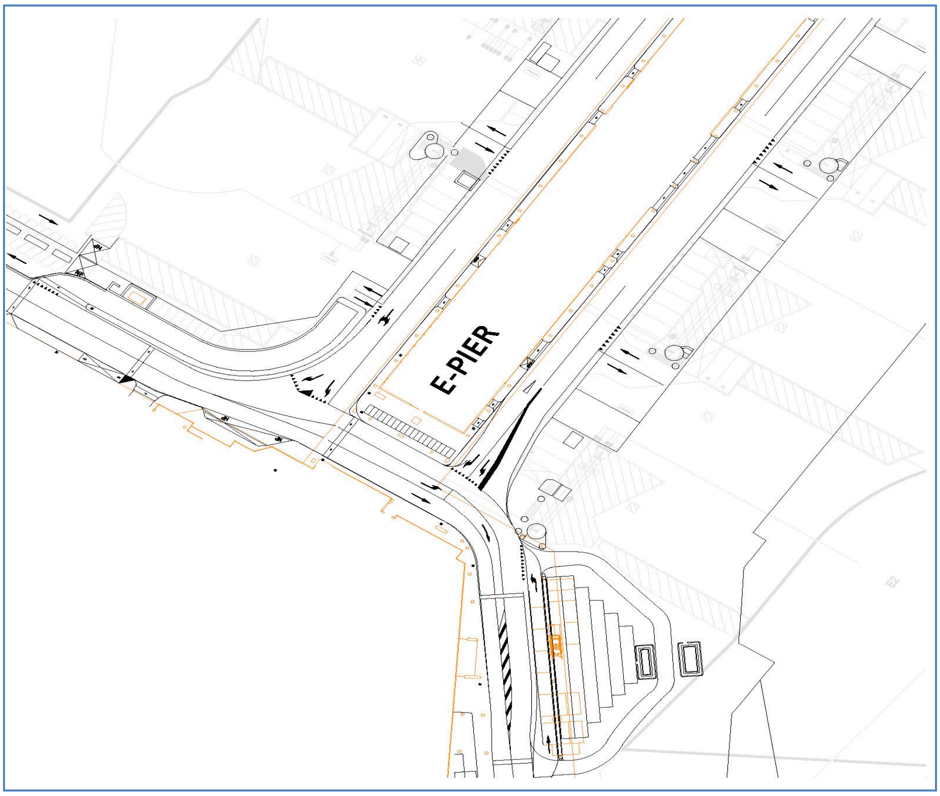

Figure 3.24; Zoomed-in area of the beginning of the E-pier

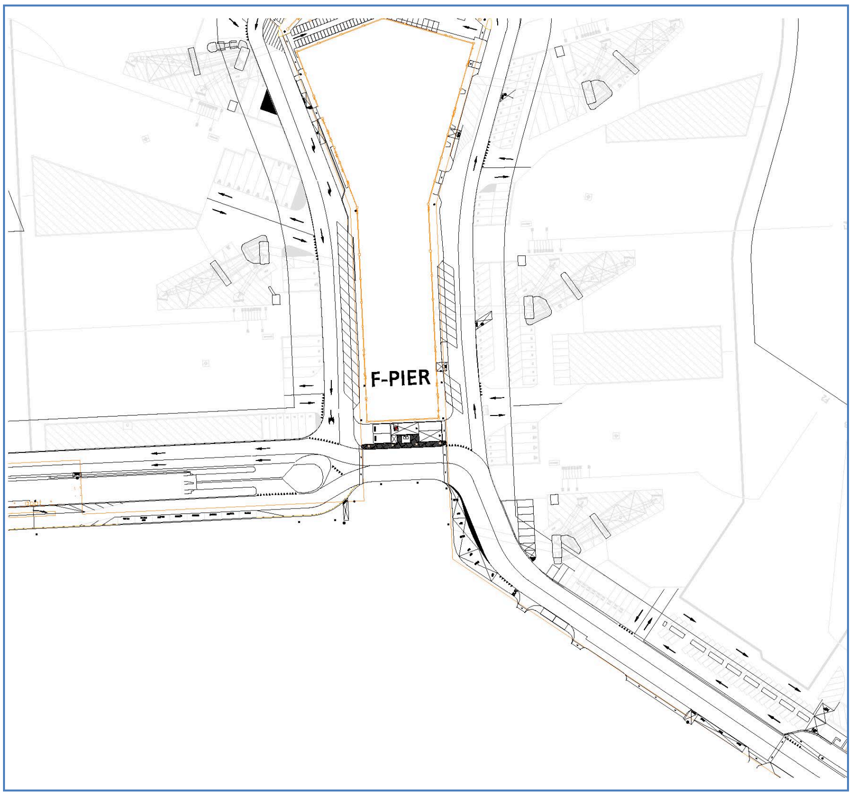

Figure 3.25; Zoomed-in area of the beginning of the F-pier

Some of the earlier discussed five different areas experience more than a certain number of accidents between January 2005 and June 2012 per square meter, which is also known as the 'density'. The number of square meter is different for each problem area and based on different experiences and logical sense. The number of collisions is made more realistic using the formula below; as one can see, collisions between vehicles 'count' double because two vehicles are involved.

$$P = A + 2 * B + C \tag{1}$$

P = Number of accident
A = Total number of unilateral collisions
B = Total number of collisions between vehicles
C = Total number of other collisions (involving people and / or animals)

As example the number of accidents in 2010 for all problem areas is also displayed (table 3.3). The B-pier will have an accident number P of 36, because P = 6 + 2*15 + 0 = 36. The number of collisions per pier of the other years can be found in appendix C.4.

Table 3.3; Number of collisions per type per problem area in 2010

Problem areas in 2010	Unilateral & other collisions	Collisions between vehicles
B-pier	6	15
C-pier	7	5
D-pier	7	22
E-pier	3	8
F-pier	4	4

When this regression method is used, the D-pier resulted as being the pier with the highest density as can be seen in table 3.4 and figure 3.26. For this reason a more in depth analysis will be performed on this pier in het next section of this research. Later on, in chapter 7, a set of improvement possibility will be proposed. First the robustness aspect will be discussed in the next chapter, followed by the reliability aspect in chapter 5 and the utilization aspect in chapter 6.

Table 3.4; Accident Number of incidents per problem area between 2005 and June 2012

P	2005	2006	2007	2008	2009	2010	2011	2012	Total
B-pier	51	74	51	49	57	36	44	10	**372**
C-pier	41	65	25	26	20	17	18	8	**220**
D-pier	87	65	71	70	54	51	31	10	**439**
E-beginning	26	36	44	46	18	19	23	11	**223**
F- beginning	22	20	23	28	10	12	13	8	**136**
	227	**260**	**214**	**219**	**159**	**135**	**129**	**47**	**1390**

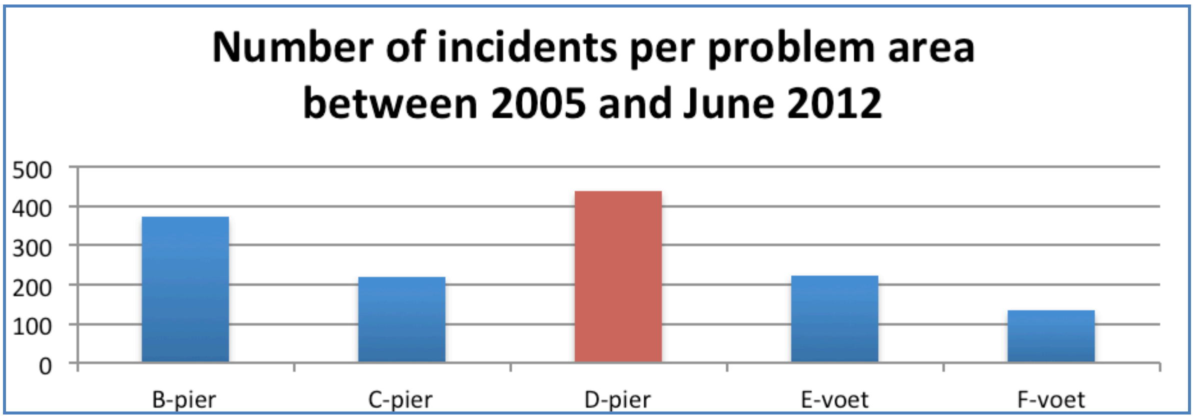

Figure 3.26; Number of incidents per problem area between 2005 and June 2012

3.9 Zooming in into the D-pier

Now the location with the highest incident density is known, as discussed in the previous section, a more in depth analysis will be conducted zoomed-in on the D-pier, which is the most important problem area. Specifically the following aspects will be analyzed more in detail: which type of collisions occur, where does the collisions occur, using which type of vehicles and for example on what time of the day the most collisions will occur? Also the consequences will be taken into account; the collisions with the most serious consequences should be analyzed more in depth on this specific 'most important problem area' than incidents with less serious consequences.

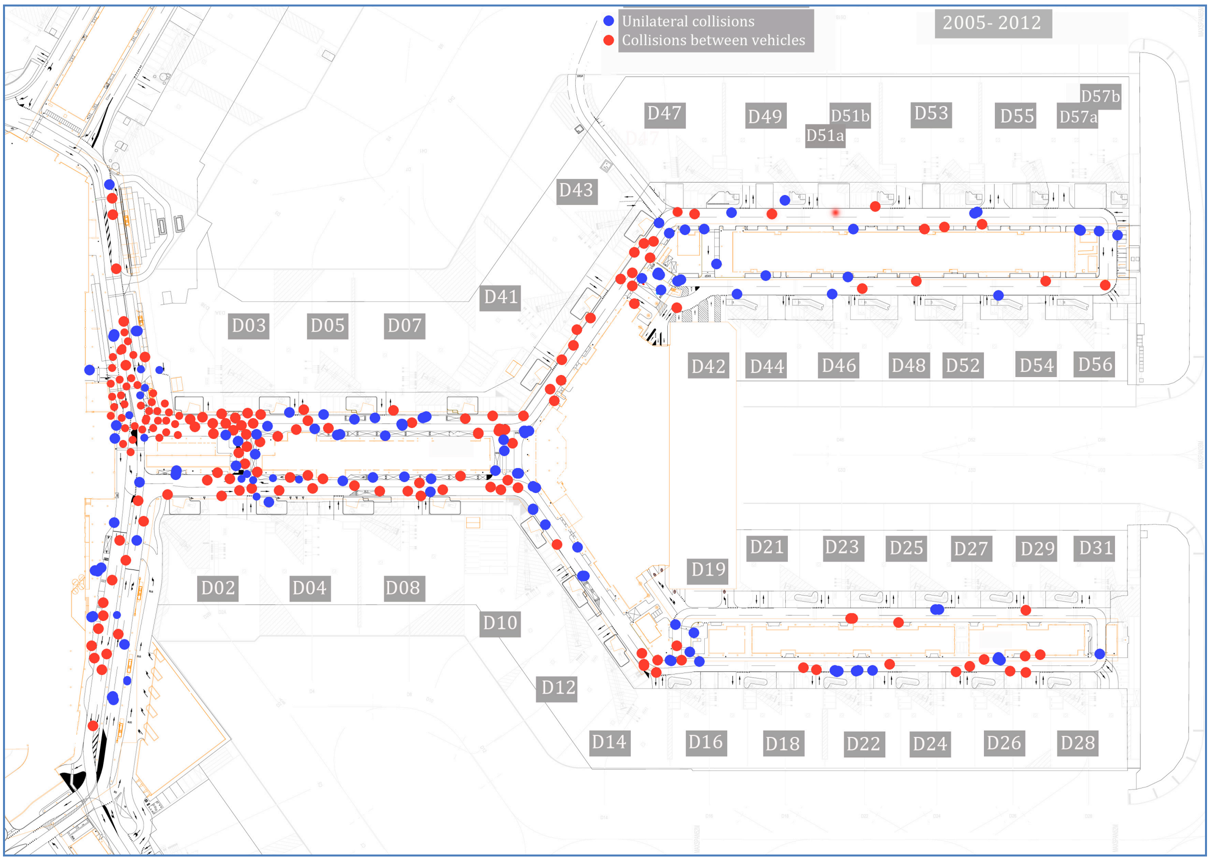

Figure 3.27; Zoomed-in area of the beginning of the D-pier, including all unilateral collisions and collisions between vehicles

Figure 3.27 displays two main problem areas where the most collisions occur: one area at the north side of the beginning of the pier and the small area used to cross the roads from even to odd or vice versa. The question is why these two major problems know considerably more collisions than other areas of the D-pier.

The area on the RH-road is experienced as a very busy junction, with many different exits and entrances. Most collisions occur when vehicles coming from the E-pier, sorting before going left, towards the D-pier because of the limit amount of space. Unfortunately, there is no quick improvement possibility to solve this problem; moving the baggage basements entrances and exits towards other locations would be possible the best improvement possibility, however this improvement possibility has major consequences and will not be in favor of many stakeholders.

The area coming from the D-pier, towards the RH-road, experiences high traffic volumes, so users have to wait relatively long to enter the RH-road and are possibly not paying enough attention there so many collisions occur, both between vehicles as unilateral with infrastructure. Also for this problem there is not really one best improvement possibility, although adjusting the infrastructure could help create more overview.

3.10 Conclusion regarding the safety analysis

Within this chapter many different analyses are performed, which all resulted in many interesting aspects regarding safety within the traffic system of AAS. This chapter started with definitions of safety, incidents and collisions and it can be stated that collisions are a specific type of incident and can be split into unilateral collisions and collisions between vehicles. The relationship between safety and collisions is of large importance further on in this research: reducing the number of collisions will result in a higher safety level at the airside of AAS.

In section 3.4 all collisions between 2005 and 2012 are visualized using the black spot analysis, resulting later on in section 3.7 in the problem areas; the areas in the traffic system experiencing the most collisions with as consequence a lower safety level. It appears that the D- and B-piers are the areas with the most collisions and are indicated as most important problem areas, although it can be said that the beginning of all piers can be seen as problem areas. For all problem areas different improvement possibilities will be designed after the analyses. To get more detailed insight in the main problem area, the beginning of the D-pier, this area is analyzed more in depth in section 3.9. It appeared that most collisions occurred on the interconnection of the D-pier and the ‘Rinse Hofstra road’, functioning as the main artery of the traffic system. This found aspects can be seen as generic principle and so potential improvement possibilities should focus on the beginning of the piers, because of the many collisions occurring on these locations and because of the operational delays resulting from a collision occurring at the main artery of the traffic system. Many more other vehicles are experiences delays from a collision on the main roads, compared to a collision on one of the supporting roads.

In between these sections, the causes and financial consequences of collisions are discussed. Most causes can be found in the knowledge and behavior of users, combined with safety causes. To be more specific, most specific causes appears to result from human errors, neglecting priority and parked vehicles. The average damage will be €1,612.99 euro, labeled as the financial consequence of one collision. It can be said that this performed safety analysis resulted in many interesting and important aspect for this research. Findings will be used both in the following analyses as in the improvements designing phase performed after the analyses. The following chapter will describe the robustness analysis of the traffic system on the airside of AAS.

4. Robustness analysis of the traffic system

Now the safety aspect of the traffic system on airside of AAS is discussed, a comparable type of analysis will be performed, but now regarding the aspect robustness, which will be performed within this chapter. Because of the fact that different definitions are used in the field, first a clear definition will be provided of the term robustness. Further on, the categorization is explained in section 4.2, which is used to construct the robustness map for AAS in section 4.3. In these maps the complete traffic system of AAS is categorized for both the current situation as for the future situation, taking into account the new masterplan of 2020. Section 4 concludes this chapter with a zoomed-in analysis on the beginning of the D-pier, as being the main problem area resulting from the previous analysis.

Comparable with chapter 3, also in this chapter both SQ 2 and SQ 3 will be answered partly; the current situation regarding robustness will be discussed (SQ 2) and the resulting problems areas (SQ 3).

4.1 Definition of robustness

The Definition of **robustness***: "the ability to fulfill the function of which the network is designed for, even in non-regular situations which differ (strongly) from regular user conditions."* (Snelder, Immers, & Wilmink, 2004). Robustness is characterized (and eventually can be improved) by the following different aspects (the way how to possibly improve them is printed *cursive*):

- **Redundancy**: apply *spare capacity* into the traffic system;
- The **impact** of non-regular situation: create a certain *resilience***,** or elasticity, and adaptability into the traffic system (of temporarily overload for example).

> **Robustness**: "The ability to fulfill the function of which the network is designed for, even in non-regular situations which differ (strongly) from regular user conditions." (Snelder, Immers, & Wilmink, 2004).

These two aspects will be used in the end of this research, namely when the improvement possibilities will be tested on the four criteria: safety, robustness, reliability and utilization. The aforementioned two measures will indicate how robust the proposed improvement possibility scenarios are currently and how they are influencing the level of robustness compared to the current situation.

In chapter 6, traffic volume measurements will be performed. The **traffic volume** will be directly related to the robustness, which will be discussed in section 6.2, after which both analyses are performed.

4.2 Categorization of robustness

Now a clear definition of robustness is provided in the previous section, in this second section the categorization of robustness will be defined, which depends from two main aspects as already discussed: redundancy and impact of non-regular situations. These two aspects will be discussed separately, section 4.2.1 and 4.2.2, concluding with the robustness categorization in sub-section 4.2.3.

4.2.1 Robustness regarding redundancy

To indicate different levels of robustness, a categorization is made and discussed in section 4.2.3. Roads are indicated as 'very robust' when there are *several possibilities to arrange easily a detour when a blockade occurs*. The moderate robust level is dedicated to roads that *have the possibility to arrange a detour if anything happen*, which is less easy to realize compared to very robust areas but easier to realize compared to non-robust areas. For example viaducts or bridges can be found in this middle category. The last category is the 'not robust' level, which is characterized by roads that *probably result in dangerous situations when a collision takes place*. Mostly tunnels can be found in this category.

It can be stated already that the roads between the D- and E-pier and between the E- and F-pier, which now exist of single lanes, could be extended to double lanes to increase the robustness of the system because it will create more space to pass in case an accident occurs.

4.2.2 Robustness regarding the impact of non-regular situations

The second aspect that will describe the robustness of the traffic system is the impact non-regular situations will have on the system. Non-regular situation will be defined here as collisions, as also used in the safety analysis earlier. As is discussed earlier in the safety analysis, different types of collisions could be identified. Logically, collisions with airplanes involved are known as the most costly collisions, but these are left out of scope because these collisions occur on the VOPs, which are not included into the traffic system as defined in chapter 3, the safety analysis.

The number of collisions is described in the safety analysis as well, and it is already concluded that the D-pier is standing out regarding the most collisions. Also the C- and E-piers are locations where many collisions occur, which will results in a lower robustness on these locations.

Some results regarding the financial consequences of collisions is already discussed shortly in section 3.6, resulting out of the executed quick scan of AAS. The lower the impact of collisions, the higher the robustness level will be. Unfortunately, it is not analyzed in detail where the most expensive collisions regarding damaging occurred, because of a lack of information on these locations.

4.2.3 The categorization of robustness

Now the three aspects are discussed individually, all discussed outcomes will be taken into account and a sufficient robustness map could be constructed. Before mapping all roads, which will be done in the final section of this chapter, first a categorization should be adopted. This categorization is based on all aforementioned outcomes of the three aspects so a good division could be made into three different levels: 'very robust', 'moderate robust' and 'not robust'. All parts of the traffic system are positioned in one of the three categories, although the boundaries between the different categories are qualitative and so not completely strict. Below the three categories will be described according to three characteristics for each level. The first mentioned characteristic of each category should at least be the case at a specific location, while the second characteristic is more an optional element which occurs very often in this category (but could be differ in exceptional situations); the third characteristic is a consequence of the first two aforementioned characteristics and also characterized this level of robustness.

The '**very robust'** category is defined as follows:

- *"Several possibilities available to arrange easily a detour when a collision occurs,*
- *Characterized by a low traffic volume,*
- *Resulting in the fact that the impact of non-regular situation will be low".*

The '**moderate robustness'** category can be characterized as follows:

- *"One possibility to arrange a detour if a collisions occurs,*
- *Characterized by a moderate traffic volume and*
- *Resulting in the fact that the impact of non-regular situation will be moderate."*

And finally, the ‘**not robust’** category is stated as follows:

- *“Probably will result in a dangerous situation when a collisions takes place,*
- *Characterized by a high traffic volume and*
- *Resulting in the fact that the impact of non-regular situation will be high.”*

An overview of the categorization is displayed in table 4.1. With this categorization a map is constructed of AAS in which the different levels of robustness can be seen; these maps will be discussed in the next section.

Table 4.1; Categorization of robustness

Different levels Of robustness	Explanation of the situation	Examples
Very robust	• ***Several possibilities*** *available to arrange easily a detour when a collision occurs,* • *Characterized by a* ***low traffic volume*** *and* • *The* ***impact*** *of non-regular situation will be* ***low***	Ring road
Moderate robust	• ***One possibility*** *to arrange a detour if a collisions occurs* • *Characterized by a* ***moderate traffic volume*** *and* • *The* ***impact*** *of non-regular situation will be* ***moderate***	Viaducts/ bridges
Not Robust	• *Probably will result in a* ***dangerous situation*** *when a collisions takes place* • *Characterized by a* ***high traffic volume*** *and* • *The* ***impact*** *of non-regular situation will be* ***high***	Viaducts/ Tunnels

4.3 Robustness maps

Now the categorization is known, the scoped area can be mapped. This scoped area contains the traffic system on the airside of AAS, so the perimeter roads and the roads along the locations where the aircrafts stand (‘VOP’s’). First the robustness map of the current situation will be discussed, followed by the robustness levels of the future situation; the new masterplan of 2020.

4.3.1 Robustness current situation

Figure 4.1 displays the robustness of the current situation, using the categorization of section 4.2.

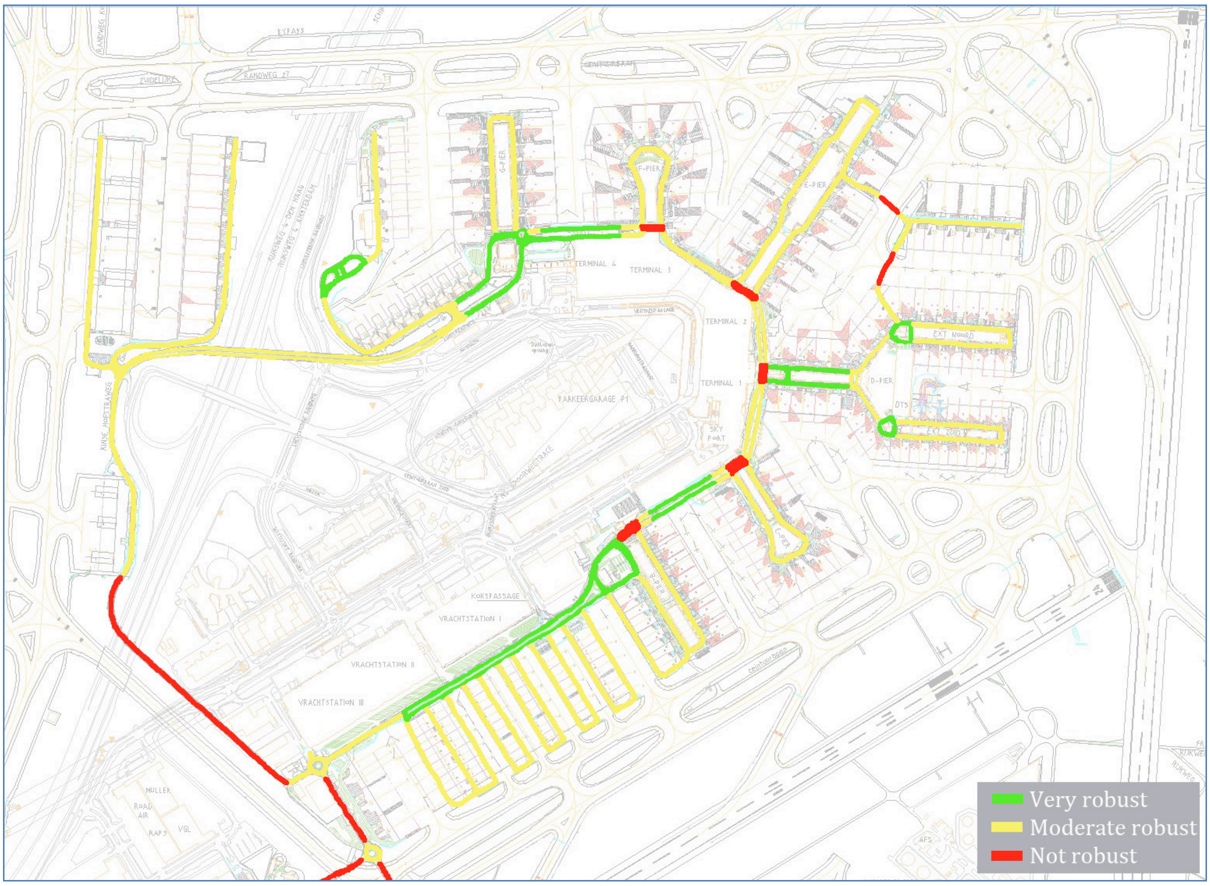

Figure 4.1; Robustness map with the related categorization

It can be seen that the traffic system on the airside of AAS is in general moderate robust. Only several parts of the system are indicated as low or high robust.

Low robust areas are the tunnels located in the South of the traffic system: the ‘Kaagbaantunnel’ and the tunnel towards the R-platform. When anything happens in one of these tunnels, probably a dangerous situation will be created resulting in possibly large secondary financial consequences, such as operation time loss. So not only because of the fact it could be dangerous within tunnels because of fire, smoke or other factors, but also because solving the problem on the location of the collisions is complex and could resolve in an even more dangerous situation and even more secondary financial damage. Finally, the tunnels are indicated as area with a low robustness because of their location; when something happens in the tunnels, the traffic system is isolated from the outside areas in the South (mostly cargo and business areas), which is a far from ideal situation. This latter argument also should be taken into account and will resolve in an advice to solve the problems in the tunnel as soon as possible because of blocking the road. The only possible detour that could be arranged is driving around the complete traffic system in the North of AAS, but this is located out of the scope of this research.

Also the beginning of almost all piers are low robust, because these are important junctions; if something happens on one of these junctions, the consequences will be large. Also the two roads that cross the taxiways, where airplanes are pushed-back, are indicated as low robust because of the large consequences to the flight schedule if something happens on one of these roads.

Large parts of the system are indicated as moderate robust, because of single road; arranging a detour is possible, but not that easy to realize. Specific elements that are identified as moderate robust are the north overpass crossing the highway A4 with two lanes, the roundabouts located in the South of the traffic system and the roads crossing the taxiways between the D and E piers. The overpassing is indicated as moderate robust, because it is possible to arrange a detour around the collision, for example using the other side of the road for a short part, while officers will lead the traffic around. It should be mentioned that this is not an ideal situation because of the overpassing and should be solved as soon as possible to avoid too much nuisance for the other road users, but still, arranging a detour is possible.

Other roads are identified as ‘very robust’, because there are several possibilities available to arrange easily a detour when a collision occurs, for example because there are two times two lanes available, which makes it possible to quickly arrange a detour.

4.3.2 Robustness future situation

Regarding the new masterplan for 2020, the situation on the airside will change, as is discussed earlier in section 2.5 and is shown again in figure 4.2. This will not have any effect on the robustness of the system, because the current roads, viaducts and tunnels are not removed. When it will be decided that another tunnel or viaduct/bridge should be build, they can be identified in the same way as in the previous section, so will be identified as ‘not robust’ and ‘moderate robust’ respectively.

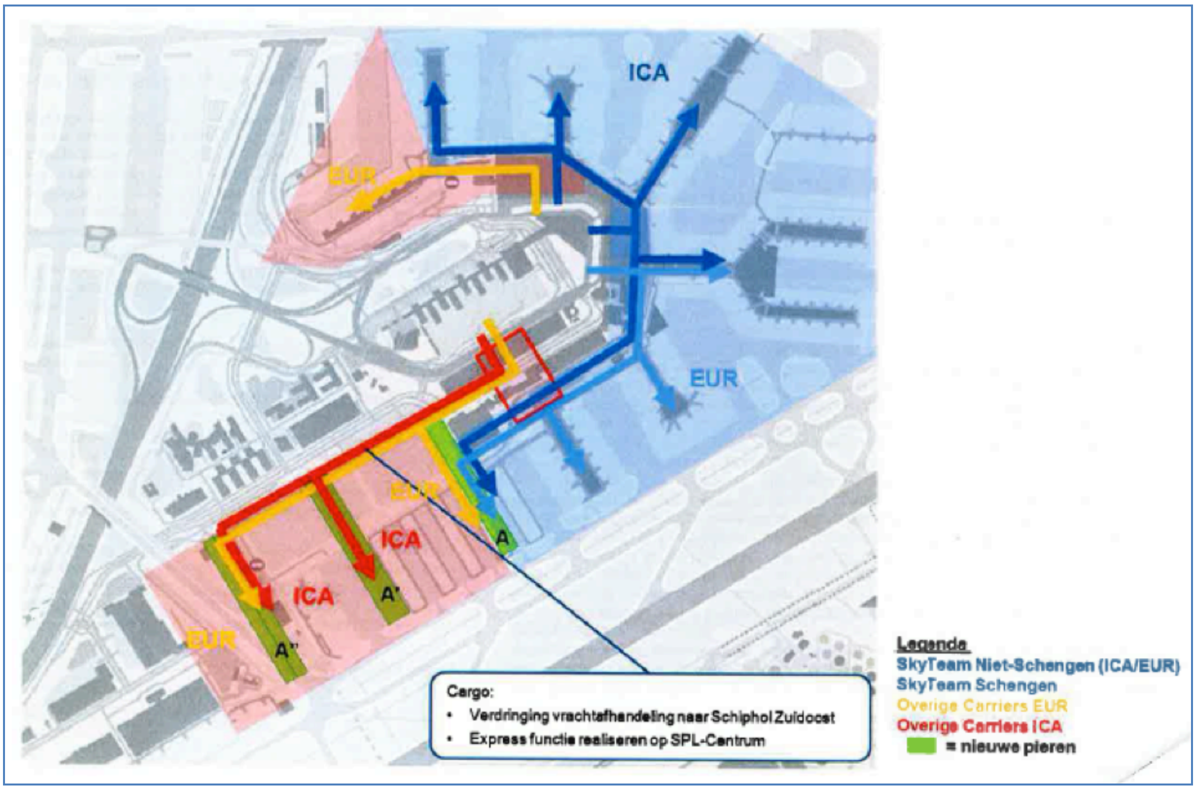

Figure 4.2; Robustness future situation; new masterplan 2020

4.4 Zooming in on the D-pier regarding robustness

As is explained before, in chapter 3 the safety analysis of the traffic system, there will be zoomed in during this research on the D-pier. Also for the aspect robustness is decided to zoom in into one part of the traffic system to get more insight in the details, because of the same reasons as is chosen for the D-pier as in chapter 3.

Only two levels of robustness are identified in figure 4.3: the 'high robust' and 'moderate robust' categories. The Rinse Hofstra road is characterized by having many possibilities to arrange a detour if a collision happen, so this is identified as 'high robust' (and colored green in the figure), even as the bypasses to the beginning of pier. The end of the bypasses, going to the both ends of the D-pier, is identified as 'moderate robust' because if a collision happens here, a detour is less easily arranged; probably the places where the airplanes stands (VOP's) should be used to reroute the traffic along the collision.

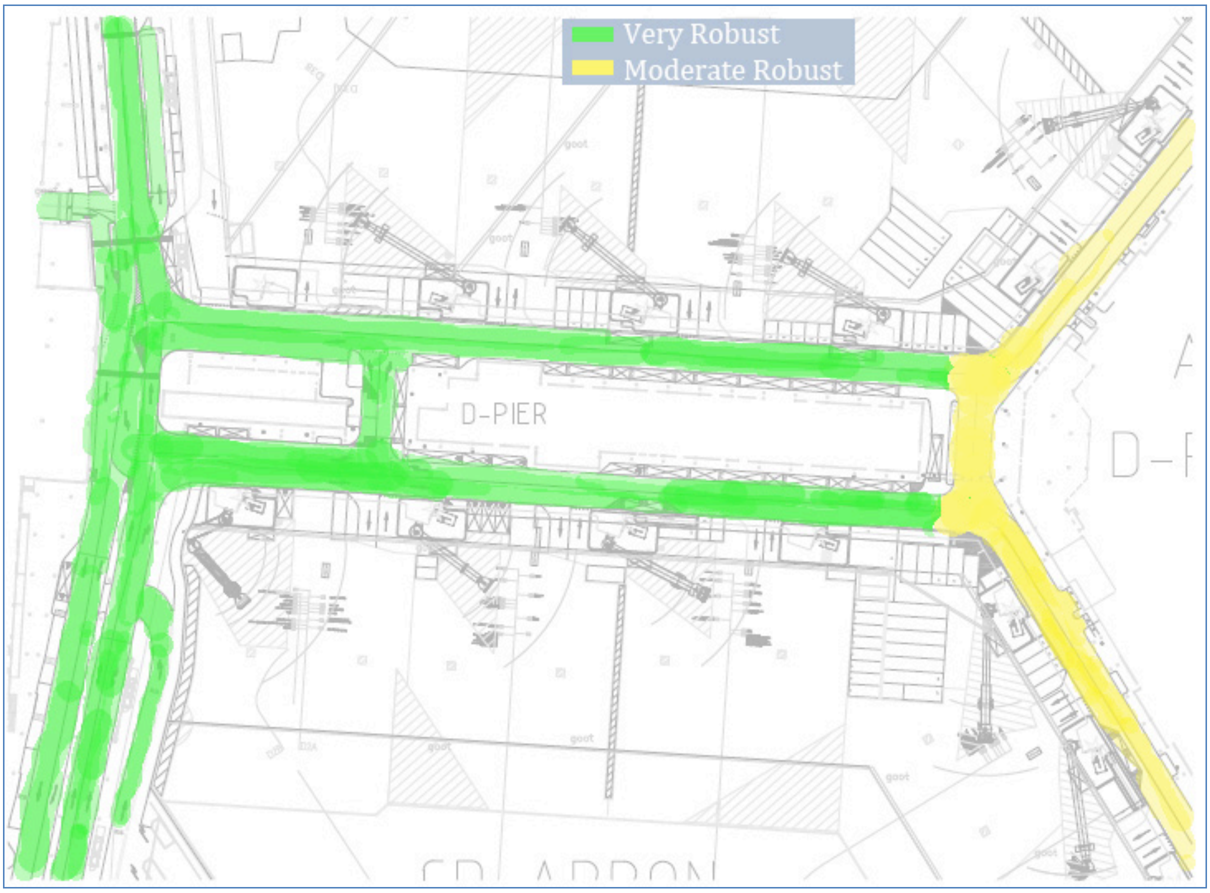

Figure 4.3; Zooming in into the robustness of the D-pier

4.5 Conclusion regarding the robustness analysis

Within this chapter clear definition is provided: "the ability to fulfill the function of which the network is designed for, even in non-regular situations which differ (strongly) from regular user conditions" (Snelder, Immers, & Wilmink, 2004). This definition implicates the level of robustness depends from the fulfillment of the function at specific moments. When a collision occurs for instance, it depends on the level of robustness on the specific locations if the collisions will have large consequences, or not. At locations with a 'high level of robustness', the consequences of a collision will be relatively low and other traffic will not experiences much hinder and / or delays. Logically, at locations that are indicated as 'not robust' users will experience hinder which causes delays. One of the main conclusions of this chapter is the fact that authority officers should take the level-of-robustness into account when acting when a road is blocked by a collision for example. At 'not robust' locations, the traffic hinder should be solved as quick as possible and so not additional time should be used to extensively research what happened.

Another conclusions which could be drawn from this analysis is taking locations with a 'not robustness' level very seriously in the end of this research during the designing phase of improvement possibilities to limit the hinder and delays on this key areas. The following chapter is focusing on the reliability of travel time on the airside of AAS, again taking all knowledge and findings of the already two performed analyses into account.

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5. Travel time reliability analysis of the traffic system

Now the safety and robustness analyses are performed and the problems areas are identified regarding these two aspects, still two more analyses should be performed on the traffic system on the airside to complete this research: the reliability and utilization analysis. Within this chapter, the reliability aspect will be discussed, again answering both SQ 2 and SQ 3, by respectively analyzing the current situation and identify the problem areas regarding this aspect.

Reliability in this research is used in the sense of reliability of the travel times, which will also provide more insight in occurring delays, possibly caused by incidents on the traffic system on the airside. This aspect will be discussed in the first section. To get more insight in the reliability aspect an experiment to gather data is designed, because there is no data available at AAS regarding this aspect that can be used for this research. More information about this experiment can be found in the second section. During this experiment the traffic on the airside is counted, using three different movie cameras, placed on strategic locations. The gathered travel times combined with the amount of traffic results in more in depth information about the travel characteristics on the airside. This chapter will conclude with the results and conclusions regarding the reliability of travel times on the airside of AAS.

5.1 Definition of the reliability of travel times

The definition of the **Reliability of travel time** is defined as follows*: "the extend to which a traveller (or user) is able to estimate with a particular certainty the time needed to travel."* (Snelder, Immers, & Wilmink, 2004). This 'certainty' is determined by the following aspects: the expected travel time, the variance in travel time, the stability of travel time, the provided information for the traveller and the possible alternatives the traveller is able to use.

Reliability of travel time: "the extend to which a traveller (or user) is able to estimate the time needed to travel with a particular certainty." (Snelder, Immers, & Wilmink, 2004).

5.1.1 Reliability in other applications

Reliability can also be defined in more manufacturing related perspective: *"the probability that a system will perform (within the boundaries) its intended function for a specific period of time under a given set of conditions. System is used here in a generic sense so that the definition of reliability is also applicable to all varieties of products, subsystems, equipment, components and parts."* (Lewis, 1994) Besides de reliability, also quantitative definition of failures and time should be defines to get more insight in the reliability of a system. Other ways to characterize the reliability of a system are for example mean time to failure, failure rate, mean time to repair and the availability of the system; in this research reliability will be defined as reliability of the travel time, which will also results in more insight in occurring delays in the traffic system of AAS.

Another reliability of the system should be taken into account, which is 'Human Reliability'. This type of reliability mainly takes a role in both accidents and maintenance. This could be easily related to the research aspects in the safety chapter before; human errors appear to be a large part of the causes of incidents on the airside of AAS. This leads to difficulties in obtaining reproducible data. Data depends not only on the physical state of the hardware, but also on training, vigilance and judgment of the maintenance personnel. These factors vary so that failure rates of the hardware are generally less variable than the probabilities of the maintenance failures and repair times (Lewis, 1994, p.291).

5.1.2 Breakdown of the definition of reliability

As mentioned in the beginning of this section, the reliability of the travel time is determined by the following aspects: the *expected* travel time, the *variance* in travel time, the *stability* of travel time, the *provided information* for the traveller and the *possible alternatives* the traveller is able to use.

The expected travel time will be measured in units of time by conducting an experiment on the airside of AAS by driving 12 different routes, 14 times per route; the experiment will be discussed in the following section. The variance in travel time can be conducted from the results of the experiment by using Excel. The stability of the travel time, the changes in travel times when volume and/or capacity changes, will be related to the robustness of the traffic system of AAS. Next, the amount and type of provided information for the traveller and the possible alternative routes will be discussed in the final section in the end of this chapter. Figure 5.1 summarizes the discussed elements of the reliability of travel times (Snelder, Immers, & Wilmink, 2004).

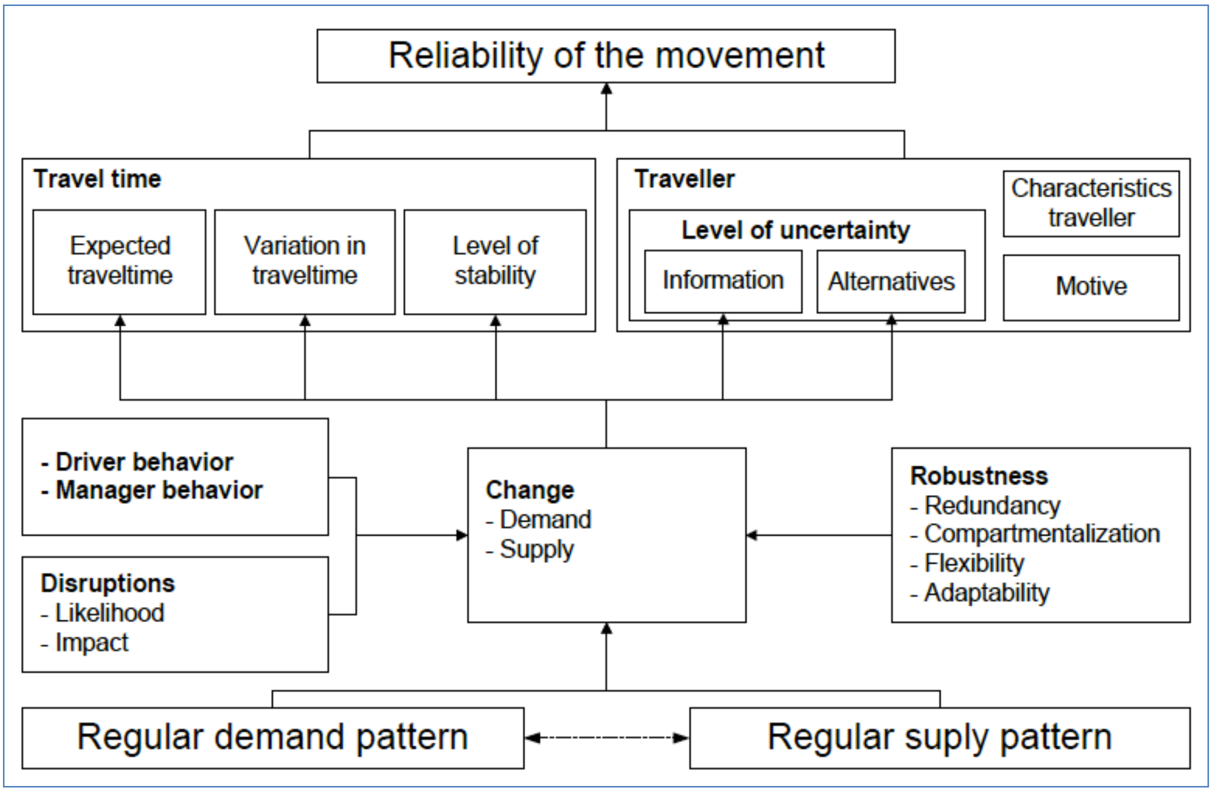


Figure 5.1; Reliability of travel time (Snelder, Immers, & Wilmink, 2004)

5.2 Travel time measurements

Earlier traffic experiments are held on the airside of AAS in 2005, but unfortunately this information and data is outdated now. For this reason, current travel time data is collected during this research in a specially designed experiment. In this section the set-up of the experiment is described, discussing the goal, the hypotheses and the practical aspects of the experiment. Detailed information could be found in appendix D.1, the measurement plan.

5.2.1 Goal of the travel time measurements

The goal of the experiment can be stated as follows: "get more insight in travel times, the reliability of travel times and the utilization of routes on the airside of AAS". At the end of this chapter a review will be provided on this goal and the hypotheses stated in the next section.

5.2.2 Hypotheses of the travel time measurements

For this experiment four hypotheses are formulated, which would be expected of the experiment:

1) "The location of collisions, if happening during the experiment, will be most likely close to the pier-locations, as is researched in the safety analysis."

2) "Most of the times no delay will occur, but when something occurs, the waiting time will be relatively low because of the robustness of the system; rerouting will take place".

3) "Travel times to B-, C-, D- and E-pier will be lower using the 'non-viaduct route'; while travel times with destination F-, G- and H- piers will be lower using the 'viaduct route'. To reach the lowest travel time to the E-pier, the route choice will have minor influence".

4) "The variance of the collected travel times will be lower of the routes using the viaducts compared to the routes which does not use the viaducts, because the traffic volume in these latter routes will be higher and so can cause delay(s)".

These hypotheses will be answered after discussing the travel time measurements in the concluding section 5.4.1.

5.2.3 Practical aspects of the travel time measurements

As described in the previous sections, the goal and expectations of these measurements are known. Also practical elements should be discussed first, before discussing the results of the measurements: the experiment is executed in five days, spread over two weeks, covering each working day of the week. The specific days on which the experiment is held are: Monday 10-09-2012, Wednesday 12-09-2012, Friday 14-09-2012, Tuesday 18-09-2012 and Thursday 20-09-2012. The experiment is executed with knowledge about the peak moments of the day: 9.00-10.00, 11.00-12.00 and 13.00-14.00 h. From the measurements clear peak moments could be conducted, which will be discussed in the next sub-section. The routes driven and results from the measurements will be discussed in the next sections 5.2.4 and 5.2.5 respectively.

Peak hour periods resulted out of the travel time measurements

The peak moments of traffic on the traffic system is caused by two main factors: the incoming airplanes and the start/ end times of employees on the airside. As an example, the flight schedule of KLM is taken as example, as KLM is the largest airline at AAS regarding vehicles (section 3.5, figure 3.14). The flight schedule of KLM is based on a wave system, which again is based on a number of daily connection waves in the airline flight schedule for flights to and from the airline hub. "A connection wave is a complex of incoming and outgoing flights, structured such that all incoming flights connect to all outgoing flights" (Bootsma, 1997). A wave system restricts the loss of passengers due to additional transfer time of an indirect flight, compared to a direct flight. Furthermore, a wave system increases the synergy between intercontinental and European flights. The downside of a wave system is a bigger peak in the flight schedule. In figure 5.2 the '7-wave-system' of the KLM is shown. The grey arrows represent ICA flights, while the black arrows represents EUR flights.

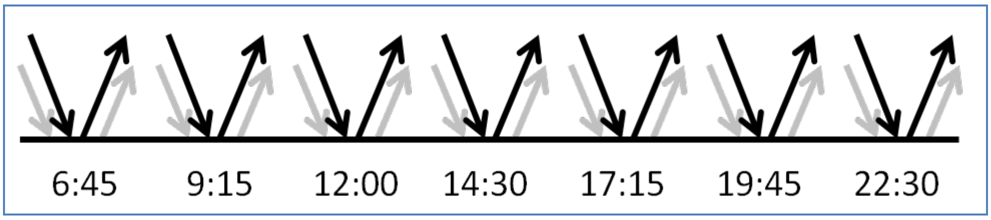


Figure 5.2; KLM wave system

With the wave system there is clustered traffic volume on the airside, which causes large differences in amounts of traffic during the day. This traffic volume mainly consists of vehicles that already are located on the airside and will stay there also (and so will not make use of the gates to enter/ leave the airside). For example when the first KLM wave will occur, around 6:30 AM, many airplanes arrive at AAS, which results in large traffic flows on the traffic system to handle all airplanes. After this wave, the amount of traffic will be reduced again, because fewer airplanes arrive. In this perspective the peak moments are around 6:00- 6:45h, 8:30- 9:15h, 11:30- 12:15h, 14:00- 14:45h, 16:45-17:30h, 19:15-20:00h and 22:00- 22:45h.

This aspect should be combined with the aforementioned assumption that the second reason of high traffic volumes is caused by the working hours of employees on the airside, which are driving in the morning to their working areas, passing one of the gates to enter the airside, and will drive back at the end of their working shift, passing again one of the gates to leave the airside. The entrances of the traffic system, the gates of AAS to enter the airside, register a lot of entering traffic between 6:30 and 9:00 h. The same development is experienced in the afternoon: The peak of vehicles leaving the airside, and so reducing the traffic volumes, is experienced between 14:00 and 16:00 h. (Meer, 2012).

It can be concluded that the peak hours on *working days* can be seen as displayed in table 5.1. This hypothesis will be checked in the end of section 6.2.3 of the next chapter in the traffic volume analysis, when the amount of traffic volume is count.

Table 5.1; Peak hours split in four parts of the day

Part of the day	Peak hours 'airside traffic'	Peak hours 'gate traffic'
Morning	6:00 - 6:45 h. 8:30 - 9:15 h. 11:30 - 12:15 h.	6:30 - 9:00 h.
Afternoon	14:00 - 14:45 h. 16:45 - 17:30 h.	14:00 - 16:00 h.
Evening	19:15 - 20:00 h. 22:00 - 22:45 h.	
Night	-	-

Finally, because of the 24/7 working mentality at airports, the weekend also should be taken into account. After interviews with experts, it seems that the traffic peak during the weekends is comparable with the daily trend of traffic volumes as is seen at working days, although with less traffic volume.

5.2.4 Routes of the travel time measurements

The final practical elements that will be discussed are the routes driven during the measurements, which will be explained in this section. As is discussed in chapter 3, the safety analysis of the traffic system, the D-pier can be seen as the pier with the highest density rate regarding collisions. For this reason, in this chapter also the D-pier will be used as one of the origins and destinations of the route to measure travel times. Because of the possible interesting choice of going left, using the two viaducts over the A4 highway, or going right, not using these two viaducts, both the E- and F-pier are also used as destinations (and so origins). It is expected that the decision of going ‘left’ or ‘right’ will be questionable for these two piers. The question is if both piers could be reached within the same amount of time independent from the route chosen.

The main starting point (and so destination) will be at the beginning of the Rinse Hofstraweg, after the roundabout, behind the ‘douane scan loods’ (DSL), because all cargo is checked here and an interesting route choice can be made, as discussed earlier. This route choice consists two alternatives, namely using the viaducts or not.

This origin combined with the three destination piers (D-,E- and F-pier), result in six different routes. Because of driving each route also the other way, the total amount of routes resulted in twelve routes. These routes are described in detail in table 5.2 and displayed in figure 5.3 and 5.4.

Besides the aforementioned reasons for the specific destinations, another reason why this route is taking as ‘experiment-route’ is because all three destinations, with as origin the DSL, are located along the locations where most collisions on the airside of AAS occur.

Table 5.2; Overview of the twelve different routes driven for collecting travel time measurements

Route number	Origin	Destination	Using the viaducts?	Amount of KM
1	DSL	E-pier	No	2.3
2	E-pier	DSL	Yes	3.4
3	DSL	D-pier	Yes	3.7
4	D-pier	DSL	No	2.2
5	DSL	F-pier	No	2.3
6	F-pier	DSL	Yes	2.7
7	DSL	E-pier	Yes	3.4
8	E-pier	DSL	No	2.3
9	DSL	D-pier	No	2.2
10	D-pier	DSL	Yes	3.7
11	DSL	F-pier	Yes	2.7
12	F-pier	DSL	No	2.3

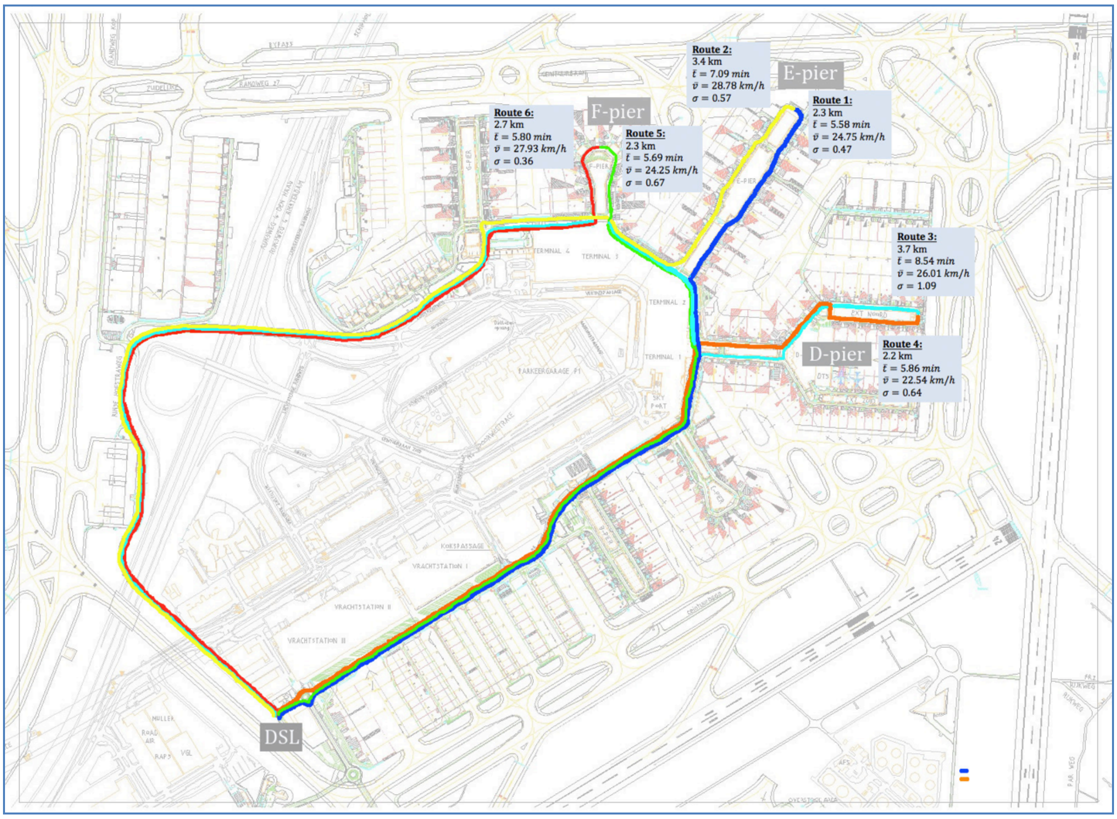


Figure 5.3; Routes 1 until 6 of the experiment, starting at the DSL and ending at the D-, E- and F-piers

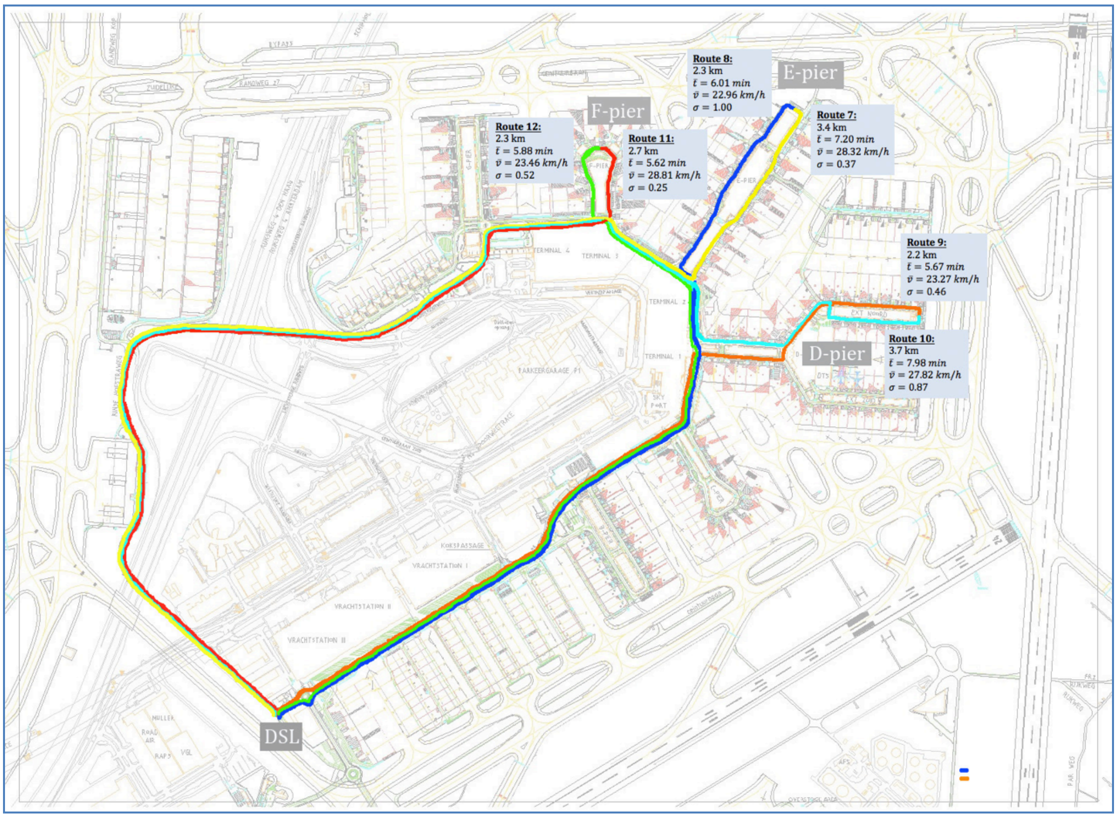


Figure 5.4; Routes 7 until 12 of the experiment, starting at the DSL and ending at the D-, E- and F-piers

5.2.5 Results of the travel time measurements

The extended results of the experiment, held between Monday 10-09-2012 and Thursday 20-09-2012 will be described now. As discussed in the previous section, 12 routes are set with the D-, E- and F-piers as destinations. Each route is driven 14 times, spread over 5 working days. Within this section the results of the travel time measurements will be displayed and shortly discussed, followed by a more extended discussion in the section 5.3 by analyzing the results more in detail. The complete gathered data is provided in appendices D.2.

Table 5.3 summarizes the average travel times ('Average tat') and the variance of these travel times. The average travel time of route 1 is for example 5.56 minutes, or 5 minutes and 0.56 * 60 = 34 seconds. Within this table also the minimum ('Min. tt') and maximum travel time ('Max. tt') of all 14 measurements per route are displayed and also the average speed driven during the measurements is shown per route. The expected travel time is defined as the average time of all 14 trips per route. So in total 12 times 14 is 168 trips are made. The variance, and so sigma, is used because it is more suitable for and more used by road authority, while for example the 'misery index' and/or 'buffer time index' is more suitable for road users. This 'misery index' can be defined as following: (average travel time of the 20% longest routes – average travel time of all routes) / (average travel time of all routes). The 'buffer time index' stands for the amount of extra time needed to be in time in at least 95% of all movements (Snelder, Immers, & Wilmink, 2004).

Table 5.3; Results of the experiment gathering travel times (routes using the viaducts are colored light blue)

Route number	Min. tt (min)	Max. tt (min)	Average tt (min)	Variance of the tt	Sigma	Average speed (km/h)
1	4.97	6.87	5.56	0.22	0.47	24.84
2	6.47	8.47	7.10	0.32	0.57	28.74
3	7.62	11.58	8.46	1.20	1.09	26.25
4	4.85	7.20	5.86	0.41	0.64	22.54
5	4.87	6.88	5.60	0.47	0.68	24.65
6	5.03	6.68	5.80	0.13	0.36	27.91
7	6.80	8.05	7.23	0.14	0.37	28.23
8	5.32	9.28	6.05	0.99	1.00	22.82
9	5.13	6.75	5.65	0.21	0.46	23.37
10	6.05	9.97	8.03	0.75	0.87	27.63
11	4.97	5.90	5.66	0.07	0.26	28.64
12	5.17	6.85	5.86	0.27	0.52	23.54

5.3 Analyzing the results of the travel time measurements

Within this chapter a more extended discussed is provided about the collected travel time measurements. As is already explained in the previous section, reaching the F-pier, starting at the roundabout at the 'DSL', will result in about the same travel time taking the 'viaducts-route' or the route along the B-pier. It can also be seen in figure 5.5 that the reliability of travel times is higher when vehicles uses the 'viaduct-route', instead of the route along the B-platform, because of the larger amplitude in the graphs for all three destination-piers. To be able to state with certain confidentiality that the measured travel times are reliable, a large amount of travel times should be gathered. Unfortunately, because of limited time constraints, the number of measurements (the driven routes) is not of a large enough to state this scientifically; a more in depth statistical analysis will be discussed below. Also the time frame in which this limited number of measurements is taken is of large variety.

Although it could be said that it is assumed as logically, that when less vehicles are taking the ‘viaducts-route’, the travel time will not depend that much from other vehicles and so will be more constant.

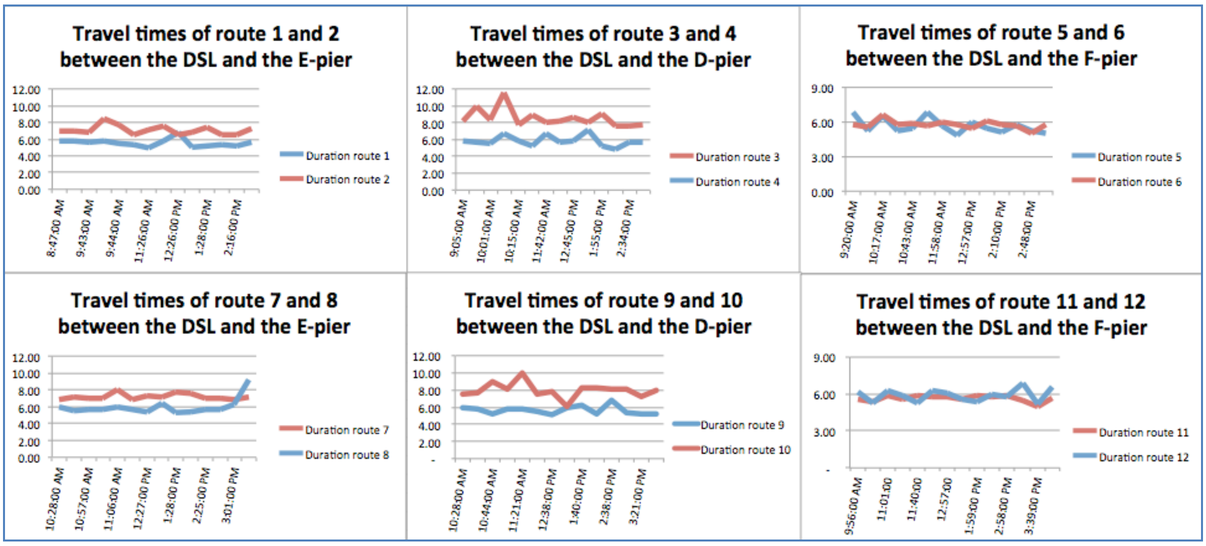
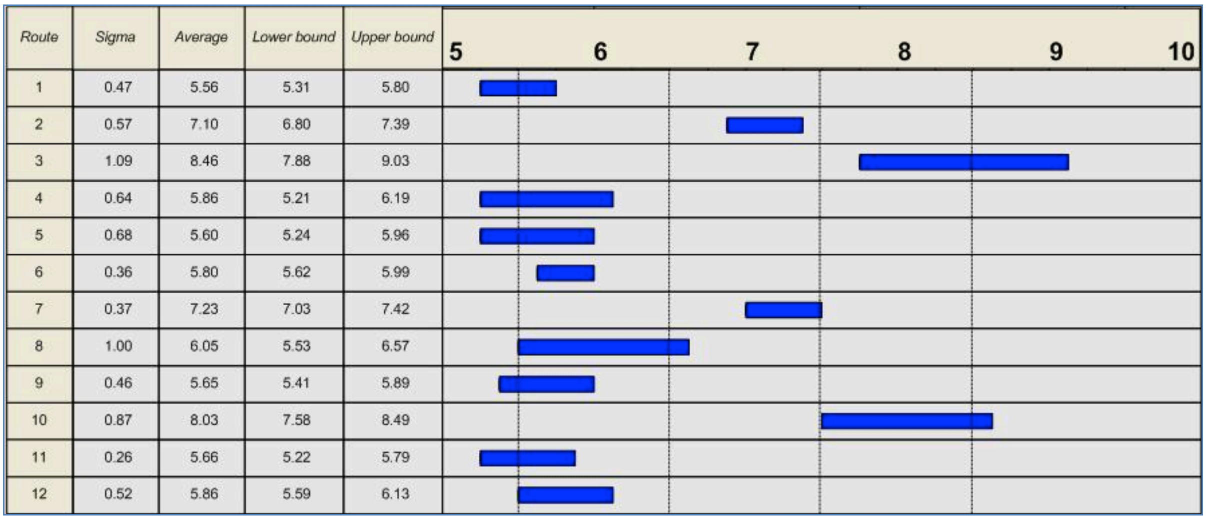


Figure 5.5; Travel times and their variance of the 12 routes

Figure 5.6 visualizes the 95% confidence intervals (CI’s) of all routes individually; indicated by the lower and upper limit of the measured travel time per route. The CI’s are not related to each other, although the figure can be used to compare the width of the intervals; knowing the fact that the wider the range of the interval is, the larger the variance and so the higher the uncertainty. The variance is also displayed in the left side of the figure. It could be seen that the uncertainty is the highest at routes 3, 8 and 10, which also can be deducted from the high sigma. These CI’s are based on 14 measurements per route, collected in travel time measurements as discussed in the beginning of this chapter. Further research should be performed to state scientifically that the travel time is more reliable of the ‘viaducts-route’, compared to the route along the B-platform.



Route	Sigma	Average	Lower bound	Upper bound
1	0.47	5.56	5.31	5.80
2	0.57	7.10	6.80	7.39
3	1.09	8.46	7.88	9.03
4	0.64	5.86	5.21	6.19
5	0.68	5.60	5.24	5.96
6	0.36	5.80	5.62	5.99
7	0.37	7.23	7.03	7.42
8	1.00	6.05	5.53	6.57
9	0.46	5.65	5.41	5.89
10	0.87	8.03	7.58	8.49
11	0.26	5.66	5.22	5.79
12	0.52	5.86	5.59	6.13

Figure 5.6; 95% Confidence Intervals of the travel times of all twelve routes

5.4 Conclusion regarding travel time reliability

Two different conclusions are drawn at the end of this chapter: conclusions of the measurements, taking the set hypotheses into account stated in the beginning of this chapter and the more general conclusions regarding the reliability of travel times.

5.4.1 Conclusion of the travel time measurements

In the beginning of this chapter, in section 5.2.2, four hypotheses were listed to be more prepared for the travel time measurements. In this section, these four hypotheses will be answered and discussed. Regarding the first hypothesis, about the locations of collisions, the conclusion can be quick and simple: the only collision happened during the measurements occurred on an aircraft stand and is very limited information to base facts on. The second hypothesis, the fact that delays if occurred will be small, is not answered for the same reason as the first hypothesis; no collisions occurred on the traffic system during the measurements. The third hypothesis could be stated as accepted: the travel times to B-, C- ,D- and E-pier are actually lower using the 'non-viaduct route'; while travel times with destination F-, G- and H- piers will be lower using the 'viaduct route'. The only comment with this hypothesis which should be made is that travel times to the F-pier do not differ when the 'viaducts-route' or using the route without viaducts. Finally, the fourth hypothesis is accepted as well: the variance of the collected travel times are actually lower when using the 'viaducts-route' compared to the route without the viaducts. It could be stated that the high traffic volume at the beginning of the piers causes this phenomenon with time delay as one of the consequences In the next section, a more in depth analysis about the gathered travel time data is conducted, providing also more detailed information regarding the discussed hypotheses.

5.4.2 Conclusions regarding the reliability of travel times

It can be concluded that traffic, coming from the 'Kaagbaantunnel' or other origins at the roundabout at the 'DSL' have the choice to take the route using the viaducts or the route along the B-platform. It appeared from the measurement, that vehicles with destinations D- and E-pier should take the route along the B-platform and so will not use the viaducts. The vehicles with destination F-pier (or earlier destinations, such as H-pier), is advised to take the 'viaducts-route'. The travel time will be around equal for the user when taking the left or right route, while the total utilization of the complete network does improve when these users are taking the 'viaduct-route'. Furthermore, their travel time also will be more reliable, because of the lower traffic intensity, than when they would have taken the route along the B-platform. It should be further researched how many measurements are needed to state if the 14 measurements are sufficient to state the reliability of travel times statistically, but logically it could be concluded that travel times of the 'viaducts-route' will be more constant because fewer other vehicles are taken the same route and so the likelihood of disruptions will be lower, which will result in more constant travel times.

The next chapter will discuss the utilization of the traffic system on the airside of AAS, using again self-collected data of actual traffic volumes. The findings of this and earlier analyses will again be taken into account in the next section while performing the last of four analyses.

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6. Utilization analysis of the traffic system

Now the safety, robustness and travel time reliability of the traffic system is described and analyzed, only the utilization aspect of the traffic system on the airside still need to be discussed to be able to completely answer SQ 2 and SQ 3; how the current situation looks like and what problem areas can be identified regarding the four aspects.

This chapter is consisting of four different sub-sections: first the definition of utilization regarding this research will be defined, followed by the discussion of actual traffic volume measurements and this chapter will conclude with more in depth information about the road capacity and the ability of the system to cope with the current and future traffic volumes. This chapter is concluding with more in depth information about the future masterplan of AAS and so will directly answer SQ 4.

6.1 Definition of utilization

Before discussed the measurements of the amount of vehicles driving on the airside, first the definition of utilization aspect will be defined within traffic engineering: "the extent to which the traffic flow is used as optimized as possible using the currently available infrastructure".

To get more insight in the utilization of the network, more information is needed about the size of the traffic flows. For this reason it is decided to place cameras on strategic locations on the airside, to be able to count the traffic passing by. Both the amount as the directions are of importance for the utilization of the traffic system.

Utilization: "the extent to which the traffic flow is used as optimized as possible using the currently available infrastructure".

Within industry a comparable, but slightly different definition is used: "The proportion of the available time (expressed usually as a percentage) that a piece of equipment or a system is operating."

$$Utilization = \frac{Operating\ hours}{Available\ hours}\ x\ 100\% \qquad (2)$$

Formula 2 could be seen as a start point to provide insight in the status of the traffic system regarding the traffic volume and road capacity. Using this basic information, statements could be made about the functioning of the system, when this formula is adjusted to this research and will be measured of important junctions. These results will provide more in depth status information of the traffic system on the airside of AAS. In the following section first the collected measurements will be discussed, followed by the calculations of road capacity in section 6.3 and a discussion on future developments in section 6.4.

6.2 Traffic volume measurements

As mentioned before, besides driving specific routes to gather (reliability of) travel time data, also the amount of traffic volume at specific locations is of interest for this research. For this reason one day, Wednesday 19th of September 2012, in between the travel time measurements, is chosen to collect film material, which is used later on to count the amount of vehicles using the traffic system on the airside. In this section first the description of how and when this filming is performed can be found, followed by the results from these movies and will conclude with more in depth information about traffic volumes on the airside in the future.

6.2.1 Methodology of measuring traffic volumes

First it will be discussed how the measurements are prepared and executed. Within the two weeks in which the experiment is held, one day is used to measure the traffic volume on the airside. This counting is executed by placing three film cameras on three strategic locations on the airside of AAS, which filmed the passing traffic by between 10:30 and 17:00 h. on Wednesday 19-09-2012. Figure 6.1 represents the three locations of the film cameras and the corresponding view of each camera or the filmed junction.

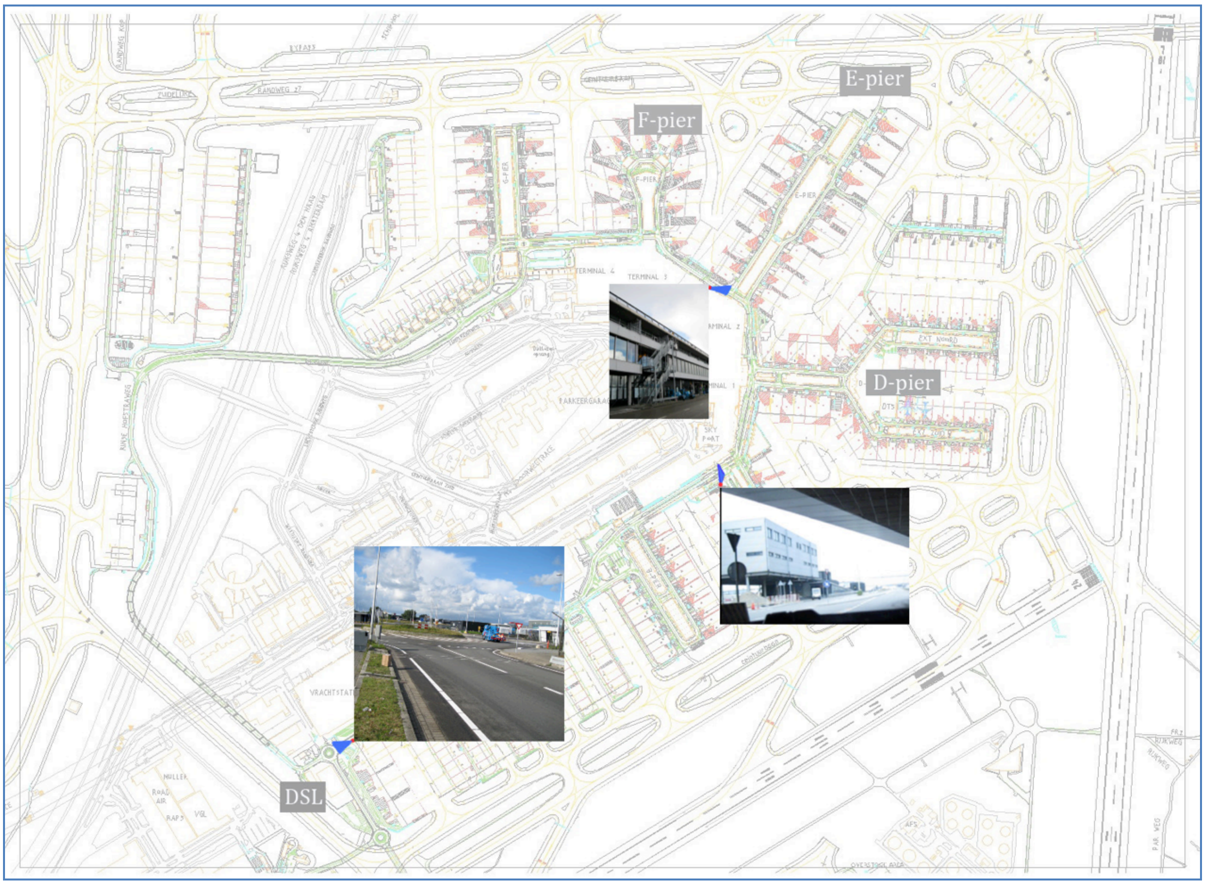

Figure 6.1; Tree strategic locations where film cameras are placed on the airside of AAS

Figure 6.2, 6.3 and 6.4 displays the location and way of positioning of the cameras on all three locations: location 1 is representing the camera placed on the beginning of the E-pier, location 2 is placed on the third floor of the 'ACC building' at the beginning of the C-pier and locations 3 is filmed the traffic on the roundabout at the 'DSL'.

Figure 6.2; Location 1: E-pier. High camera position focusing on the E-pier

Figure 6.3; Location 2: the ACC-building at the beginning of the C-pier

Figure 6.4; Location 3: DSL. Low camera position focusing on the roundabout at the DSL

6.2.2 Traffic volumes

Now the methodology is described how traffic volumes are measured on the airside, the results of these measurements can be discussed. In the end of the section the direction (and related amount) of the traffic flows is made visual and will be discussed.

The results of counting the traffic flows on the airside during one day are displayed in table 6.1, also including the total number of counting's. In section 2.2.1, where all different types of vehicles are already discussed, that the type of vehicles is divided into two categories: "slow speed vehicles" and "normal speed vehicles". It can be concluded that location 3 experiences relatively less traffic compared to the other two locations. Also the amount of "normal speed traffic" is much larger than the amount of "slow speed traffic". To get more insight in possible peak hours, the histograms of the three locations are displayed in the next sub-section.

From this utilization analysis it could be stated that the traffic volume is the highest at the D- and E-piers. Less than at the D- and E-pier, but still many vehicles could be found around the B-, C- and F-piers. The rest of the traffic system, e.g. the viaducts/ roundabout at the 'DSL'/ B-buffer/ G- and H-piers, could be indicated as locations with relatively low traffic volume.

Table 6.1; Traffic volumes of the three film locations, divided in 'normal' and 'slow' traffic

Amount of traffic volume	Location 1: E-pier			Location 2: ACC			Location 3: roundabout DSL		
	Normal	Slow	Total	Normal	Slow	Total	Normal	Slow	Total
10.30-11:00	384	18	402	232	28	260	134	12	146
11:00- 11:30	368	40	408	263	34	297	129	28	157
11:30- 12:00	426	50	476	352	54	406	134	19	153
12:00- 12:30	401	45	446	311	34	345	116	23	139
12:30-13:00	446	56	502	237	30	267	130	29	159
13:00- 13:30	383	38	421	254	30	284	144	18	162
13.30-14:00	446	44	490	341	51	392	147	20	167
14:00- 14:30	325	28	353	255	25	280	132	19	151
14:30- 15:00	323	37	360	240	30	270	111	9	120
15:00- 15:30	300	35	335	261	30	291	123	17	140
15:30-16:00	302	40	342	290	35	325	96	18	114
16:00- 16:30	298	45	343	328	30	358	83	18	101
16:30- 17:00	289	33	322	230	31	261	101	20	121
	4691	**509**	**5200**	**3594**	**442**	**4036**	**1580**	**250**	**1830**

6.2.3 Traffic volume analysis

Now the actual number of the number of vehicles driving on the airside of three specific locations is known, this data can be analyzed and used to draw conclusions about the relation between traffic volume and the individual aspects: safety, robustness, reliability and utilization. This sub-section ends with more insight in the peak hours on the airside resulting from the traffic volume data and visualizations are provided of the precise direction of the measured traffic flows.

The relation between traffic volumes and safety

Now the amount of vehicles, or traffic volume, on the airside of AAS is known at three strategic locations, the relation with safety could be discussed. Within chapter 3, the safety analysis, it is seen that the least safe areas on the airside are located at the beginning of the piers. When analyzing the actual measured traffic volume, it could be stated that a clear relation between the amount of vehicles and the safety on locations is recognized; the more vehicles driving at a specific location, the more unsafe this location will be. Logically, more factors are involved in the level of safety on specific locations, for example the amount of overview and the way of constructing infrastructure and/ or lining on the road.

The relation between traffic volumes and robustness

The locations with high traffic volumes will certainly have influence on areas that are less robust than locations with lower traffic volumes. But it can be stated that robustness is an independent aspect regarding traffic volume, labeled as high or low because of the possibilities to keep the system functioning although a collision for instance happened, and so the number of vehicles passing by does not influence the robustness level. This is not implicated that the two elements are not related; it can be said that the a combination of high traffic volume on a 'low robust' location will lead to more collisions, as could be seen in the safety analysis at the beginning of the piers. Both in the safety analysis it is seen that most collisions occur at the piers, while also the infrastructure could be improved there (because of the indicated low robustness level in the robustness analysis).

Concluding, the robustness level could be increased by adjusting the infrastructure, for example the number of lanes at specific locations, while a change in traffic volume is not directly influencing the robustness level.

The relation between traffic volumes and reliability of travel times

The reliability of travel times is highly depending on the traffic volume; the more vehicles are occupying the traffic system, the more delay will arise and the larger the different between the fastest possible travel time and the actual travel time will be. Although the remark should be made that the reliability is not only depending of the amount of vehicles, but also of the *type of vehicles*; if there were only passenger cars and vans, all able to drive 30 km/h, the possibility on and the size of the delay in travel time will be limited, while large cargo trains will block the traffic system and will result in larger delays. Also the aspect of 'luck' of not being behind "slow speed vehicles" at crucial locations, for example single lane roads with a low robustness level, plays an important role here.

The relation between traffic volumes and utilization

The final relation that will be discussed is the relation between traffic volume and utilization of the traffic system. It can be pointed out that the traffic volume is a effective measure to indicate the utilization of the network; the larger the differences between traffic volumes within the network, the more the utilization could (and should) be improved within that network. So the number of vehicles not directly results in optimizing the utilization, but it is complementary to each other providing insight in the system and pointing out which routes could be utilized even more to create a balanced utilization within the complete system.

Peak hours resulted out of the traffic volume measurements

Now the amount of traffic volume is known, as is discussed in section 6.2.2, interesting histograms could be drawn to get more insight in possible peak hours. First the peak hour of each location is displayed individually (figure 6.5, 6.6 and 6.7); after which a combined histogram will be discussed with the traffic volume of the three locations combined (figure 6.8). After the histograms, more in depth information is provided over the contents of the histograms.

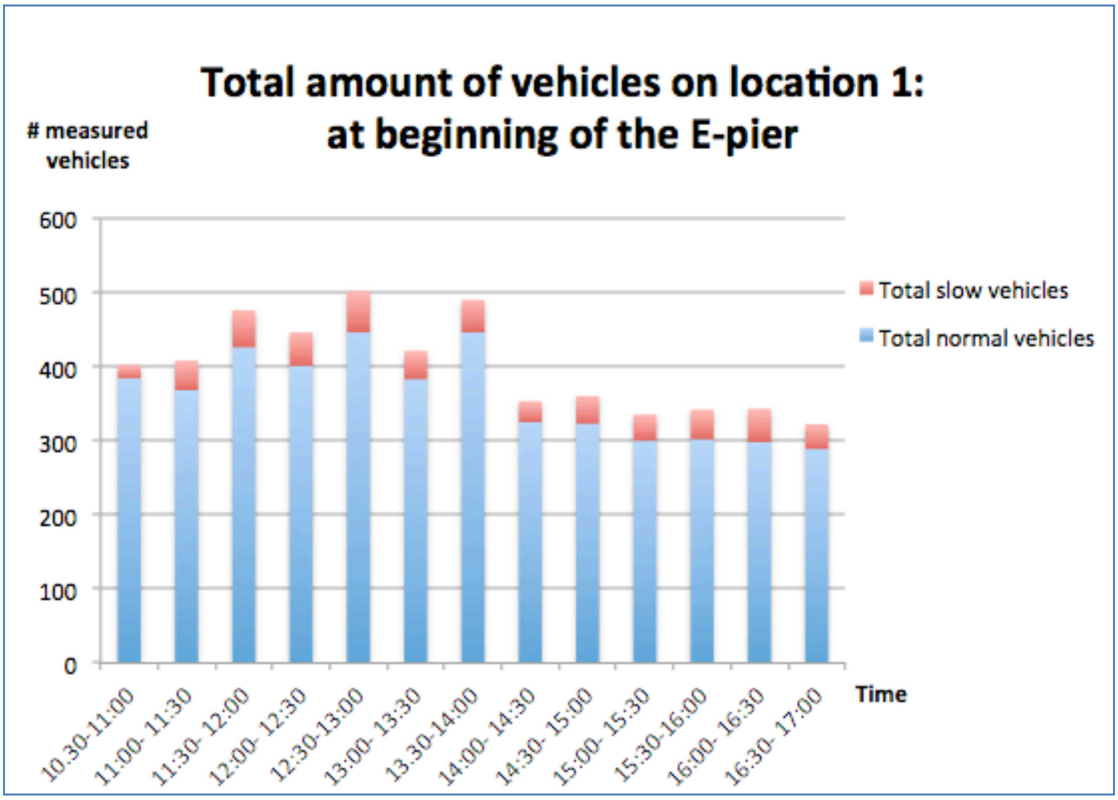

Figure 6.5; Total traffic volume on location 1: the beginning of the E-pier

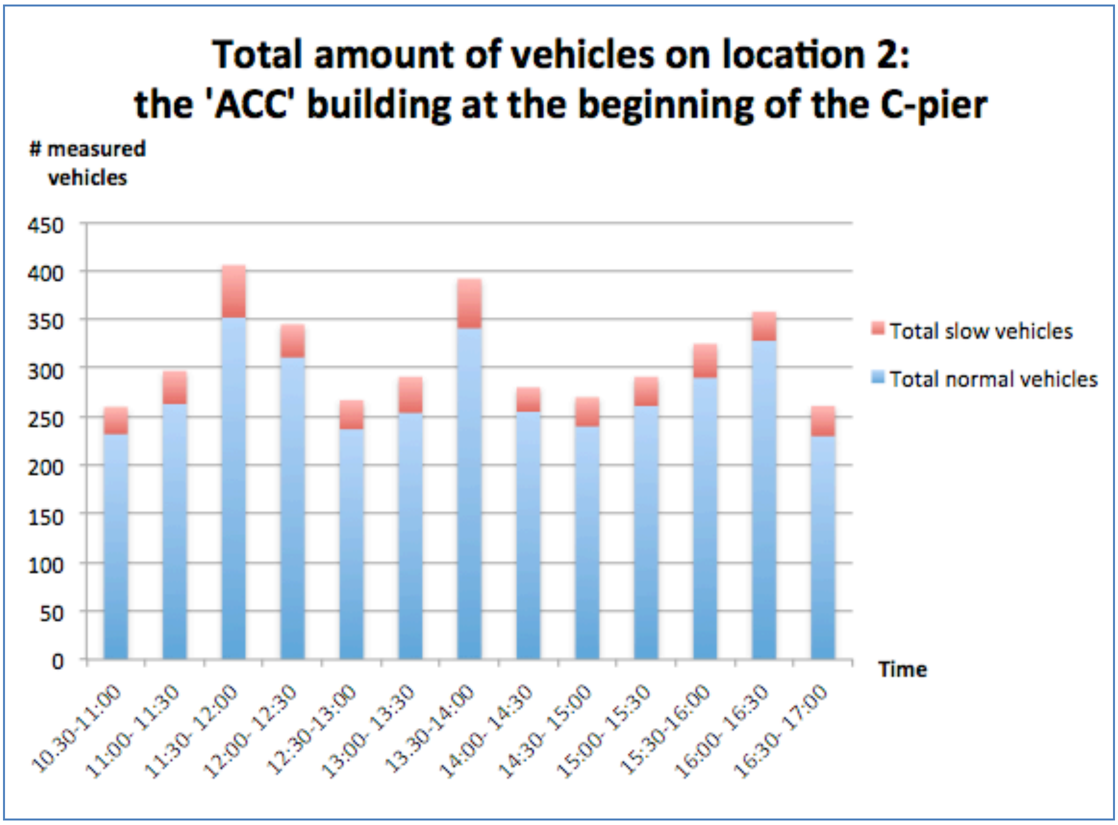

Figure 6.6; Total traffic volume on location 2: the 'ACC-building' at the beginning of the C-pier

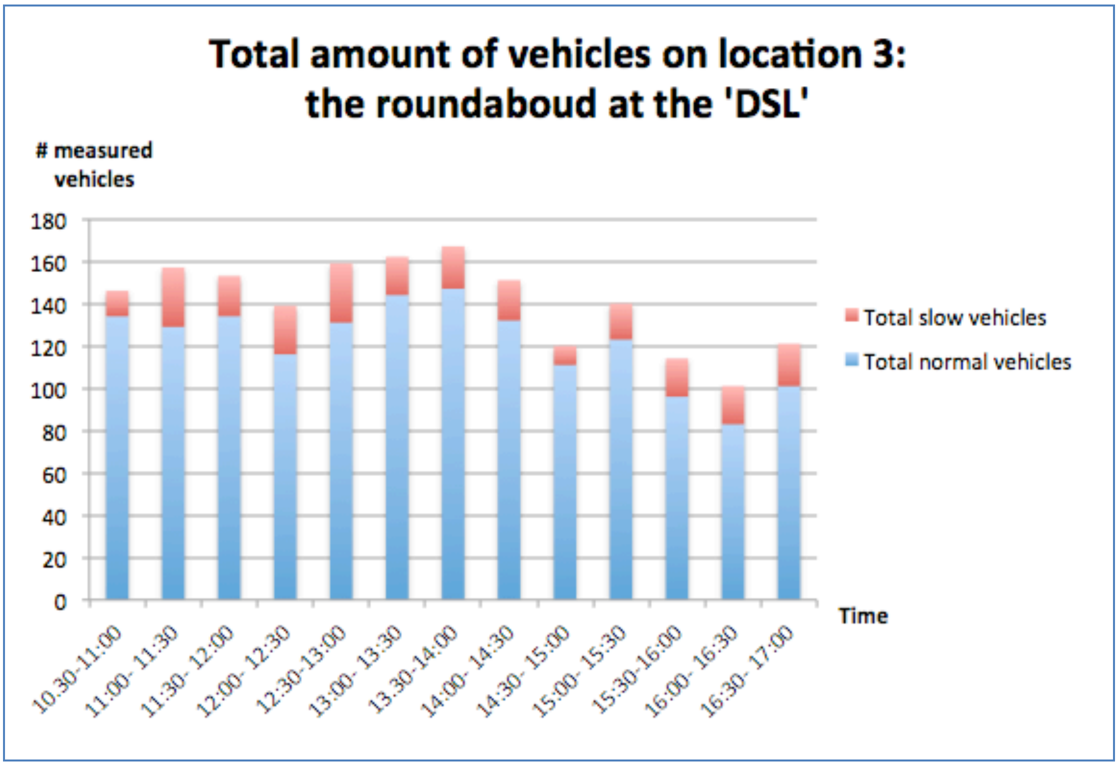

Figure 6.7; Total traffic volume on location 3: the roundabout at the 'DSL'

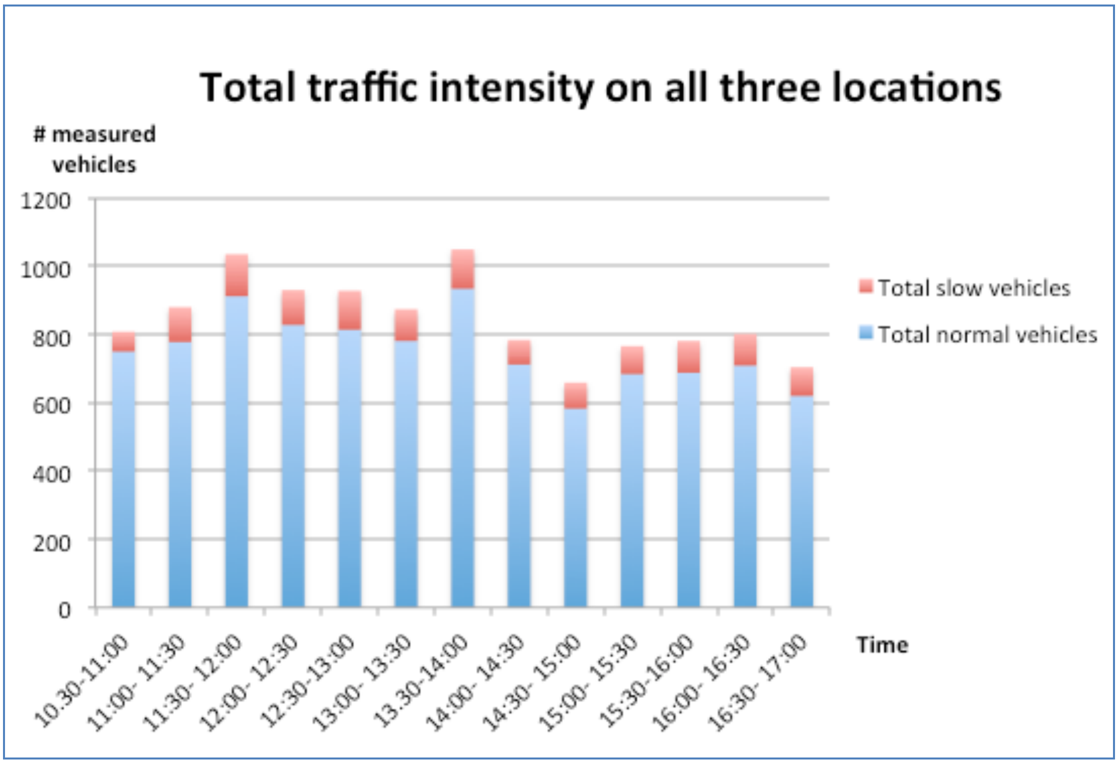

Figure 6.8; Total traffic volume of all three measured locations combined, resulting into two main traffic volume peaks during the day

The graph of location 1 (figure 6.5) already implicates that the following peak hours can be recognized: 11:30 – 12:00h, 12:30 - 13:00h and 13:30 - 14:00h. Figure 6.6 displays the traffic volume of location 2, the 'ACC-building' at the beginning of the C-pier; recognizable peak moments are: 11:30 – 12:00h, 13:30 - 14:00h and 16:00 - 16:30h. Location 3, the roundabout near by the 'DSL', seems also to have three peak moments during the day: 11:30 – 12:00h, 12:30 - 14:00h and 15:00 - 15:30h (figure 6.7).

When these three locations are combined into one histogram, figure 6.8 arises. Within this total traffic volume of the available locations, which can be seen as the complete traffic system in this research, two major peak moments can be distinguished: **a morning peak between 11:30 and 12:00h.** and a **afternoon peak between 13:30 and 14:00h.** It can be stated that these peak hours are complying with the hours set in section 5.2.3, although more specifically.

It can be seen that the ratio "normal sped vehicles" and "slow speed vehicles" is remaining constant within all histograms; no remarkable changes occurred and the amount of "normal speed traffic" is still representing the largest part of the complete traffic flows.

Direction of the traffic flows

Besides the relations between traffic volume and the four aspects, and the peak hours that resulted out of the measurements of the traffic volume, also the direction of traffic flows is of importance for this research. The following three figures 6.9, 6.10 and 6.11 representing visualizations of the traffic flows with corresponding traffic volume included in grey blocks. In general, the conclusion could be drawn that the largest traffic flows are passing the piers over the RH-road and continue their trip to other piers using this main artery.

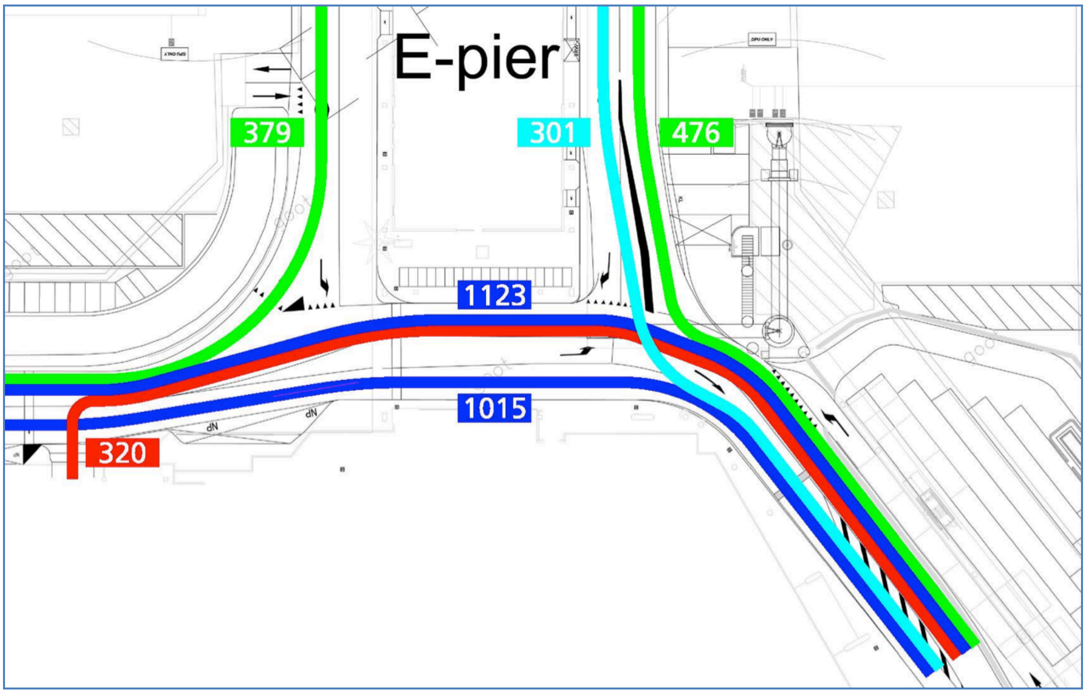

Figure 6.9; The traffic flow directions at the beginning of the E-pier, including the number of vehicles

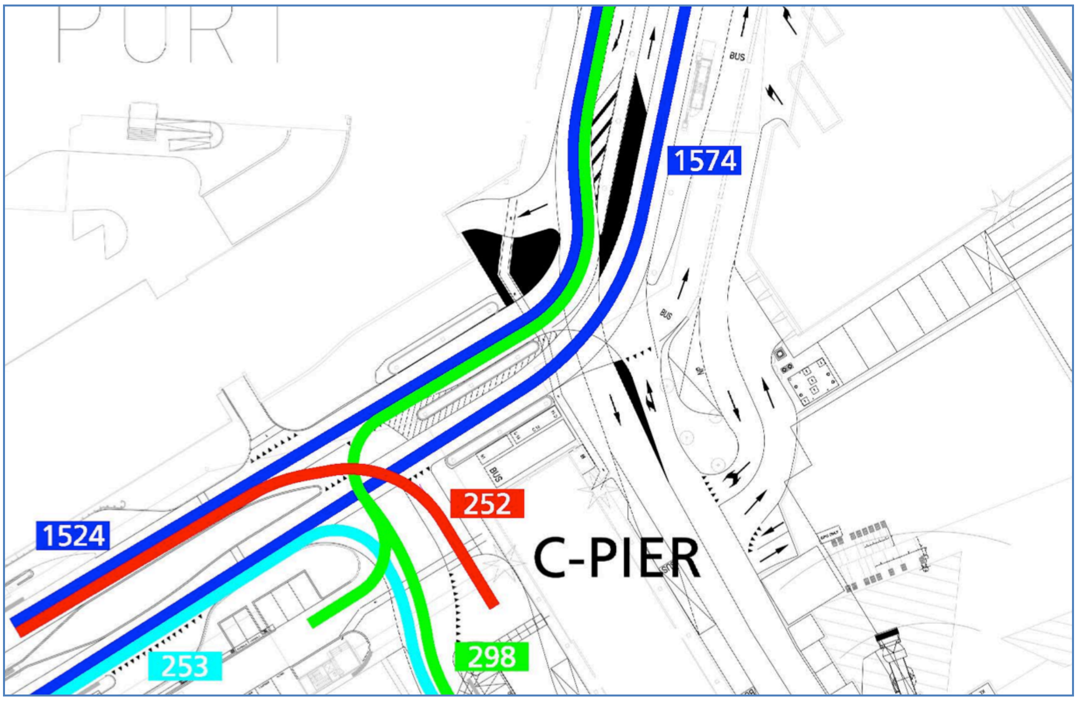

Figure 6.10; The traffic flow directions at the beginning of the C-pier, including the number of vehicles

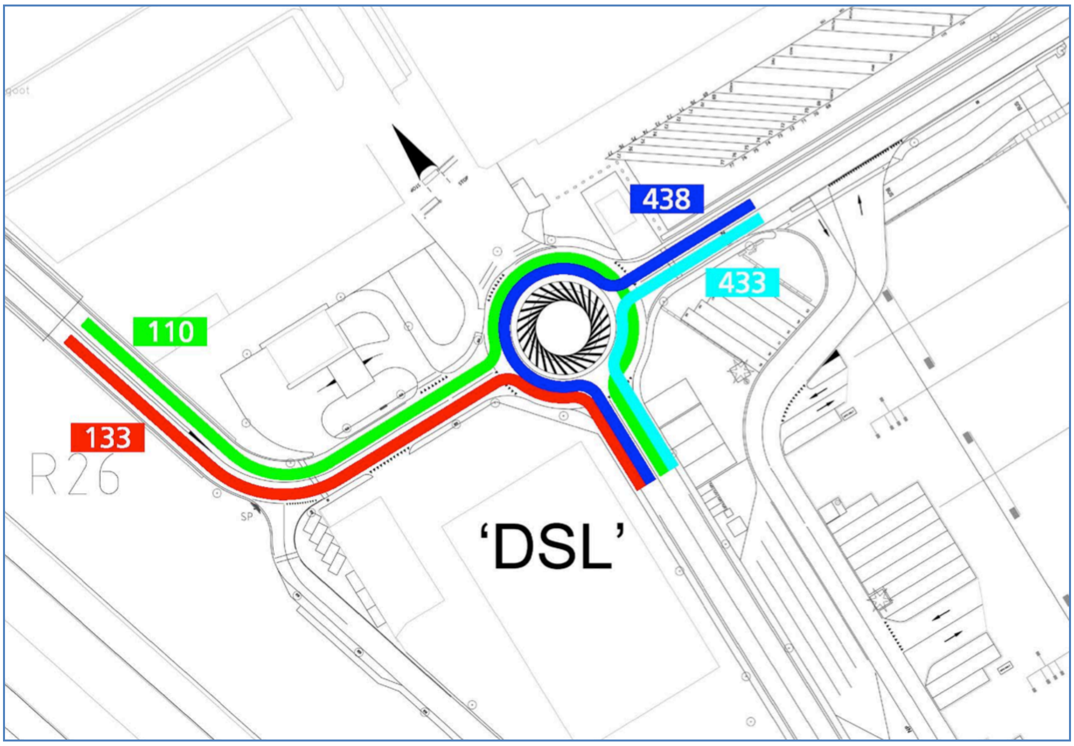

Figure 6.11; The traffic flow directions at the roundabout at the 'DSL', including the number of vehicles

6.3 Road capacity

Within the previous section the traffic volume is identified on different locations on the airside. This information is very useful for different perspectives, but to be able to know if the network is sufficient enough for these amounts of traffic, the road capacity should be taken into account. In this section, first a definition of road capacity is provided (section 6.3.1), after which an assessment of the roads on the airside will be conducted in the second section (section 6.3.2); for example whether congestion will occur or not. Section 6.4 will extrapolate the measured traffic volume, discussed in the previous section, to the future situation. Also the question whether or not the road capacity on the airside will be sufficient in the future, will be answered in the next section.

6.3.1 Defining road capacity

There are many different literature studies regarding calculating road capacity, although the used parameters are comparable within some researches. For this research, the methodology of the TU Delft is chosen (De Jong, 2004), because of its simple, but accurate way of measuring road capacity. If possible, realistic numbers are used within the calculation; if not, the numbers are carefully validated in sensitivity analyses.

The capacity of a single lane will depend on the following parameters: design speed (km/h or m/s), deceleration (m/s), response time(s), braking distance (m.), vehicle length (m.) and the time between two vehicles (s.). Capacity is defined in this research as the number of vehicles per hour (3600 s.) (De Jong, 2004).

Table 6.2 displays an overview of all eventually used parameters; to get to this numbers, a sensitivity analysis is performed which can be found in appendix E.1. The design speed is set on 15 km/h, because this is the maximum speed for some vehicles on the airside. Regarding **deceleration**, it should be mentioned that law at sets the deceleration of minimal – 5.2 m/s^2, the normal value is assumed to be -7 m/s^2. Within this research also a value of -7 m/s^2 is chosen because of the 'normal value' mark and because it is advised in literature of the TU Delft (De Jong, 2004). The influence of the deceleration is analyzed more in detail within the sensitivity analysis in appendix E.1. The **response time** is generally accepted to be 1 second, which therefore also is used in this research (Lamm et al., 1999). De Jong uses a **vehicle length** of 10 meter within his research, because also larger trucks, which are driving at the airside of AAS, are taken into account in his research. Both the **braking distance** as the **time between two vehicles** is resulting out of calculations, which will be discussed now.

Table 6.2; Parameters, with corresponding units, to calculate the road capacity (De Jong, 2004)

Capacity-related aspect	Unit	Fixed parameters
Design speed	Kilometer per hour or meter per second	**15.00 km/h = 4.17 m/s**
Deceleration	Meter per square second	**-7* m/s^2**
Response time	Seconds	**1.00 s.**
Braking distance	Meter	**5.41 m. (see formula)**
Vehicle length	Meter	**10 m.**
Time between two vehicles	Seconds	**3.70 s. (see formula)**

The braking distance depends from the design speed, deceleration and the response time. The necessary parameters can be seen in table 6.2 and the used formula is displayed below in formula 3 and 4 (both the general formula as the formula applied with corresponding parameters of this research are visualized):

$$Breaking\ distance = Response\ time * Design\ speed - \frac{0.5 * Design\ speed^2}{Deceleration} \tag{3}$$

$$Breaking\ distance = 1.00 * 15.00 - \frac{0.5 * 15.00^2}{-7.00} = 5.41\ m/s^2 \tag{4}$$

The time between two vehicles depends from the design speed, the braking distance and average vehicle length. Formula 5 and 6 display the calculated time between 2 vehicles (both the general formula as the formula applied with corresponding parameters of this research are visualized):

$$Time\ between\ 2\ vehicles = \frac{Vehicle\ length + Breaking\ distance}{Design\ speed} \tag{5}$$

$$Time\ between\ 2\ vehicles = \frac{10.00 + 5.41}{15.00} = 3.70\ s. \tag{6}$$

Now all necessary elements are calculated, the capacity per single road can be determined. Formulas 7 and 8 are used to calculate the capacity of the road (both the general formula as the formula applied with corresponding parameters of this research are visualized):

$$Capacity = \frac{3600}{Time\ between\ 2\ vehicles} \tag{7}$$

$$Capacity = \frac{3600}{3.70} = 973.60\ pae/h/lane \tag{8}$$

As formula 8 visualized, the single lane capacity on the airside of AAS is determined to be 973.60 vehicles/h/lane. Within the sensitivity analysis in appendix E.1 four different scenarios are tested with four different capacity outcomes. Scenario 4 is used in this research because it can be seen as the most realistic scenario. It is assessed that a capacity of 973.60 pae/h/lane (passenger car equivalents per hour per lane) is quite an accurate capacity number for the traffic system on the airside of AAS, taken into account the measured traffic volumes at all locations and how this number relates to the measured capacity. For example at location 1 this resulted in quite some congestion at some moments. Although all available literature is using public roads in their research, and so the given data cannot be compared completely, still the way of calculating capacity is slightly comparable. The difficult corners, entrances and exits to the main road and the large variety of vehicles results in a different environment than the public road.

Another aspect that is not discussed yet is the influence of junctions on the system. The capacity of junctions will determine the capacity of the complete system, which will again be determined by the amount of gaps in the traffic flow of the conflicting direction. There is free space needed to be able to turn of the main road, so vehicles waiting to get off the main road will not congest this road. Because the measured data is located on three important junctions, it is assumed the calculated capacity is realistic for the complete network. The time between two vehicles is not calculated on 3.70 seconds, which is close to the 4 seconds as stated by an expert to be the minimal time gap needed to avoid congestion and be able to turn off the road at junctions (Van Lint, 2012).

For now, the calculated capacity will be taken further into account and will be used in measuring concrete consequences on the traffic system involving the actual and future traffic volumes in the next section.

6.3.2 Assessment of the road capacity

To get more insight if the determined single lane capacity of 1752 vehicles is sufficient enough to be able to process the traffic flows on the airside, the 'Volume/ Capacity ratio' (I/C-ratio) will be used as an assessment measure. Besides checking if the capacity is sufficient enough, also the quality of the traffic flow throughput can be assessed with this ratio. It could be stated the I/C ratio characterized the utilization of a specific location. The ratio consists of four different levels, which are displayed in table 6.3 (Ministerie van Verkeer en Waterstaat, 2004).

Table 6.3; Four levels of Volume/ Capacity ratio, including if and how each level will result in congestion (Ministerie van Verkeer en Waterstaat, 2004)

I/C ratio	Traffic flow handling	Resulting in congestion?
I/C < 0.7	Good traffic flow handling	No congestion
0.7 ≤ I/C < 0.85	Moderate traffic flow handling	Little congestion
0.85 ≤ I/C < 1.00	Bad traffic flow handling	Congestion
I/C ≥ 1.00	Overloaded network	Heavy congestion

Now single lane capacity is calculated, the number of lanes per location should be determined so the capacity could be calculated. It appears that all used locations are characterized as one-lane locations. The beginning of the E-pier, the junction at the 'ACC building' and the roundabout are all consisting of single lanes and so also all have a road capacity of 1568 pae/h. Figure 6.12 represents the road capacity with the set parameters at different design speeds.

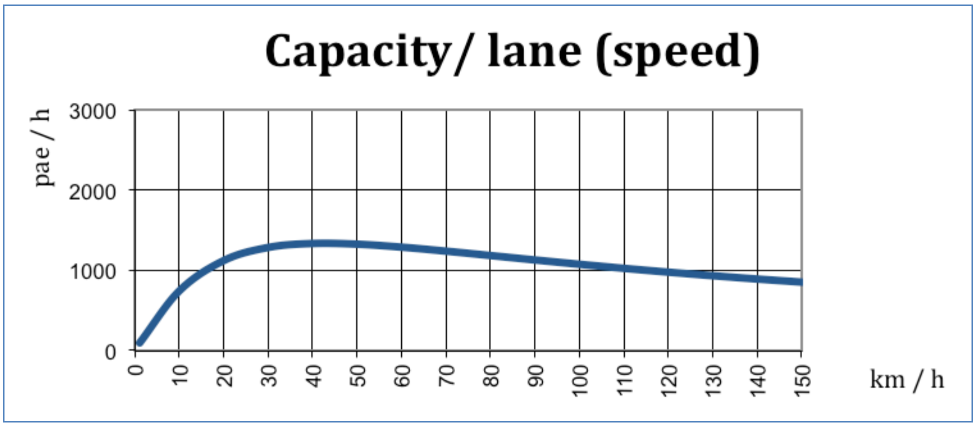

Figure 6.12; Lane capacity in passenger car equivalents set against different design speeds with the discussed parameters (De Jong, 2004)

Next, the traffic volumes as discussed in the previous chapter can be used, to get the I/C-ratios. Table 6.4 displays the traffic volumes and the included I/C-ratios. It could be concluded that some locations are not experiences any congestion, mostly at location 3, when the methodology and described parameters are used to assess the network (De Jong, 2004). Location 1 is the most congested location, compared to the other two locations. The results in table 6.4 also indicated that the busiest period on the airside regarding traffic volumes is between 11:30 and 14:30 o'clock, where the level of 'bad traffic flow handling' is reached. In the next section the 2018 situation will be predicted.

Table 6.4; Measured traffic volumes per hour and the I/C-ratio of the three film locations on 19-09-2012 (De Jong, 2004)

Amount of traffic volume	Location 1: E-pier	I/C	Location 2: ACC	I/C	Location 3: roundabout DSL	I/C
10.30-11:30	810	0.83	557	0.57	303	0.31
11:30-12:30	922	0.95	751	0.77	292	0.30
12:30-13:30	923	0.95	551	0.57	321	0.33
13.30-14:30	843	0.87	672	0.69	318	0.33
14:30-15:30	695	0.71	561	0.58	260	0.27
15:30-16:30	685	0.70	683	0.70	215	0.22
16:30-17:00	322	0.33	261	0.27	121	0.12
Total	5200		4036		1830	

6.4 Future developments

As explained in the previous section, the current situation on the airside of AAS is calculated and analyzed and more in depth information is gathered about the status of the traffic system. Providing insight in the current situation was one of the main aspects within this research, together with providing insight in the future perspective of this research if possible. This section will elaborated on the second part: the future situation on the airside of AAS.

The future traffic volume can be predicted in two ways: extrapolate the traffic volume measurements performed with cameras earlier in this research, of which the results can be seen in table 6.4, or research the theoretical amount of handling traffic is needed nowadays and then extrapolate this data to the future 2018 situation. Because in the latter situation only the equipment can be estimated, determined by interviews with KLM platform handling (appendix G.14), a large difference appeared because all other vehicles besides equipment are very difficult to estimate. The theoretical data is almost a factor 5 lower than the actual measured data. Exact numbers can be found in appendix E.2. For this reason, it is decided that the future traffic volume on the airside is predicted using the volume measurements made by cameras.

With the knowledge of the actual traffic volume and the number of air traffic movements at AAS of being 420.249 in 2011, as discussed in section 2.1 in the general description, a prediction can be made for the functioning of the traffic system on the airside could be provided. First a literature analysis is performed to get more insight in growth predictions; after which is decided to take one realistic growth prognoses and calculate the expected future traffic flows on the airside with this number. Eurocontrol specifies the expected yearly growth in air traffic movements to be 1.9% per year for the period 2012 – 2018 (appendix E.3). With this **growth of 1.9% per year**, the air traffic movements will be rounded 479,431 movements in 2018 (Eurocontrol, 2012). The volumes from the measured origins and destinations, for example the amount of traffic coming from the F-pier, driving towards the D-pier, can be found in appendix E.4. Table 6.5 displays also the exact new vehicle volumes, measured per hour, including the relation to lane capacity by the I/C-ratio.

It can be seen that now more locations are measured as being ‘congested’ or even ‘heavy congested’ in the predicted situation of 2018, so more congested than the current situation and partly not acceptable within the set norms by De Jong (2004). Furthermore, the same phenomenon can be seen regarding the fact that location 1 is the again the most congested location, compared to the other two locations. The roundabout at the ‘DSL’, location 3, is less congested of all locations due to mainly the relative less traffic volume on that location. Finally, it can again be stated that the period 11:30 - 13:30 o’clock can be seen as the busiest period of the day. The remark that should be made is the fact that this capacity calculation assumes straight lanes without disturbances. Because the situation on the airside of AAS is not straight and without disturbances, the norms should be adjusted to the situation of AAS and could in that case result in even more congested areas.

Table 6.5; Future traffic volumes per hour and the I/C-ratio of the three film locations on 19-09-2012 (De Jong, 2004)

Amount of traffic volume	Location 1: E-pier	I/C	Location 2: ACC	I/C	Location 3: roundabout DSL	I/C
10.30-11:30	924	0.95	636	0.65	346	0.36
11:30-12:30	1052	1.08	857	0.88	334	0.34
12:30-13:30	1053	1.08	629	0.65	366	0.38
13.30-14:30	962	0.99	766	0.79	363	0.37
14:30-15:30	793	0.81	640	0.66	297	0.31
15:30-16:30	781	0.80	779	0.80	245	0.25
16:30-17:00	367	0.38	298	0.61	138	0.28
Total	**5932**		**4604**		**2088**	

6.5 Conclusion regarding the utilization analysis and four analyses

At the end of the final analysis performed, two conclusions could be distinguished: a conclusion of the utilization analysis and a conclusion about the complete analyses. Therefore this section is split into two sub-sections;

Conclusion regarding the utilization analysis

Within the utilization analysis traffic volume measurements are performed, providing more insight in the amount of traffic using the traffic system on the airside of AAS. At the beginning of the E-pier, C-pier and at the roundabout near toe the ‘DSL’ cameras are placed and the material is analyzed to gather more insight in the traffic flows. Combining the traffic volumes with the calculated capacity of the road at the specific locations will result in quantitative statements about the current state of the system. This road capacity is calculated using a methodology of the TU Delft and results together with the traffic intensity into the ‘Intensity / Capacity ratio’ (I/C-ratio). This ratio is compared to a framework of ‘Rijkswaterstaat’, part of the Dutch Ministry of Infrastructure, with different levels and it appears that the current state of the system is sufficient on most locations. However, at the beginning of the E-pier the most traffic volume is measured and between 11:30 and 14:30h. the level of ‘bad traffic flow handling’ is calculated, resulting in a congested road.

Besides an analysis of the current state of the traffic system, also the future situation is calculated, extrapolating the traffic volumes with a growth factor. Again the same I/C-ratio is calculated and compared to the standard of ‘Rijkswaterstaat’. It seems that the future state of the traffic system becomes more problematic, with even more traffic volume than capacity at the E-pier between 11:30 and 13:30h., resulting in an overloaded network. The next section will draw conclusions from the four performed analyses, before the design of potential improvement possibilities will be discussed in the next chapter.

Conclusion regarding the four analyses

With the end of the fourth analysis, the utilization analysis, all four analyses are performed of this research. It appears that much information is gathered from interviews with stakeholders and already gathered data from information systems of AAS, for instance ASIS, but also two other measurement experiments were necessary for providing a sufficient overview of the complete traffic system on the airside of AAS.

From the safety analysis it appeared that the beginning of the piers could be seen as the problem areas, experiencing the most collisions on the airside of AAS, with the beginning of the D-pier as main problem area. Different types of incidents and collisions are defined and a black spot analysis is used within this chapter. Also more insight is gathered into the causes of most collisions to be able to design improvement possibilities that actually are able to change the number of collisions on the airside of AAS.

The second performed analysis was the robustness analysis, which indicated the vulnerable locations within the traffic system. It is important to be aware of these locations, for instance as advise for airside authority the focus on clearing the road when a collision occurs at one the 'not robust' locations. The not robust locations are: the beginning of the piers, the crossings of taxiways between the D- and E-pier, the (one-lane) south viaduct and the tunnels south of the roundabout at the 'DSL'.

The reliability analysis is the third analysis executed in this research, indicating the reliability of travel times of specific routes on the airside of AAS. Because the lack of recent data, actual travel time data is gathered driving 12 different routes each 14 times. The outcomes are analyzed and resulted in the following conclusion: starting at the roundabout at the 'DSL' the F-pier is accessible within the same travel time using the route with or without the viaducts. Travel times to the D- and E-piers are lower using the route along the B-platform (no use of the viaducts). These outcomes resulted in the suggestion of changing the maximum speed on the viaducts from 30 to 50 km/h; in this way not only the F-pier is accessible faster using the viaducts, now the E-pier is accessible within the same travel times using the route with or without the viaducts. These outcomes functioned as starting point for the next analysis; the utilization analysis.

The fourth and final performed analysis within this research is the utilization analysis. With the results gathered in the reliability analysis, the idea rose to apply the traffic principle of optimizing the utilization of complete system. The beginning of the piers appeared to be problem areas, resulting of the first two analyses, and the hypotheses were conducted that the viaducts are relatively used less compared to the route along the beginning to the piers. To get more insight in these statements, the actual traffic volume would provide more insight in the accurateness of the hypotheses. It appears to be correct that the beginning of the piers, in particular the D- and E-piers, are experiencing a high traffic volume, while the viaducts are hardly used. Spreading the traffic more equally over the complete network, the principle of utilization, would relieve the beginning of the piers and will not lead to any problems at other locations of the network; the measurements indicated enough space at other locations than the beginning of the piers. With regards to the future situation on the airside of AAS it advised urgently to start implementing this principle as soon as possible, before congestion gets drastic levels at urgent locations resulting in many negative consequences.

All mentioned problem areas and direct improvement possibilities of the context of chapter 2 and the four performed analyses of chapters 3 until 6 are taken into account in the following chapter. Within this chapter, potential improvement possibilities will be designed and discussed in detail. Also the origins of all improvement possibilities will be elaborated on, concluding with an assessment of all designed improvement possibilities on the four analyzed aspects and including an extra costs-aspect. After discussed all potential improvement possibilities, the implementation strategy per improvement suggestion is provided in chapter 8.

7. Potential improvement possibilities including evaluation

In this concluding chapter, all gained knowledge, results and outcomes of the performed analyses will be used to design and evaluate different improvement possibilities. The *safety analysis* resulted the most dangerous situations where the most collisions happened on the airside, performed with data from the previous eight years, collected by the Schiphol Group. This provided more insight in the specific location where to focus on partly during the research. The qualitative *robustness analysis* indicated the 'weak trajectories' within the traffic system on the airside of AAS. The next analysis that was performed within this research was the *reliability analysis*, which is performed using travel time measurements on the airside. The reliability of travel times on the airside appears to be higher when using the 'viaducts-route', compared to the most-often used route along the B-pier. Finally, the utilization of the traffic system is analyzed within the *utilization analysis*, by placing cameras on three different strategic positions on the airside to get more insight in the traffic volume at these places. This final analysis is also used to quantify earlier constructed improvement possibilities, in the analyses of the three other aspects, by labeling these improvement possibilities with exact numbers of the amount of vehicles.

All individual improvement possibilities, constructed at the end of this chapter, can be assigned to one of the two originally set main goals; let the main axes flow and / or create overview in the network. The first goal resulted from the GGB+ methodology, described in section 1.5.3 as scientific framework within this research, from which 'letting the main axes flow' is the main function of the large arteries, which could be seen as the most relevant roads because they experience the highest traffic volumes (Van Kooten & Adams, August 2011). For that reason, this goal is also set as main goal of this research. The second main goal, 'creating overview in the network' resulted from several interviews, and so AAS and/or the stakeholders of AAS, and the GGB+ methodology (Van Kooten & Adams, August 2011).

Finally, within this chapter, sub-question 5 will be answered: *"How can we solve the main bottlenecks in the traffic system at AAS both in the current and future situation?"* Also sub-question 6 will be answered within this chapter, in section 7.3 to be more precise; *"What are the differences between the improvement possibilities regarding robustness, reliability, safety and costs?"* So first the focus will be on how to solve the current problems within the traffic system and then the difference between several improvement possibilities will be discussed more in detail. The next chapter will focus on the implementation phase of the proposed improvement possibilities in this chapter.

This chapter is constructed of four different sections. First an overview of all improvement possibilities is provided (section 7.1), followed by the section explaining where all improvement possibilities are originating (section 7.2). Next, all improvement possibilities will be described individually (section 7.3), followed by a multi-criteria analysis to compare the improvement possibilities with each other (section 7.4). The chapter concludes with a short discussion about to which of the two main goals the individual improvement possibilities are contributing.

7.1 Overview of all improvement possibilities

Within this research, different analyses are performed. All insight and knowledge from these analyses are used to design improvement possibilities for the different problems on the airside of AAS as is already mentioned. The specific origins of all improvement possibilities will be discussed more extensively in section 7.2. Only improvement possibilities with positive consequences are taken logically into account. Also expensive improvement possibilities, for example design a complete new airport with a complete new traffic system, are left out of scope.

Now first a quick overview is provided of al potential improvement possibilities. The fifteen proposed improvement possibilities are clustered in four different categories: traffic management related, infrastructure-based, policy related and 'no regret' improvement possibilities. This categorization is based on the commonly used by Rijkswaterstaat as division for infrastructural related topics and will for that reason also be used within this research (Taale, 2011), although it is adjusted to this research by (slightly) changing categorisation names. Table 7.1 lists all improvement possibilities per category, including the corresponding level of detail; all improvement possibilities are also visualized together within figure 7.1. A list of improvement possibilities that are eliminated, because of different reasons, can be seen in appendix F.1, including the different reasons for which these improvement possibilities are eliminated.

Table 7.1; All proposed improvement possibility directions categorized in four different levels

Categorization	Potential improvement possibilities
Traffic management related	1) Reroute the traffic using the viaducts more often. 2) Monitoring traffic. 3) Increase the speed on the viaducts.
Infrastructure-based	4) Add extra lanes between D-E piers and E-F piers. 5) Change piers in a one-direction situation. 6) Create separate turning right lanes (unraveling) and reduce turning left. 7) Adjust the corners at the beginning of the C- and F-piers. 8) Parking places: remove next to main axes and design off-road at other roads. 9) Create (physical) lane separation.
Policy related	10) Reduce the number of (new) registered vehicles. 11) Increase the cooperation between AS and airport authority. 12) Add extra traffic system safety component to the training of users.
'No regret'	13) Improve drainage. 14) Remove the green pedestrian crossings. 15) Reduce the number of traffic signs.

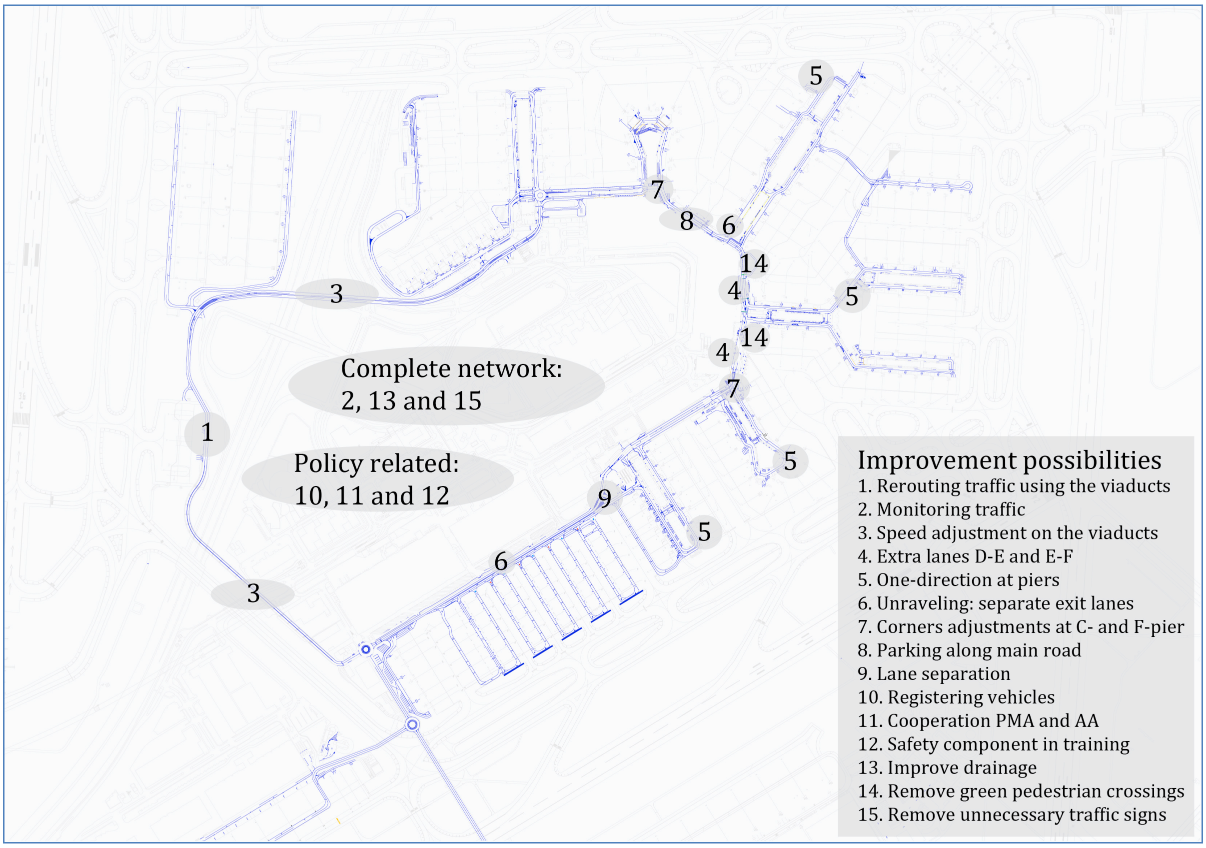

Figure 7.1; All improvement possibilities visualized within one overview

7.1.1 Demand- and supply-oriented improvement possibilities

A distinction can be made between demand-oriented policies and supply-oriented policies. As described in a digital article of Verkeerskunde.nl the following definitions are used (Meurs & Van Wee, 2012); *“demand-oriented policies result in an improved spread of traffic over the day using the entire network or simply reduce the amount of traffic.”* In this case, more choices should be available and offered to the users of the network. On the other hand, a supply-oriented policy *“optimizes the available capacity of the infrastructure within the network, applying (minor) adjustments to the network, applying new technologies to guide traffic more smoothly for example and/ or adopt agreements among stakeholders.”* This section focuses on increasing the capacity of parts of the network to reduce the negative consequences of bottlenecks during rush hours.

Taking into account the fifteen suggested improvement possibilities, only two improvement possibilities can be categorized as a demand-oriented improvement possibilities: ‘rerouting traffic using the viaducts more often’ and ‘reduce the amount of registered vehicles’. The first improvement possibility influences the complete network by improving the utilization of the network, as is already explained in the previous chapter. The second improvement possibility will limit the inflow of the traffic system, by reducing the number of registering vehicles; this improvement possibility lowers the demand of traffic.

7.2 Overview of the origins of the improvement possibilities

In the previous chapters several different analyses are discussed which are performed to get more insight in the traffic system on the airside of AAS, regarding the four aspects: safety, robustness, reliability and utilization. Both several quantitative and qualitative analyses are performed of which an overview is provided in figure 7.2.

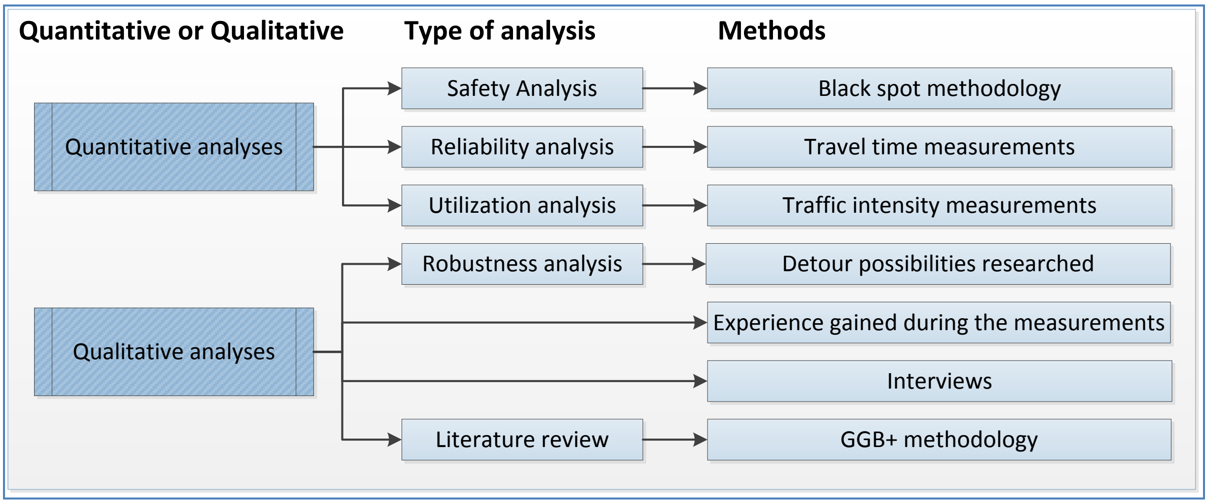

Figure 7.2; Schematic overview of all performed quantitative and qualitative analyses and used methodology

Different methodologies are used in this research, as can be seen in figure 7.2. All of the performed analyses, using specific methods, have resulted in improvement possibility directions. Which improvement possibilities are originating from which analysis can be read out table 7.2. For example improvement possibility 13, 'improve the drainage on the airside', is originated from experience during the measurements and improvement possibility 7, 'Adjust the corners at the beginning of the C- and F-piers', is originated from the safety analysis, performed in chapter 3, also from experiences gained during the measurements and resulted out of interviews.

A quick overview of all *problems areas* resulted out of the previous four chapters will be provided;

- **Safety**: primarily the beginning of the D- and B-piers, but also the beginning of the C-, E- and F-pier should receive attention regarding safety.
- **Robustness**: the beginning of all piers, the viaducts and the currently single lane structure between D-E- and E-F-piers.
- **Reliability**: the beginning of all piers experiences the highest amount of vehicles.
- **Utilization**: the beginning of the E-pier and the complex corner at the C-pier.

Some of aforementioned problem areas could directly be solved with a proposed improvement possibility, but other first are analyzed further in depth. Also improvement possibilities to specific problems areas are extrapolated to the complete network; for example the complex corner at the C-pier, resulted out of the utilization analysis, while a comparing situation currently is nowadays at the corner of the F-pier. In this example, both problem areas are taken into account within this chapter.

Table 7.2; Overview from which analyses the improvement possibility directions originated

Improvement possibility: Type of analysis	Rerouting traffic using viaducts 1	Monitoring traffic 2	Increase the speed on viaducts 3	Add extra lane D-E and E-F 4	Change beginning of E-peer into 1-direction 5	Unravel traffic: create 'turning-right-lanes' 6	Adjust corners beginning C- and F-peer 7	Parking places 8	Create (physical) lane separation 9	Reduce the # new registered vehicles 10	Improve cooperation AS and airport authority 11	Add extra traffic system safety component to the training of users 12	Improve drainage on the airside 13	Remove the green pedestrian crossings 14	Reduce # traffic signs on the airside 15
Safety Analysis	✓				✓	✓	✓								
Reliability analysis	✓		✓												
Utilization analysis					✓	✓				✓					
Robustness analysis				✓											
Experience during measurements					✓		✓	✓					✓	✓	✓
Interviews	✓				✓		✓			✓	✓	✓		✓	
Literature review	✓	✓				✓		✓	✓						

An overview is provided of all improvement possibilities and more insight is gathered in the origins of these improvement possibilities in the previous sections. The following section will provide more in depth information in all improvement possibilities by discussed them individually. Section 7.4 will continue after the detailed discussion of the improvements with assessing all improvement possibilities with each other regarding the four analyzed aspects: safety, robustness, reliability and utilization. Also the costs aspect will be taken into account in this multi-criteria assessment.

7.3 All potential improvement possibilities individually described

All 15 potential improvement possibilities are introduced in table 7.1 and visualized in figure 7.1 (both displayed in the beginning of this chapter) and will be discussed individually below. The origin, consequences, costs and implementation process of each potential improvement possibility will be discussed. Also different levels of aspects, which will be used in the next section when the potential improvement possibilities will be assessed, are already indicated in the final column, indicated with **low**, **medium** or **high**.

7.3.1 Traffic management related improvement possibilities

There are three improvement possibilities designed in this research related to traffic management aspects: reroute the traffic using the viaducts, monitoring traffic on the airside of AAS and Increase the speed on the viaducts from 30 km/h to 50 km/h. All three will be discussed in the next section in detail;

1) Reroute the traffic using the viaducts

The first potential improvement possibility can be characterized as network wide improvement possibility, because of the influence on the complete traffic system. The origin of this potential improvement possibility can be found in both the safety, reliability and utilization analyses. At first, within the safety analysis, it appears that the most collisions occur at the beginning of the D-pier, which directly can be related to the high traffic volume in that area, measured in the reliability analysis. When the pressure on the system could be relieved by steering traffic more over de viaducts, coming from the tunnel at the ‘DSL’, which will reduce the traffic volume at the beginning of the C-, D- and E-piers, the amount of collisions could be reduced also. This aspect is discussed in chapter 6, the utilization analysis.

As is discussed before in chapter 3, the safety analysis, 439 collisions take place at the beginning of the D-pier in the past 7.5 years. This numbers represents an average of 59 collisions per year, which is the highest average of collisions per year of all analyzed areas; the B-, C-, D-, E- and F-piers. Besides the number of collisions, also the traffic volume is analyzed. The traffic volume discussed in the utilization analysis, chapter 6; currently the number of vehicles using the viaducts is 431 vehicles per day (between 10:30 and 17:00 h.). Of these 431 vehicles, 192 are going towards the viaducts and 239 vehicles are coming out of the direction of the viaducts. The number of vehicles counted from the roundabout (different directions) towards the B-pier is 731, of which 97 slow vehicles are counted between 10.30 and 17:00 h. These slow vehicles are moreover cargo trucks with several cargo dolleys, coming from the ‘DSL’ where they are security-scanned, and several slow vehicles such as palletizers, animal transport and push-back trucks. To provide an indication of the number of vehicles that can be rerouted using the viaducts, it can be assumed that all of these 97 slow vehicles going to the direction of the B-pier will have the E- or F-pier as their destination and so could be rerouted. The travel times towards the E- and F-piers are analyzed in chapter 5, the reliability analysis, and it was concluded that the travel times, starting from the ‘DSL’, to the F-pier is as good as equal for using the viaducts or not using the viaducts. The travel times towards the E-pier, starting also at the ‘DSL’, is researched to be faster using the route along the B-pier, instead of using the viaducts, although the reliability of the travel time is higher using the route of the viaducts, compared the route along the B-pier. For this reason, it is assumed that 97 vehicles could be rerouted per day using the viaducts, which is 13% of the total traffic flow starting at the roundabout in the direction of the B-pier. An increased traffic volume of almost 40% of the viaducts can be realized in this way, resulting in an improved utilization. Table 7.3 displays an overview of improvement possibility 1.

Table 7.3; Consequences, costs, measures and origin of improvement possibility 1 (the latter column displays the level of the corresponding element, with H, M or L, respectively ‘High’, ‘Medium’ and ‘Low level’)

Consequences	Large consequences: spread traffic flow more equally	H
Costs	Relatively low; investment in sign and meeting	L
Measures	- (Dynamic) traffic sign displaying the possibility of taking the viaducts, even possible with corresponding travel times - Stakeholder meeting to explain and interest stakeholders	
Location	Roundabout next to the ‘DSL’	
Originated from?	Safety and reliability analyses, interviews and literature review	

The current reasons not to choose the ‘viaduct-route’ given by the handlers is the fact that the dolleys (especially cargo) could block and fly off the viaduct on the highway A4, which will have major consequences. At the moment, KLM is developing improved and adjusted dolleys, which are following the truck better and in a more straight line then before, which reduces the changes on blocking or flying off considerably. This new development of improved dolleys, executed by KLM, the largest handler at the Schiphol Group, is a good reason why the improved dolleys also could make use of the ‘viaduct route’.

2) Monitoring traffic on the airside of AAS

The second improvement possibility proposed to AAS is to start monitoring traffic driving on the airside; a measure resulting out of common traffic literature. When all vehicles, and so traffic flows, are monitored, not only the effect of implemented measures could be easily evaluated, also more insight could be gained in other (additional or new) potential problems areas or aspects within the traffic system. Different traffic measuring systems are available nowadays, even with automatic traffic volume counting included, so traffic volume could be read out easily. Another simple measure, which would be a good measure to start with, is to keep more (detailed) track of the number of registered vehicles. Included for example also equipment material within the registering system, which is not included at the moment. The consequences of this improvement possibility could be high, but depends on the way it is implemented and what is done with the gathered data. The cost aspect of this improvement possibility depends on how and what systems are exactly implemented. Finally, the location of placing the measuring systems depends on the goal of which the system is placed for. If evaluating a specific measure is the function of the monitoring system, the system should be placed strategically to be able to measure the consequences of the implemented measure. If it is preferred to get more insight in the complete traffic flows on the airside, more monitoring systems at spread locations should be placed, or even GPS transponders could be placed in all vehicles driving on the airside, so they could be tracked accurately. This latter proposal will result in a lot of useful data and insight in the current situation, but will have larger financial consequences than the aforementioned monitoring techniques. Table 7.4 displays an overview of improvement possibility 2.

Table 7.4; Consequences, costs, measures and origin of improvement possibility 2 (the latter column displays the level of the corresponding element, with H, M or L, respectively 'High', 'Medium' and 'Low level')

Consequences	Keep track of traffic movements, easier evaluation of implemented measures possible and more insight in (additional or new) problem areas	L
Costs	Could be high, but depends on which measurements	M
Measures	- Cameras - Track the amount of yearly registered vehicles	
Location	Roundabout, beginning of the E-pier, between D-E, between E-F. Additional locations depend on which measures are implemented.	
Originated from?	Literature review	

3) Increase the speed on the viaducts from 30 km/h to 50 km/h

The final traffic management improvement possibility is increasing the speed on the viaduct from 30 to 50 km/h. This improvement possibility could be seen as a sub-improvement possibility of improvement possibility 1, because the consequences of allowing a higher speed on the viaducts will attract more traffic on the viaducts, which will reroute more vehicles along the 'viaduct-route' and will relieve the traffic volume around the beginning of the busiest piers. Another consequences of this (sub-) improvement possibility are safety-consequences; the impact on safety will be relatively small because no pedestrians are allowed on the viaducts. The regulations for baggage, cargo and fuelling truck will still remain; restricting these vehicles to drive maximum 15 km/h when descending the viaducts. Also the financial investments of this improvement possibility will be limited, because only traffic signs should be adjusted, combined with providing information to the users of the traffic system. The origin of this (sub-) improvement possibility could be found in the reliability analysis in which travel time measurements are performed. It appears from these measurements, that only with the F-pier as destination the 'viaducts-route' could be an interesting alternative compared to the regular route along the piers, while driving 30 km/h. Changing the speed on the viaducts to 50 km/h will results in both the E- and F-piers as destinations for which the 'viaducts-route' could be an competitive option; this will results in even more vehicles using the viaducts.

It is calculated that a time gain could be realized of 96 seconds (1.6 minutes) when changing the speed from 30 to 50 km/h. There is chosen for a proposed speed of 50 km/h, because the current infrastructure of the 'viaducts-route' is suitable for this speed and can be compared with other 50 km/h public roads, together with the fact that 50 km/h is the general accepted speed on the public road, compared to 40 or 60 km/h. Table 7.5 displays an overview of improvement possibility 3.

Table 7.5; Consequences, costs, measures and origin of improvement possibility 3 (the latter column displays the level of the corresponding element, with H, M or L, respectively 'High', 'Medium' and 'Low level')

Consequences	Save travel time (1.6 minutes) and increase the use of the viaducts to spread traffic; small negative safety aspect, depends on the new maximum speed (50 km/h)	M
Costs	Low investments	L
Measures	Adjust signs at viaducts, organize an information meeting	
Location	Viaducts crossing the A4	
Originated from?	Reliability analysis	

The consequences of this improvement possibility could be read out of table 7.8 below. With the maximum speed limit set equally within the complete traffic system, the route choice of users at the 'DSL' with destination D- or E-piers will experience the least travel time when taking the route along the B-platform and the other way around; users at the 'DSL' with destination the F-pier, and the other way around, will experience about the same travel time when taking the 'viaduct-route' or not. When introducing a higher speed limit on the viaducts, the 'viaduct-route' will be 1.6 minutes faster than the regular route along the B-platform. Routes 2, 3, 6, 7, 10 and 11 will profit from this measure, and it could be seen in table 7.6 that the route choice is changed; users with the F-pier as destination will now experience the least travel time when using the viaducts, users with destination D-pier will still have the least travel time when taking the regular route along the B-platform and now for users with the E-pier as destination it does not make any difference which route to take.

Concluding, in the new situation, both the E- and F-destinations could make use of the viaducts, which will lead to higher traffic volume and an improved utilization of the complete network. The users with destination D-pier should keep taking the regular route along the B-platform because of the least travel time.

Table 7.6; Calculated travel time (tt) saved because of increasing the speed limit from 30 to 50 km/h on the viaducts (the 'viaduct-routes' are cursive within the table, the green blocks are the fasted routes and the orange blocks indicate it does not make a large difference which route to take).

Route number (destination)	Average tt (min), driving 30 km/h	Average tt (seconds), driving 30 km/h	Average tt (min), driving 50 km/h on the viaducts	Average tt (seconds), driving 50 km/h on the viaducts
1 (E)	5.56	333.6	Same as 30 km/h	Same as 30 km/h
2 (E)	*7.10*	*426*	*5.5*	*330*
3 (D)	*8.46*	*507.6*	*6.86*	*411.6*
4 (D)	5.86	351.6	Same as 30 km/h	Same as 30 km/h
5 (F)	5.60	336	Same as 30 km/h	Same as 30 km/h
6 (F)	*5.80*	*348*	*4.2*	*252*
7 (E)	*7.23*	*433.8*	*5.63*	*337.8*
8 (E)	6.05	363	Same as 30 km/h	Same as 30 km/h
9 (D)	5.65	339	Same as 30 km/h	Same as 30 km/h
10 (D)	*8.03*	*481.8*	*6.43*	*385.8*
11 (F)	*5.66*	*339.6*	*4.06*	*243.6*
12 (F)	5.86	351.6	Same as 30 km/h	Same as 30 km/h

7.3.2 Infrastructure related improvement possibilities

There are six improvement possibilities designed in this research related to infrastructure adjustments, after which they all will be discussed separately:

- Add extra lanes between D-E piers and E-F piers.
- Change piers in a one-direction situation.
- Create separate turning right lanes (unraveling) and reduce turning left.
- Adjust the corners at the beginning of the C- and F-piers.
- Parking places: remove next to main axes and design off-road at other roads.
- Create (physical) lane separation.

4) Add extra lanes between D-E piers and E-F piers

The robustness analysis (chapter 4) has pointed out that the area around the D-, E- and F-piers could be made more robust to create a comparable robustness-level as in the rest of the system. Especially the RH-road between the D-E and E-F piers, which functions as main axes within the complete traffic system, is relatively not robust enough to fulfill its function. This situation could be solved with creating extra lanes at the aforementioned location, so a detour could be arranged more easily when an accident happens. An interesting additional factor of this measure is the fact it creates a higher capacity on those locations, which is a very welcome aspect because the traffic volume is measured in the utilization analysis in chapter 6 to be relatively high on these locations. A better flow could be realized, which complies with the main function of these roads. Table 7.7 displays an overview of improvement possibility 4.

Table 7.7; Consequences, costs, measures and origin of improvement possibility 4 (the latter column displays the level of the corresponding element, with H, M or L, respectively 'High', 'Medium' and 'Low level')

Consequences	A higher robustness and road capacity will be realized	H
Costs	Between D-E: higher costs because of the roof Between E-F: still relative high construction costs E-F: combine with construction works to minimize costs	H
Measures	Extra road next to the existing road	
Location	Between D-E and F-E piers	
Originated from?	Robustness analysis	

5) Change the piers in a one-direction situation

Besides the advice to adjust one-lane trajectories into double lane roads between the piers, infrastructure adjustments are also advised around the piers. This advice consists of adjusting the two-directional situation as is currently on the airside of AAS into a one-directional situation. As example to get insight in the consequences of this improvement possibility, the E-pier is taken as example to get more into detail. Two different phases will be conducted, to be able to see the differences and concrete consequences of specific measures; first only the beginning of the E-pier will be changed into a one directional situation, followed by the second phase changing the complete pier in a one-direction road.

Changing the current two-way-direction at the piers into a one-direction situation will have large influences on the traffic flows and the users of the system. Many positive consequences can be named: less complex junction at the main axis, less crossing traffic flows and a clearer overview of the situation will be created. All of these three important aspects will results in less accidents and a higher safety level. Because of construction around the F-pier already a one-direction system is conducted, the focus within this improvement possibility will be on the B-, C-, D- and E-piers.

Unfortunately, also a negative aspect could be indicated of this improvement possibility: airplane handlers should cope with minor extra travel times when driving to the other side of the pier. Regarding the negative consequences; it is calculated what the average delay will be when having origin E2 and destination E3. It is calculated that taking the detour, passing E2 and E4 first, crossing the terminal below and then arriving at the right destination, will take around on average 36.33 seconds extra travel time. Per day, it is estimated that on average 9 planes arriving within 24 hours for both locations; 4.5 planes at E2 and 4.5 planes on E4. The estimation of these numbers can be found more in detail in appendix F.2. Combined with the 12.1 average amount of traffic which will be generated from one plane, a total of 9 planes x 12.1 average amount of traffic per plane handling x 36.33 vehicle loss seconds will results in 65.9 minutes average delay per day for all users of the beginning of the E-pier.

It can be stated that these 65.9 minutes average delay for all users of the mentioned aircraft stands is a relative low number, taking into account the positive effects and very likely reduction of accidents, resulting direct in less damage costs for all stakeholders driving on this location. The deviation should be made for the assessment of the severeness of this delay between baggage handling and cargo handling; baggage handling could be a process involving small margins and large risks with large financial consequences if baggage will not be in time at the right plane. Logically, for baggage handling this delay will have serious consequences. From the cargo handling perspective, with larger time margins and relative low risk numbers, this amount of delay will not lead to direct consequences. For this reason, it could be considered to mitigate the baggage handlers by letting them using the second lane around the piers, which will be limited used because of the one-directional situation, partly for parking their equipment vehicles. In this way less trips will be made back to the main base at other piers, when more bases are conducted at several piers.

The example of creating a one-direction situation at the E-pier is even more extended within this improvement possibility, by changing the complete piers into a one-direction road; when the complete pier will be adjusted to a one-directional situation, as can be seen in figure 7.3, also in the middle and top parts of the E-pier this delay will occur. Although the total delay is almost an hour, the delay per vehicle will be around half a minute. For this reason, also a middle improvement possibility option is designed in which only the beginning of the E-pier is changed into a one-directional situation; this improvement possibility option is displayed in figure 7.4. It should be mentioned that the complete one-directional situation is simpler for the users, because of a clear direction how to drive and how to get to the other side, compared to the situation in which only the beginning of the E-pier is changed into one-direction situation. Before it was decided that these two figures are the best option, several other alternatives are constructed. These alternatives can also be found in appendix F.2.

It is stated by the manager safety of AAS that the number of collisions is reduced with almost 40% because of the changed situation at the F-pier from a two-directional to a one-directional situation (Leek, Interview, 2012). This large reduction of collisions results in a much safer area near the F-pier. Although the negative aspects regarding time delay for handlers, this measure could be seen as a large opportunity within this research because of a high number of collision reductions.

As is explained in this section, the possibilities of the E-pier are research more in detail, but also at the B-, C- and D-pier there are many opportunities for one-direction roads. At all locations it will directly lead to less complex junctions with the main road because of the reduced traffic directions, which will especially improve the junction at the beginning of the C-pier as being one of the largest problem areas, resulted of the safety analysis discussed in chapter 3. Also the (roofed) junction at the beginning of the D-pier will get less complex when adopting one-direction road along the D-pier.

Now, the beginning of the D-pier already consists of one-direction roads, except for passenger buses. It is urgently advised when investing in new passenger buses, these buses will have entrances at both sides, so the exception for buses could be eliminated (which is the reason for the exception now), and buses also can take the one-direction road and are able to unload their passengers directly at the left side. The urgency to change the B-pier into a one-direction situation is of less importance compared to the other piers, because of the lower traffic volume, but still will be an interesting improvement possibility to take into account because of the aforementioned positive consequences.

Table 7.8 displays an overview of improvement possibility 5.

Table 7.8; Consequences, costs, measures and origin of improvement possibility 5 (the latter column displays the level of the corresponding element, with H, M or L, respectively 'High', 'Medium' and 'Low level')

Consequences	Less complex junctions, less crossing traffic flows; handlers should cope with minor extra travel times (36.33 s.)	H
Costs	Low investments, minor measures needed	L
Measures	Adjust lining, add traffic signs and organize a information meeting	
Location	Beginning of the E-pier	
Originated from?	Safety and utilization analyses, experience gained during the measurements and interviews	

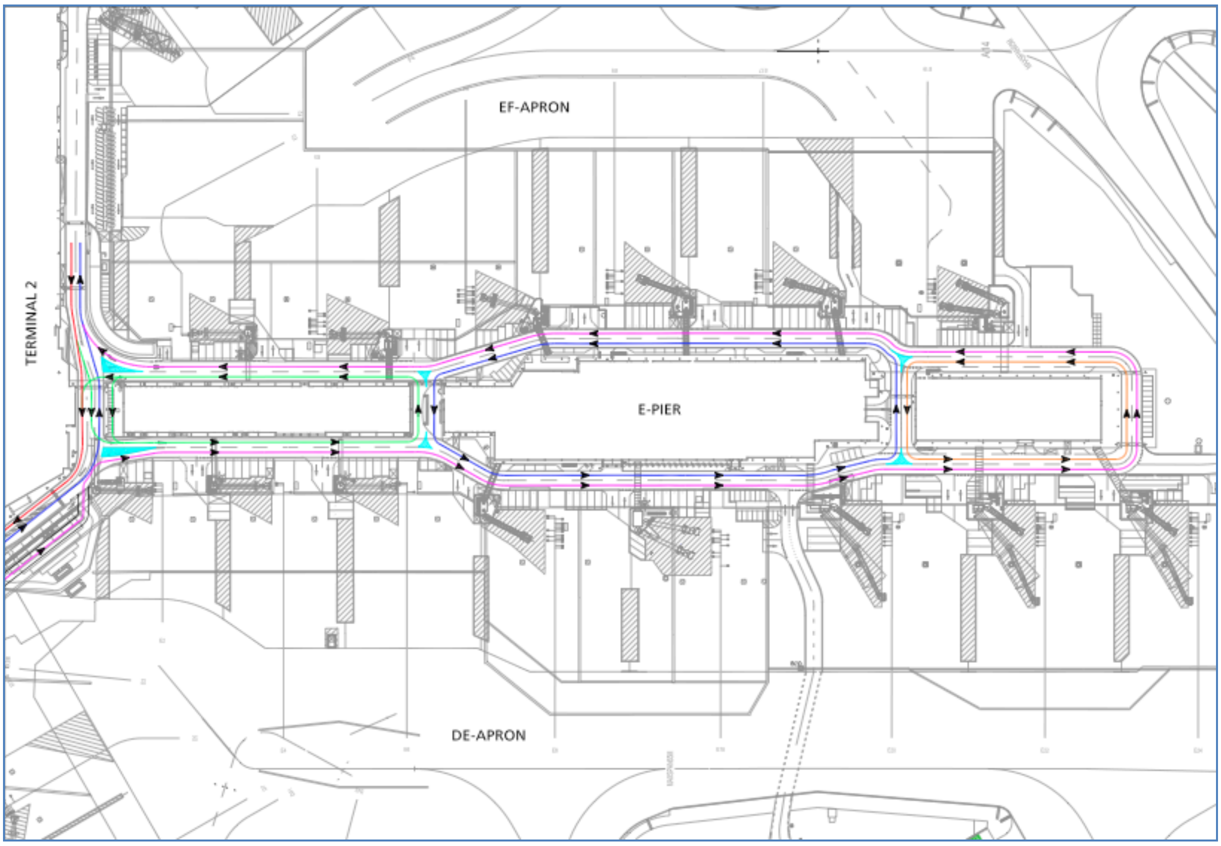

Figure 7.3; Proposed improvement possibility for changing the E-pier in a complete one-directional situation (Verhaar, 2012)

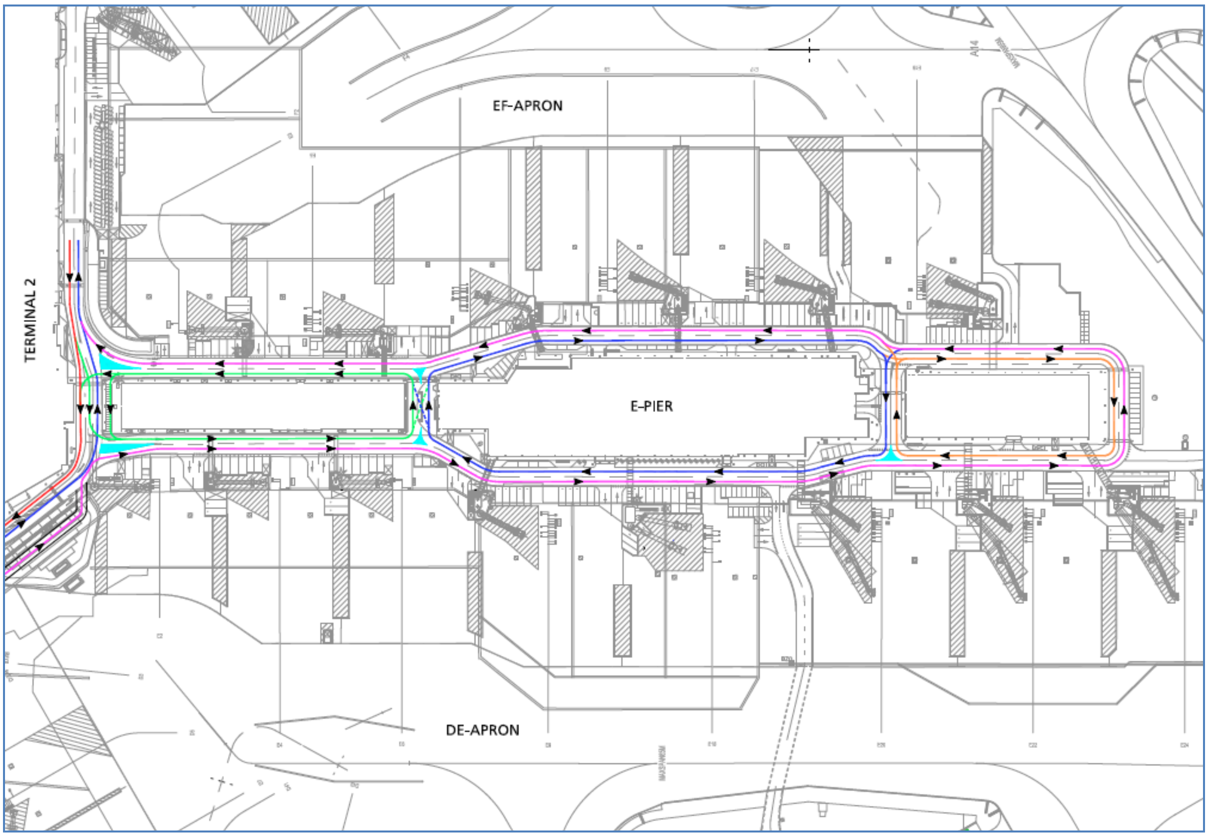

Figure 7.4; Proposed improvement possibility for changing the beginning of the E-pier in a one-directional situation (Verhaar, 2012)

6) *Create separate turning right lanes (unraveling) and reduce turning left*

At specific places on the airside special turning right lanes already exist, for example at the beginning of the D-pier. Because of the high traffic volume at the (beginning of the) D-pier, a proposed turning right lane coming from the D-pier, towards the E-pier situation is designed and can be seen in figure 7.5. An earlier version of this proposed improvement possibility could be found in appendix F.3, but figure 7.5 also has the changed direction advantage and reduces the difficulty of the junction at the beginning of the E-pier. It also complies with improvement possibility 4: adding an extra lane between the D- and E-pier.

There are more possibilities to create dedicated lanes for entering or exit the main axes: exit the main axis towards KLM Cargo, enter the supporting road at the F-pier, enter the main axis from the F-pier and exit turning right lane from north viaduct towards J-buffer. At the beginning of the E-pier also several opportunities exist, but these are taken into account in improvement possibility 5.

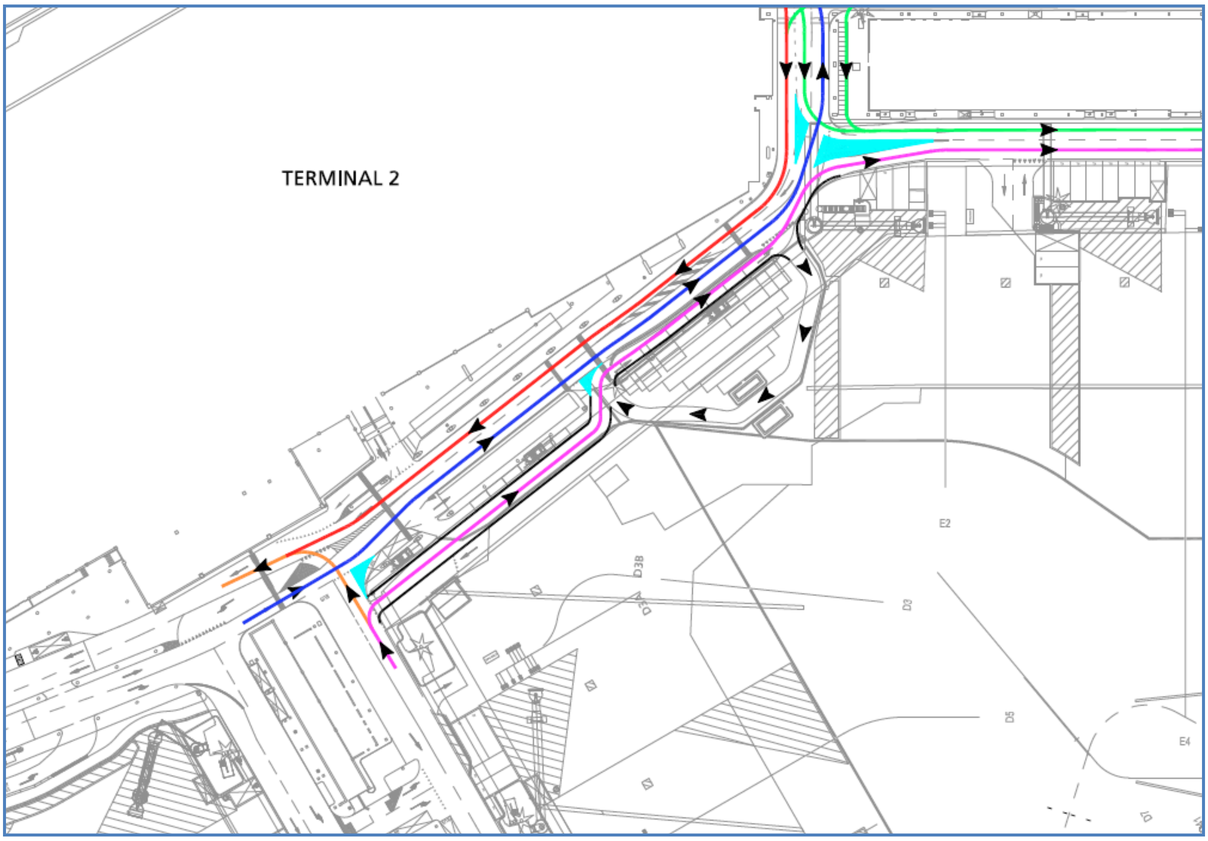

Figure 7.5; Proposed improvement possibility for a separate turning right lane coming from the D-pier towards the E-pier (Verhaar, 2012)

At two places in the traffic system improvement possibility 6 can be implemented, namely at the roundabout from the tunnel turning right towards the RH-road along the B-buffer and turning right leaving the main axis towards the C-pier (‘ACC-building’), however these two locations will not be taken into account. The traffic volume on these two locations is relatively low and therefore is not (yet) creating any problems. It should be taken into account in the future, with the changes of the new masterplan in mind, that this improvement possibility can be implemented on these two locations, but for now this will not be necessary.

Adjusting ‘turning-left-lanes’ could be performed on two locations: on the main axis to KLM cargo and at the beginning of the E-pier. The current situation of the RH-road along KLM cargo can be seen in figure 7.6 and 7.7. The latter location is already discussed in improvement possibility 5. Table 7.9 displays a complete overview of improvement possibility 6.

Table 7.9; Consequences, costs, measures and origin of improvement possibility 6 (the latter column displays the level of the corresponding element, with H, M or L, respectively ‘High’, ‘Medium’ and ‘Low level’)

Consequences	Split traffic flows before junctions, resulting in a higher safety level and a more clear situation	H
Costs	Construction costs and space	M
Measures	Extra lane to enter or exit the main axes	
Location	- Main axis towards KLM Cargo - Enter the supporting road at the F-pier - Enter the main axis from the F-pier - Exit turning right lane from north viaduct towards J-buffer	
Originated from?	Safety and utilization analyses, literature review	

Figure 7.6; Photo of the RH-road (main axis) with possible space on the right side (19-09-2012, 14:10:23 PM)

Figure 7.7; Photo of the KLM Cargo security post on the right side of the RH-road (main axis) (07-11-2012, 14:11:01 PM)

7) Adjust the corners at the beginning of the C- and F-piers

Table 7.10; Consequences, costs, measures and origin of improvement possibility 7 (the latter column displays the level of the corresponding element, with H, M or L, respectively 'High', 'Medium' and 'Low level')

Consequences	Improved traffic flow, safety and junction overview	H
Costs	High costs involved because of construction works, but could be combined with the future terminal-expansion	H
Measures	Construction adjusted corners, lining	
Location	Beginning of the C- and F-pier (figure 7.9 and 7.10)	
Originated from?	Safety analysis, experience gained during the measurements and interviews	

Table 7.10 displays an overview of improvement possibility 7. The junction at the beginning of the C-pier can be characterized as a very complex junction, as can be seen in figure 7.8. Not only all different directions, but also different destination roads combined with partly under passing the terminal roof is making this location extra complex. The measured traffic volume coming from the E-pier is 1676 normal and 171 slow vehicles (total traffic volume is 1847 vehicles), as discussed in the previous chapter. A improvement possibility for many problems will be changing the bi-directional roads of the C-pier to a one-direction-situation. But because of the large impact of this improvement possibility to the area and users, mostly the users of the 'ACC-building', combined with the fact the traffic volume is relatively low, for now it is advised not to implement this drastic improvement possibility. It should be taken into account in the future through, with the perspective of the new masterplan in mind. When the traffic volume rises, this improvement possibility could solve easily many problems.

The corner at the beginning of the F-pier is relative less complex compared to the junction at the beginning of the C-pier as just discussed and the F-pier can be seen more in detail in figure 7.9. Although, at the right side an almost 90 degrees corner is constructed, coming from the E-pier. In reality, this corner creates problems for traffic from both sides. Coming from the E-pier, turning right is relatively simple, while turning left invites vehicles to 'cut off' the road using a small part of the other side of the road in the corner and thus neglecting the exact lining. This aspect results in problems for users of the other side, coming from the G-pier, for both turning left and right. Out of interviews with the airport authority appears many accidents are happening here because of this fact. Also turning left, coming from the G-pier, results sometimes in long waiting times, a dangerous situation on the middle of the junction and waiting queues. Construction works are planned for the future for extending the terminal between E and F in March 2013, which could be ideally used to also adjust this corner. A less high degree, or less ‘sharp’, corner should be constructed optimizing the behavior of the traffic flow passing this corner. A short note: the F-pier is now constructed in a one-directional supporting road because of construction on the head of the pier. With the traffic and transportation knowledge gained from literature and the less complex junction arising because of this temporarily measure, it is suggested to leave the situation this way as it is right now, so keep it one-directional. A positive side-effect is the fact that almost all users are used to the current situation now, which was one of the major arguments to not change specific areas to a one-directional situation also.

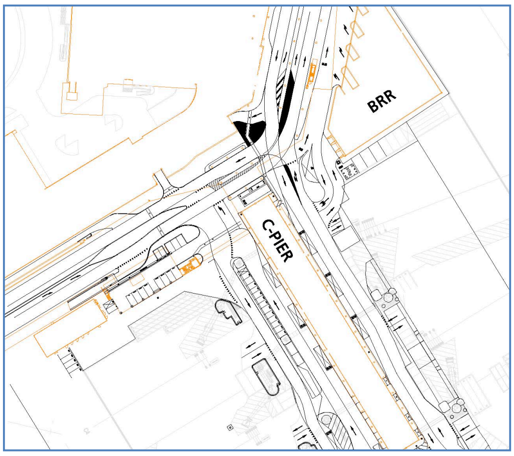

Figure 7.8; Detailed view of the C-pier corner

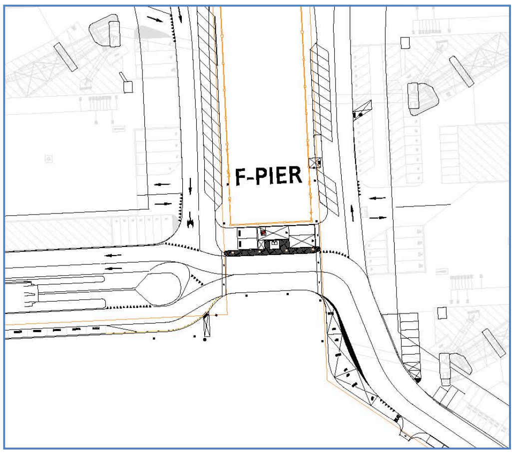

Figure 7.9; Detailed view of the F-pier corner

8) Parking places: remove next to main axes and design off-road at other roads

As is discussed earlier in this research (section 2.3.4), the traffic system on the airside of AAS can be divided into two main road categories: main axes and supporting roads. The main axes have the function to keep the traffic flow going, while the supporting roads function as destination road, distributing the traffic flows from the main axes to their destinations: the VOP’s on the airside.

In many places on the airside, the functions of the roads are influences by disturbances. For example, the main axes are connected to entrances and exits of different origins, mainly around the piers. Officially, each road connected to the main axes should be designed in such a way a clear junction is formed, so all users can anticipate on the coming exit. Because of the specific situation on the airside, this is not always possible and should be reduced as much as possible. It is not very easy to eliminate exits or entrances, without moving complete buildings or baggage handling areas, but it is possible to intervene with smaller adjustments. One possibility is to reduce the number of parking places directly to the main axes. Parking places are necessary to perform airside activities, but are less disturbing when placed connected to the supporting roads. Figure 7.10 displays the situation between the E- and F-pier, where many KLM vehicles are parked directly to the main axes, which coincidently results in flow disturbances on the main axis. Moving these parking places to the beginning of the F-pier, which already has a one-direction situation and so has space left, will eliminate disturbances. Table 7.11 displays an overview of improvement possibility 8.

Table 7.11; Consequences, costs, measures and origin of improvement possibility 8 (the latter column displays the level of the corresponding element, with H, M or L, respectively ‘High’, ‘Medium’ and ‘Low level’)

Consequences	Less disturbances along the road and reduce the number of unexpected situations	M
Costs	Mostly infrastructural adjustments, medium costs	M
Measures	Along the main axis: remove parking places directly to the axis Along the supporting roads: design more and/or more sideways parking places to reduce hinder	
Location	Main axis: between E- and F-pier Supporting roads: along the E-pier	
Originated from?	Experience gained during the measurements and literature review	

Figure 7.10; Parked vehicles along the main axis between the F- and E-piers (07-11-2012, 13:45:34 PM)

9) *Create (physical) lane separation*

Another (local) link-based improvement possibility is creating (physical) lane separation on the main axes to create more overview at junctions (Van Kootenai & Adams, 2011). Already lane separation locations are implemented on the airside, for example at the north side at the beginning of the B-pier, and it could be seen there that a safer and structured junction resulted. One location will be discussed more in detail, but more potential locations to implement this measure will be suggested on the end of this sub-section.

A potential location to implement this specific measure is at the south side of the beginning of the B-pier (between the transview building and the B-buffer platform), as can be seen in figures 7.11 and 7.12. A more detailed figure of the location could be found in appendix F.4. Because of the relative much space for this specific junction, it appears that users drive relatively fast here, while many large vehicles passes here, such as busses and fuelling trucks. Creating elevated parts in the middle of this junction will create a more structured and safer junction. Costs of this measure are infrastructural related, but relatively low compared to other infrastructural costs.

An alternative improvement possibility for elevated parts in this case could be placing LED's on the lining, so vehicles are made aware of the fact if they are not completely following their own lane. A small remark with this additional alternative which should be mentioned is the fact that there are driving heavy vehicles around on the airside, which could easily damage these LED's. Hypothetically, all vehicles should always keep their lanes and so will not damage these LED's, but in practice this will probably happen. Table 7.12 displays an overview of improvement possibility 9. Other suggested locations where this improvement possibility could be applied are the following locations:

- After the roundabout, turning right to parallel road B-buffer platform
- At (one of the) junctions halfway the D-pier
- At the beginning of the E-pier (related to improvement possibility 5)

Table 7.12; Consequences, costs, measures and origin of improvement possibility 9 (the latter column displays the level of the corresponding element, with H, M or L, respectively 'High', 'Medium' and 'Low level')

Consequences	Vehicles are pushed to only use their own lane, which results in a better organized and safer traffic system	M
Costs	Relative low to moderate investment compared to other improvement possibilities	M
Measures	Physical blocks or LED's on lining	
Location	- Between the beginning of the B-pier (transview building) and the B-buffer platform - At the beginning of the B-pier - After the roundabout, turning right to parallel road B-buffer platform - At (one of the) junctions halfway the D-pier - At the beginning of the E-pier (related to improvement possibility 5)	
Originated from?	Literature review	

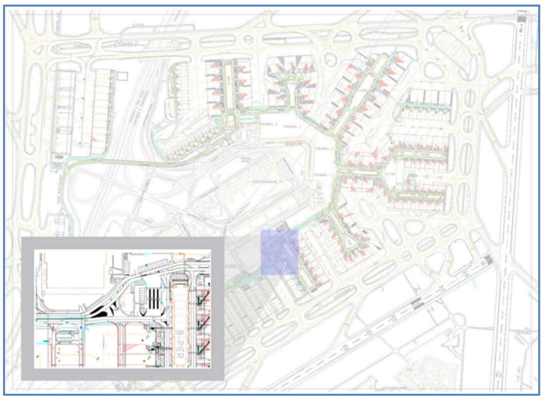

Figure 7.11; Location of the proposed physical lane barrier. The zoomed-in figure of the location can also be found in appendix F.4.

Figure 7.12; Possible location for physical lane separation to reduce the speed and increase safety (07-11-2012, 12:13:32 PM)

7.3.3 Policy related improvement possibilities

There are three improvement possibilities, numbered 10, 11 and 12, designed in this research related to policy aspects: reduce the number of (new) registered vehicles, increase the cooperation between AS and airport authority and add an extra traffic system safety component to the training of users. All three improvement possibilities will be discussed in the next three subsections.

10) Reduce the number of new registered vehicles

This improvement possibility is the first of the three policy improvement possibilities and can be implemented in two different ways: *from a specific date* the registration of vehicles will become more stricter and set more regulation to vehicles who want to register to be allowed on the airside (improvement possibility 10.a) *or also the current registered vehicles* will be checked, together with all new applications to be allowed entering the airside, whether is it necessary that all registered vehicles actually need the registration (improvement possibility 10.b). Logically, the second suggested improvement possibility would result in less registered vehicles, while the first improvement possibility will be easier to implement and probably with less resistance from registered users of the traffic system. Table 7.13 displays an overview of improvement possibility 10.

Table 7.13; Consequences, costs, measures and origin of improvement possibility 10 (the latter column displays the level of the corresponding element, with H, M or L, respectively 'High', 'Medium' and 'Low level')

Consequences	Reduce the amount of inflow in the system and the number of vehicles within the current system	M
Costs	Little investment needed	L
Measures	Discuss with registration department (David van der Meer)	
Location	Not relevant	
Originated from?	Utilization analysis and interviews	

11) Increase the cooperation between PMA and the airport authority

As is also indicated as one of the goals of the PMA department at the Schiphol Group (see also the 'goals poster' of PMA, appendix F.5) 'increasing the cooperation with the 24-shift on the airside', the cooperation between the office department and the employees operating on the airside could be improved. An example could be asking airside authority for their opinion when introducing new adjustments to the traffic system. These authority officers are the daily users of the traffic system on the airside and know the area in the smallest details. Also planned detours for scheduled construction works could sometimes be constructed differently, so less operational disturbances occur. A proposed concrete measure could be a steering committee, which will consists of volunteers from the airside, which will be available about once every two months, to discuss several specific activities or planned detours.

Currently, a new project is running at AAS called the Collaborative Decision Making (CDM) project. This project started in 2009 together with KLM and 'Air traffic control in the Netherlands' (LVNL) to increase the cooperation between the largest parties at AAS and integrate different ICT system together. The proposed improvement possibility of improving the cooperation between AS and AA with using CDM as example. Table 7.14 displays an overview of improvement possibility 11.

Table 7.14; Consequences, costs, measures and origin of improvement possibility 11 (the latter column displays the level of the corresponding element, with H, M or L, respectively 'High', 'Medium' and 'Low level')

Consequences	Creates more understanding towards each other, motivated different parties to contribute with new ideas to improve (and keep improving) the traffic system; also suggestions how to organize (large) construction works even better can be provided to the designers	M
Costs	Relative low, although motivation is needed from stakeholders	L
Measures	Set up a steering committee which discuss all adjustment to the traffic system once in two months	
Location	'ACC-building' or 'SHG'	
Originated from?	Interviews	

12) Add an extra traffic system safety component to the training of users

All users of the traffic system on the airside of AAS have to follow a special training day, followed with a platform test, to get familiar with the rules and regulations on the airside. This training is organized by the 'Traffic Trainings Centre (VTC in Dutch)' and takes half a day. Out of interviews and own experience resulted that this training mostly focuses on the VOP areas, so around the airplanes. This is a logically decision, because accidents related to planes results in large financial consequences compared to accidents at the roads. But it could be argued that there should be paid slightly more attention to the main ring (RH-) road and the roads towards the VOP locations and how to behave correctly on these roads. Also what to do when you are involved in a collision and paying attention during the detour that day to relative dangerous locations, for example the beginning of the D-pier and the corners of the C and F-pier, could help creating more awareness by the new users of the traffic system. An overview of improvement possibility 12 is displayed in table 7.15.

Table 7.15; Consequences, costs, measures and origin of improvement possibility 12 (the latter column displays the level of the corresponding element, with H, M or L, respectively 'High', 'Medium' and 'Low level')

Consequences	More awareness of new users of the system for specific dangerous junctions which should results in safer driving behavior	M
Costs	Relative low	L
Measures	Add a short extra information moment within the safety and security training adjusted to the new adjustments to the system, so the users (which are obligated to follow this training) get more familiar with difficult junctions on beforehand	
Location	Not relevant	
Originated from?	Interviews and literature	

7.3.4 'No regret' improvement possibilities

There are three improvement possibilities, numbered 13, 14 and 15, designed in this research as suggestions that can encounter probably large support among all stakeholders. For this reasons these suggestion are called 'no regret' improvement possibilities. Three different improvement possibilities are designed in this research: improve drainage, remove the green pedestrian crossings and reduce the number of traffic signs. All three improvement possibilities will be discussed in the next three subsections.

13) Improve drainage

The first 'no regret' related improvement possibility is the suggestion to improve the drainage on the airside of AAS. During the measurements held on the airside in September 2012, it happened that rainfall caused flooding on the pavement. This can resulted in dangerous situation as longer braking time and aquaplaning. Because of the fact it rains on average 129 days per years, which is 35% of the time and representing on average 10.75 days with rainfall per month on average as can be seen in figure 7.13 (Støwer, Bjerkaas, & Eliassen, 2012), this improvement possibility receives middle priority within this research. Table 7.16 displays an overview of improvement possibility 13.

Table 7.16; Consequences, costs, measures and origin of improvement possibility 13 (the latter column displays the level of the corresponding element, with H, M or L, respectively 'High', 'Medium' and 'Low level')

Consequences	More safety during rainfall	M
Costs	High investment needed	H
Measures	ZOAB is not possible; improving drainage around the RH-road (main axis)	
Location	Most road improvements will be on the main axes	
Originated from?	Experience gained during measurements	

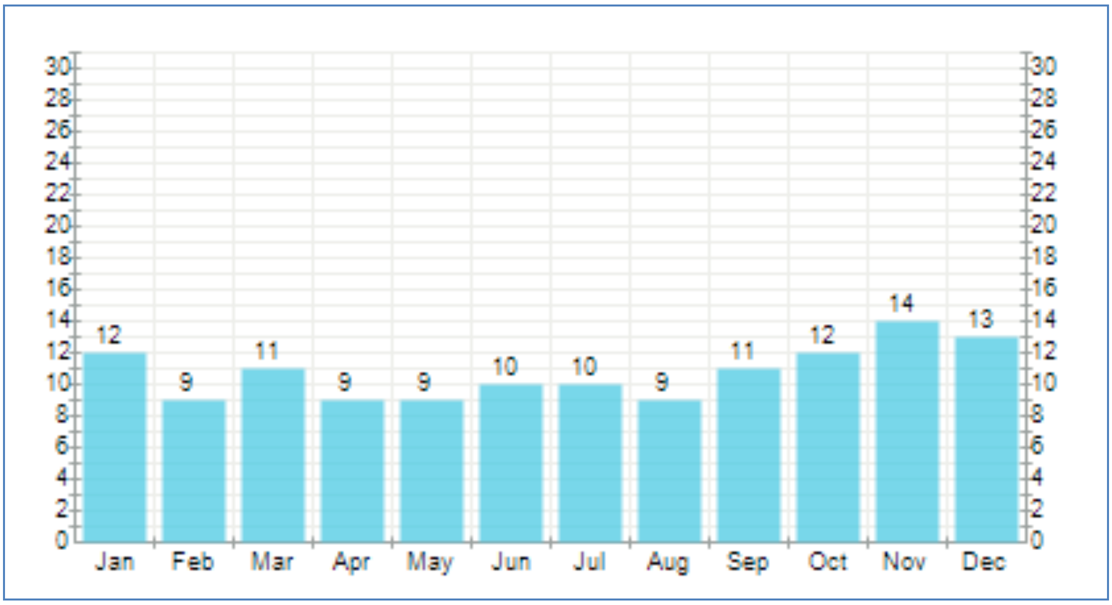

Figure 7.13; Average number of days with precipitation per month at AAS (Støwer, Bjerkaas, & Eliassen, 2012)

Different improvement possibilities could be implemented to solve the water flood problem; the most simple, and financially least costly, is to construct more drains along the road, to drain the water in the sewer. This could be a suitable improvement possibility for specific areas, for example under de F-pier as figure 7.14 shows. A small research is performed to other improvement possibilities to improve the drainage on the airside, of which another type of asphalt could be a improvement possibility. For the public roads special asphalt is developed called 'Very open asphalt concrete', or in Dutch 'Zeer Open Asphalt Beton (ZOAB)'. This type of asphalt is very effective against for example the aquaplaning effect, as could be the case regarding the current drainage situation on the airside displayed in figure 7.15. Unfortunately, this type of asphalt is most effective on highways, with speeds around 100 km/h. Other disadvantages are the high costs (both investment and maintenance costs) and the fact that heavy vehicles on the airside could easily damage this relatively vulnerable asphalt compared to other asphalt types. Concluding could be said that constructing more drains at strategic locations, to drain the rainwater more effectively and further research is needed for potential type of asphalt types suitable for the airside situation.

Figure 7.14; Beginning of the F-pier, no good drainage (07-11-2012, 13:11:01 PM)

Figure 7.15; Photo of the RH-road (main axis) after rainfall (19-09-2012, 5:27:23 PM)

14) Remove the green pedestrian crossings near the D-pier

Another 'no regret' improvement possibility will be removing the green pedestrian crossings close to the beginning of the D-pier on the 'Rinse Hofstra road'. Within the traffic system on the airside six green pedestrian crossing indications are constructed in May 2010. These six crossings first were only dotted lines, as is in the rest of the system still the case, and without resulting in priority for pedestrians. The original reason was creating more awareness among the drivers for pedestrians crossing the main axes, but during interviews it appears to be confusing for the users. Because the fact the effect is not reached and resulted even in a more negative situation, because users now break occasionally suddenly because they think pedestrians now do have priority (while this is official still not the case) it is suggested to clear the green paint of the road and go back to the original situation of only dotted pedestrian crossings and create a more clear and consistent overview on the road. An overview of improvement possibility 14 is displayed in table 7.17.

Table 7.17; Consequences, costs, measures and origin of improvement possibility 14 (the latter column displays the level of the corresponding element, with H, M or L, respectively 'High', 'Medium' and 'Low level')

Consequences	More clear overview of the traffic situation under the overpassing at the D-pier and reduce confusion on possible pedestrian priority	M
Costs	Limited costs, only the cost for removing the green paint of the road	L
Measures	- Remove green sections on the road, leave dotted line intact - Organize a stakeholder meeting to inform all road users	
Location	Several places on the main axis, under the terminal along the beginning of the D-pier	
Originated from?	Experience gained during measurements and interviews	

Figure 7.16 displays the current available pedestrian crossings on the airside. It is advised to remove the green paint and leave the channeling stripes on the road. When this advice is adopted, pedestrian crossings with only channeling stripes will results, which can be seen in figure 7.17. Now the situation will be more clear for all users of the traffic system, namely that pedestrians not have priority while crossing the road. The 'empty' pedestrian crossings could be made more visual with painting a pedestrian sign within the channeling strips to receive more attention. In December 2012 already a new proposal is presented for these pedestrian crossings by the manager safety Kees van der Leek, increasing more awareness and suggesting a different design of crossings.

Figure 7.16; Green pedestrian crossing, located at the beginning of the D-pier (07-11-2012, 12:57:02 PM)

Figure 7.17; Pedestrian crossing, using channeling stripes, at the 'ACC building' (07-11-2012, 12:52:32 PM)

15) Reduce the number of traffic signs on the airside of AAS

The final improvement possibility advised to AAS is the aspect of traffic signs on the airside of AAS. A remarkable situation can be concluded when driving on the airside of AAS, namely the large amount of information that the users should process to be able to drive safety through the environment. Several causes can be indicated resulting in this 'information overload': the different types of vehicles driving around, the high traffic volume on specific locations, the many on- and off-ramps and the many traffic signs. The first element will be discussed more in detail in improvement possibility 10 (registering of vehicle); the high traffic volume is already discussed in improvement possibility 1 (rerouting traffic) and the many on- and off-ramps in improvement possibility 6 (unraveling) and 8 (parking along the main road). The many traffic signs will be discussed in this improvement possibility. Table 7.18 displays an overview of improvement possibility 15.

Table 7.18; Consequences, costs, measures and origin of improvement possibility 15 (the latter column displays the level of the corresponding element, with H, M or L, respectively 'High', 'Medium' and 'Low level')

Consequences	Less distractions for users of the traffic system, which will results in a safer system	L
Costs	Little investment	M
Measures	Remove mostly walking signs	
Location(s)	At the beginning of the B-pier and the end of the F-pier	
Originated from?	Experience gained during the measurements	

The function of traffic signs is to achieve safe and desirable traffic behavior of road users (MOT, 2012) and can exist in many different types and shapes. When this goal is not achieved, as is the case on the airside of AAS, it should be questioned if the corresponding traffic signs are necessary and needed. In literature is stated that too many signs leads to information overload (AA For the road ahead, 2009), which should therefore be avoided all times. It appears that there are too many traffic signs on the airside and strikingly (too) many pedestrian warning signs. Removing a number of traffic signs will save maintenance costs and will provide more oversight within the traffic system. Two illustrating photos are displayed in figure 7.18 and 7.19, where an information overload can be seen in reality. Figure 7.18 is taken at the head of the F-pier, while figure 7.19 is taken near the beginning of the B-pier, but there are more possible locations where (pedestrian/ traffic) signs can be removed.

Figure 7.18; Unnecessary traffic sign at the F-pier (07-11-2012, 13:04:11 PM)

Figure 7.19; Overload of traffic signs near to the B-pier (07-11-2012, 12:17:32 PM)

7.4 Assessment of the improvement possibilities

A complete overview and detailed description of all individual improvement possibilities is provided in the previous section, which is kept in mind continuing this research. Besides the origin of each improvement possibility, as discussed in the beginning of this chapter, also the effect and consequences of the improvement possibilities are of importance for this research. With this information sub-question 6 could be answered: *"What are the differences between the improvement possibilities regarding robustness, reliability, safety and costs?"* To answer this question the following two questions should be answered first, which will lead to an answer on sub-question 6:

- How can we test different improvement possibilities in a realistic way to see if it provides a improvement possibility and what the effects are from the different improvement possibilities?
- How do the different improvement possibilities score on different aspects, using a multi criteria scoring-methodology?

For these questions, a scorecard is constructed, in which all improvement possibilities will be ranked qualitatively to get more insight in the differences between the improvement possibilities. First the reason for choosing the scorecard-method will be explained, followed by the scorecard methodology applied on this research.

7.4.1 Different MCA-methodologies

In literature, different ways to score different alternatives, or in this case improvement possibilities are known. The four most known methods are: weighted summation, concordance analysis, regime methodology and the EVA-mix (Ministerie van Financiën, 1986). Because limited quantitative elements could be indicated, a qualitative multi criteria methodology should be chosen to be able to make any difference between the improvement possibilities. One of the most common used qualitative MCA-methodologies is the scorecard (Ministerie van Financiën, 1986), which will be used for that reason within this research as well.

7.4.2 The scorecard methodology

As is discussed before more in detail, mainly because the aspects are measured completely qualitative, the scorecard methodology is assumed to be the best scoring methodology to compare all different improvement possibilities. Table 7.19 displays the results of this scorecard method.

Table 7.19; Simple MCA-table ranking the individual improvement possibilities on the four aspects plus costs and stakeholder support

Improvement possibilities		Influence on the four different aspects				Costs
	- - - 0 + ++	Safety	Robustness	Reliability	Utilization	
1	Rerouting	+	0	+	++	+
2	Monitoring	+	0	0	0	-
3	Speed adjustment	-	0	+	++	+
4	Extra lanes	-	++	+	0	--
5	1-direction	++	+	-	0	0
6	Unraveling	++	+	+	0	-
7	Corners adjustments	++	0	+	0	-
8	Parking	++	0	+	0	-
9	Lane separation	++	--	0	0	+
10	Registered vehicles	++	0	+	0	++
11	Cooperation	+	0	0	+	++
12	Training	++	0	0	+	++
13	Drainage	++	0	+	0	--
14	Pedestrians	++	0	+	0	+
15	Traffic signs	++	0	0	0	+

7.4.3 Weighted aspects

All different aspects are related to each other and can be split up in effectiveness and costs. The effectiveness is again split up into safety, robustness, reliability and utilization, as is explained earlier. Not all aspects weight the same in terms of effectiveness; for example the safety analysis is more extended, because more data was available on this aspects, compared to the robustness analysis. Also the fact that the safety aspect can be seen more as a necessity within a improvement possibility than as favor, because of the large consequences of this aspect (collisions, traffic injuries or even traffic deaths). Because of these reasons, the safety aspect is weighted two times a normal aspect.

Furthermore, several departments on AAS already indicated that the cost aspect is of large importance to all new projects and ideas. For this reason, the cost aspect is indicated even three times more than an average aspect. All other aspects, robustness, reliability and utilization are weighted single, so the score of each individual improvement possibility will be counted once, while the safety score will be counted double and the cost aspects three times the score. An overview of these weights is provided in table 7.20. Table 21 displays the translation from the MCA to the histograms, and so change plusses and minuses in values. Using this translation, the scorecard with all proposed improvement possibilities can be changed into a table with actual values as can be seen in table 7.22.

Table 7.20; Different weight per aspect

Weights	
Safety	**2**
Robustness	**1**
Reliability	**1**
Utilization	**1**
Costs	**3**

Table 7.21; Translated from the MCA to the histograms

Different levels	
++	**1.00**
+	**0.75**
0	**0.50**
-	**0.25**
--	**0.00**

Table 7.22; Weighted improvement possibilities resulting out of MCA, with the following weights: safety*2, robustness*1, reliability*1, utilization*1 and costs*3

Improvement possibilities (weighted)							
Improvement possibilities		Influence on the four different aspects				Costs	Overall
	- - - 0 + ++	Safety	Overall	Reliability	Utilization		
1	Rerouting	1.50	0.50	0.75	1.00	2.25	6.00
2	Monitoring	1.50	0.50	0.50	0.50	0.75	3.75
3	Speed adjustment	0.50	0.50	0.75	1.00	2.25	5.00
4	Extra lanes	0.50	1.00	0.75	0.50	0.00	2.75
5	1-direction	2.00	0.75	0.25	0.50	1.50	5.00
6	Unravelling	2.00	0.75	0.75	0.50	0.75	4.75
7	Corners adjustments	2.00	0.50	0.75	0.50	0.75	4.50
8	Parking	2.00	0.50	0.75	0.50	0.75	4.50
9	Lane separation	2.00	0.00	0.50	0.50	2.25	5.25
10	Registered vehicles	2.00	0.50	0.50	0.50	2.25	5.75
11	Cooperation	1.50	0.50	0.50	0.75	3.00	6.25
12	Training	2.00	0.50	0.50	0.75	3.00	6.75
13	Drainage	2.00	0.50	0.75	0.50	0.00	3.75
14	Pedestrians	2.00	0.50	0.75	0.50	2.25	6.00
15	Traffic signs	2.00	0.50	0.75	0.50	3.00	6.75

Sensitivity analysis

These two deviating aspects have influences on the different improvement possibilities. To get more insight in this factor, the histograms of the original (figure 7.20) and the histogram with the weighted scores (figure 7.21) are displayed. The histograms are building up from all individual scores of each improvement possibility, of all already discussed aspects. For example, it can be seen that improvement possibility 1 scores relatively high on utilization, which also can be seen in the histograms and is discussed earlier. So the higher the score within the histograms, the more positive this improvement possibility scored on all aspects. Also the cost aspect is set within this scale, so the larger the orange bar, the more positive the cost aspect will be for this improvement possibility, and so this improvement possibility will include little financial investments compared to the other improvement possibilities.

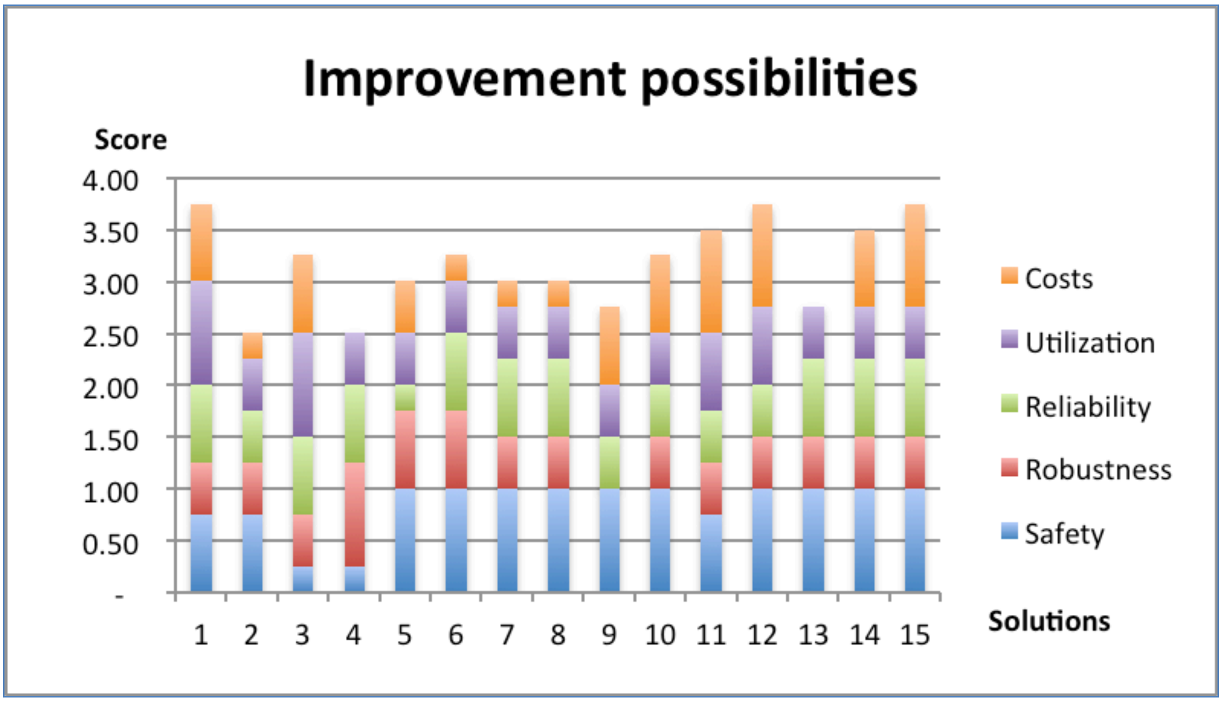

Figure 7.20; Histogram with all different improvement possibilities split up per aspect

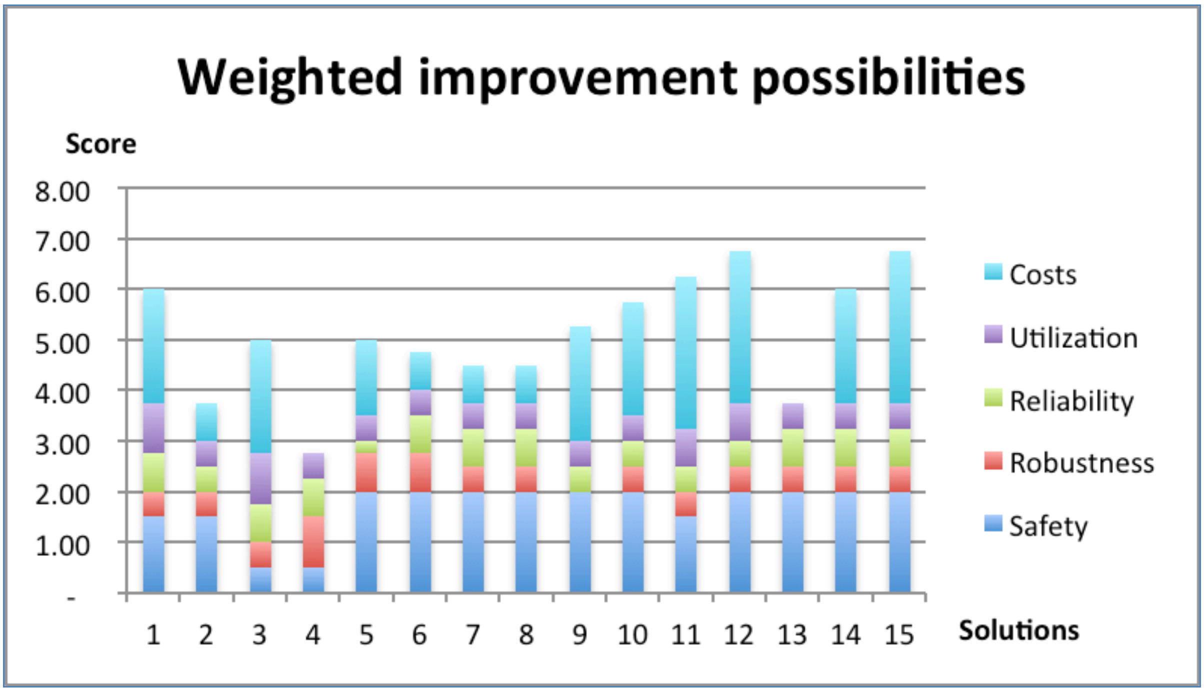

Figure 7.21; Histogram with all different improvement possibilities split up per weighted aspects

In the original version, so with all aspects having the same weight, improvement possibilities 1, 12 and 15 are standing out, compared to the rest of the improvement possibilities, followed by improvement possibilities 11 and 14. While in the new scenario, with differences in weights for the different aspects, only improvement possibility 12 and 15 are striking out, followed by improvement possibilities 1, 11 and 14. So the specific improvement possibilities are comparable, with or without weighting the different aspects, only the order of the improvement possibilities differs.

Appendix F.6 discusses a detailed sensitivity analysis, performed by testing the influence of different weights to the outcome of the analysis. Table 7.23 displays the used weights within the sensitivity analysis, in which alternative 4 is chosen as the final alternative and so is displayed earlier; the histograms can be found in the appendix and it could be concluded that the same improvement possibilities stands out in all alternatives. In this way, the results are more valid because of the performed sensitivity analysis.

Table 7.23; Different weights per aspect for the four different sensitivity alternatives

Weights	Alternatives					
	1	2	3	4	5	6
Safety	1	1	2	2	3	3
Robustness	1	1	1	1	1	1
Reliability	1	1	1	1	1	1
Utilization	1	1	1	1	1	2
Costs	1	2	2	3	3	3

7.4.4 Stakeholder attitude towards all improvement possibilities

Now the differences between the improvement possibilities are indicated, by analyzing the histograms with all different aspects taken into account, a concrete advice about improvement possibilities will be provided in the next section. But first, to get more insight in the opportunity and potential of all individual improvement possibilities for the Schiphol Group, a more detailed step will be performed, including also the stakeholder support regarding all individual improvement possibilities. An overview is created in figure 7.22 in which all aforementioned introduced improvement possibilities, with the corresponding number, are positioned on two main criteria: the (qualitative) consequences towards the costs of all improvement possibilities. The first criteria is important because the effect of the improvement possibility is of interest to all stakeholders of this research whether or not the improvement possibilities are solving a specific problem and/ or contribute positive to the traffic system and so should be taken as one of the decision criteria. The latter criteria, the costs of each improvement possibility, is also suggested by the Schiphol Group, because this is one of the major go / no-go decision aspects currently because of the economic crisis, as is explained before in section 1.3.1. Within this figure, also the level of stakeholder support for the different improvement possibilities is displayed, representing the willingness of all stakeholders to implement this specific improvement possibility.

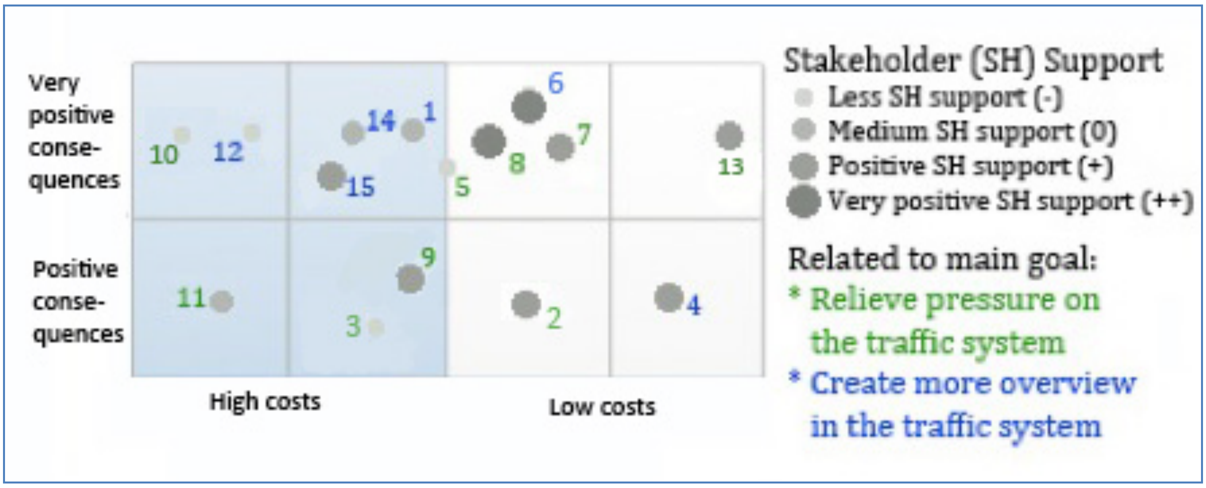

Figure 7.22; Overview diagram of all individual improvement possibilities regarding their consequences and costs (both investment and maintenance costs)

As described in the general description (chapter 2) and the beginning of this chapter, all individual improvement possibilities can be assigned to one of the set main goals; create overview in the network and/ or let the main axes flow. Within the graph of figure 7.22 the proposed improvement possibilities regarding the first goal are numbered in blue and are the following numbers: 1, 3, 4, 11, 12 and 15. The proposed improvement possibilities regarding relieving the pressure on the traffic system and so let the main axes flow (RH-road) are displayed in green and are the following improvement possibilities: 2, 5, 6, 7, 8, 9, 10, 13 and 14.

7.5 Conclusion regarding potential improvement possibilities

After the context and conducting four different analyses, different problem areas were indicated to focus on. Within this chapter 15 different improvement possibilities are designed and discussed, including their origins within this research. The 15 improvement possibilities are clustered in four different categories: traffic management, infrastructure, policy and 'no regret' related improvement possibilities. An example of a traffic management related improvement of the traffic system could be the rerouting of traffic over the relative quite viaducts more often, relieving the beginning of the piers, resulting in less collisions and so in a higher safety level and less delays. Infrastructure related improvements are focusing on adjusting infrastructure to create more safety at specific locations, for instance the corners at the C- and F-piers. Also improving the robustness between the D-E and E-F piers by adding another lane on both sides is an infrastructure related improvement possibility. Policy related improvements are focusing on for instance organization aspects, for example improving the cooperation between PMA and the airport authority. Finally, an example of 'no regret' improvements is improving the drainage on the airside of AAS, creating a safer environment during rainfall.

Within section 7.4 all 15 potential improvement possibilities are assessed by performing a multi-criteria analysis; using the scorecard methodology. The improvements are assessed on the following five aspects: safety, robustness, reliability, utilization and costs, using different weights resulting out of a extended sensitivity analysis. The following five potential improvement solutions resulted as most positive from this assessment with the number in brackets:

- "Add an extra traffic system safety component to the training of users." (12)
- "Reduce the number of traffic signs on the airside of AAS." (15)
- "Increase the cooperation between PMA and the airport authority." (11)
- "Reroute the traffic using the viaducts." (1)
- "Remove the green pedestrian crossings near the D-pier." (14)

Also regarding stakeholder attittude, discussed in section 7.4.4, these five improvements resulted best of the multi-criteria analysis and so are advised to implement first. It is not remarkable that no infrastructural related improvement possibilities are resulting best out of the assessment, regarding the large investment costs of infrastructure related adjustments and the relative high, but realistic weight of costs within the assessment.

A complete overview of all different types of potential improvement possibilities are provided, including an advice of which improvements to apply first within the traffic system on the airside of AAS. The next chapter will provide the implementation strategy of all potential improvement possibilities and the complete research will conclude with conclusion and recommendations in chapter 9.

8. Implementation strategy

Within this chapter an advice will be provided for AAS, which and how to implement the improvement possibilities mentioned in the previous chapter. With this advice, SQ 7 will be answered: *“What elements should be taken into account regarding implementation of the proposed improvement possibilities*?” To get more insight first the future construction works will be discussed, to see if individual improvement possibility could be implemented during an already planned construction project, followed by a section about the attitude of different stakeholders against the improvement possibilities and how to mitigate their attitude if necessary. Then a more detailed overview of the financial consequences is provided when implementing the improvement possibilities, followed by an identification of the implementation risks. This chapter will conclude with labeling the improvement possibility with a certain realization time frame, for which a three-level categorization is used, to get more insight in the realization time aspect.

8.1 Future construction works

With regards to the implementation of improvement possibilities the future construction works, those that are related to the improvement possibilities and so possibly could be combined together, are mapped in table 8.1. Only the future construction works of 2013 are taken into account, because these are the only known construction projects planned so far as AAS is aware of.

Table 8.1; Future construction works in 2013 related to the proposed improvement possibilities

Location of construction	Period	Related improvement possibility
Terminal expansion between E- and F-pier	29/04/’13 – 2014	4: Add lane between E-F
		7: Corner of the F-pier
		8: Between E-F
C05 and C07	08/04/’13 – 14/04/’13	7: Corner of the C-pier
Stands E-pier (phased)	28/02/’13 – 31/03/’13	5: 1-direction F-pier
		8: Parking places E-pier
D03, D05 and E02	21/01/’13 – 27/01/’13 or 04/03/’13 – 10/03/’13	4: Extra lane between D-E
		6: Turning right lane D-E
Stands B-pier (phased)	01/04/’13 – 12/05/’13 or 17/06/’13 & 30/06/’13	5: Possible one-direction of the B-pier
Stands C-pier (phased)	18/03/’13 – 28/04/’13	5: Possible one-direction of the C-pier

Not all improvement possibilities are mentioned in table 8.1; there are improvement possibilities that could not be combined with future planned construction works, because those improvement possibilities are not infrastructure-related. The proposed way to implement these improvement possibilities is displayed in table 8.2. It is advised to execute all proposed improvement possibilities at night because of least operational disturbances.

Table 8.2; Way of implementing the non-structural improvement possibilities

Improvement possibility	Implementation strategy
1) 'Reroute traffic using the viaducts more often'	First inform related stakeholders, e.g. KLM Cargo and other cargo handlers by a personal presentation. Then install a (dynamic) sign at the roundabout with current travel times to different destinations.
2) 'Monitoring traffic'	First update all users of this development by sending an information mail. Then, install cameras at strategic places.
3) 'Increase the speed on viaducts'	First inform all stakeholders that use the traffic system by sending an information mail with the adjustment in speed on the viaducts. Next, adjust the traffic signs at the viaducts.
9) 'Create (physical) lane separation'	First design the situation more in detail; inform then all users of this development by sending an information mail. Then, adjust the junction at the B-pier.
10) 'Reduce the number of (new) registered vehicles'	Plan a meeting with the manager security (e.g. David van der Meer) to discuss how to execute this improvement possibility. For example design new registration restriction. Then inform all companies on the airside with the new registration-regulations.
11) 'Increase the cooperation between AS and airport authority'	Organize a first brainstorm meeting with both AS and airport authority and then choose a regular-based meeting day and time. The new Collaborative Decision Making (CDM) project currently running at AAS can be used as example.
12) 'Add extra traffic system component to the training of users'	Plan a meeting with the VTC-center to discuss the possibilities for adding an extra traffic -system-awareness-component within the training program.
13) 'Improve drainage'	Start up a drainage analysis, where to start improving the road after heavy rainfall. Then adjust the road balance so the water will flow to the drains. Install extra drains if necessary.
14) 'Remove the green pedestrian crossings'	Temporarily close the road to remove the crossings one by one. Reroute the traffic with clear guidance.
15) 'Reduce the number of traffic signs'	Perform an analysis to see which traffic signs could be removed. Plan a night to actually remove the signs.

8.2 Stakeholder cooperation

As discussed in section 2.2.2, the stakeholder overview, many different stakeholders are operating on the airside of AAS. All stakeholders are already placed within a specific square within the power versus interest grid and are labeled for that reason. A quick recap of these labels can be seen in table 8.3 below; it should be mentioned that the interest of all listed stakeholder is positive and so is left out of the table.

To be able to get all stakeholders on the same level, a stakeholder mitigation strategy could provide more insight in how to manage all these stakeholders, when implementing the proposed improvement possibility(s). Table 8.3 displays the different companies, which all have their own perspective. In the latter column of the table the mitigation strategy is described.

It can be concluded from the table that the passenger-handling companies should be motivated to care for project related to improving the traffic system, although it is not their core business. The most stakeholders on the airside should be kept informed and satisfied.

Table 8.3; Stakeholder labels with their influence on their power, attitude and interest (Hill son & Simon, 2007)

Label	Power	Attitude	Companies at AAS	Mitigation strategy
“Savior”	Influential	Active	Cargo-handling companies Baggage-handling companies Technical services Airplane maintenance Fuelling companies Catering companies Safety & Security Infra maintenance	Do whatever is necessary to keep them this actively involved and positive.
“Friend”	Insignificant	Active	Cleaning companies Waste companies Vehicle maintenance Special services	Mainly useful as sounding boards. They gain only additional power.
“Sleeping Giant”	Influential	Passive	Passenger-handling companies	They need to be awakened and motivated to care for the project.
“Acquaintance”	Insignificant	Passive		They should be kept informed. When their power of interest changes, they move up on the priority list.

8.3 Financial consequences

Now the way to implement per improvement possibility and the stakeholder mitigation strategy are discussed, the costs of the improvement possibilities should be defined more in detail. In the previous chapter costs are already taken into account when using the scorecard methodology, but within this section the deviation will be made between investment and maintenance costs.

Table 8.4 displays all improvement possibilities and the impact on both investment and maintenance costs.

Table 8.4; Financial consequences per improvement possibility, split in financial investment and maintenance consequences on a five-level scale (--,-,0,+,++)

Improvement possibility number		Financial consequences regarding on investment costs	Financial consequences regarding maintenance costs	Overall financial consequences
1	Rerouting	0	-	5
2	Monitoring	-	-	6
3	Speed adjustment	+	++	2
4	Extra lanes	--	0	6
5	1-direction	--	0	6
6	Unraveling	--	+	5
7	Corners adjustments	--	0	6
8	Parking	-	++	4
9	Lane separation	-	++	4
10	Registered vehicles	+	++	2
11	Cooperation	++	+	2
12	Training	++	++	1
13	Drainage	--	0	6
14	Pedestrians	0	++	3
15	Traffic signs	+	++	2

From the table 8.4 it can be seen that there can be a ranking from 1 to 6 indicted between the improvement possibilities, the lower the number, the lower the financial consequences and so the more positive the improvement possibility will be. Improvement possibilities numbered 12, 3, 10, 11 and 15 are resulting with the lowest financial consequences, regarding both investment and maintenance costs. It is possible that improvement possibilities are sharing a position, as is the case with number 3, 10, 11 and 15 for instance, the overall financial consequences can then be seen as of the same order.

8.4 Implementation risks

There could be two main possible implementation risks identified, of which it could be useful to realize that these possible problem situations could happen. When one is aware of the possible problems the improvement possibilities could run into, it could create more awareness and focus into unnecessary a specific direction on beforehand. The two main possible implementation problems that are identified are: no/limited financial resources available and/or no/limited cooperation of stakeholder(s). An overview is provided in table 8.5.

Table 8.5; Overview of the possibly expect possible implementation risks identified per individual improvement possibility. When the mentioned risk could be applicable for the improvement possibility, this is indicated with an X.

Improvement possibility number		No/ limited financial resources available	No/ limited cooperation of stakeholder(s)
1	Rerouting		✓
2	Monitoring		✓
3	Speed adjustment		✓
4	Extra lanes	✓	
5	1-direction	✓	✓
6	Unraveling	✓	
7	Corners adjustments	✓	
8	Parking	✓	✓
9	Lane separation	✓	✓
10	Registered vehicles		✓
11	Cooperation		✓
12	Training		✓
13	Drainage	✓	
14	Pedestrians		
15	Traffic signs		

8.5 Realization time frame of potential improvement possibilities

The time frame of the proposed improvement possibilities is different for each improvement possibility, as is discussed in the previous sections and even in the previous chapter, in which all improvement possibilities are scored already. To be able to keep a clear overview, a three-level categorization is made within the realization time of the improvement possibilities: *short-term, medium-term* and *long-term realization time*. When a improvement possibility is easy-to-implement, regarding costs, stakeholders and policy aspects, the realization time frame of this improvement possibility will be on the short-term. On the other hand, when high costs are involved, the stakeholder participation level is low and/or policy aspects are heavily involved, the improvement possibility will be characterized with a long-term realization time frame. Improvement possibilities that cannot be identified as having a short of long term realization time frame are identified as a realization time frame labeled as medium-term realization term.

The short-term realization time improvement possibilities are:

- 11) ‘Increase the cooperation between AS and airport authority.’
- 12) ‘Add an extra traffic system safety component to the training of users.’
- 10) ‘Reduce the number of (new) registered vehicles.’
- 15) ‘Reduce the number of traffic signs.’

The medium-term realization time improvement possibilities are:

- 1) ‘Reroute the traffic using the viaducts more often.’
- 2) ‘Monitoring traffic.’
- 3) ‘Increase the speed on the viaducts.’
- 8) ‘Parking places: remove next to the main axes and design off-road at other roads.’
- 9) ‘Create (physical) lane separation.’
- 14) ‘Remove the green pedestrian crossings.’

The long-term realization time improvement possibilities are:

- 4) ‘Add extra lanes between D-E piers and E-F piers.’
- 5) ‘Change the beginning of the E-pier in a one-direction situation.’
- 6) ‘Create separate turning right lanes (unraveling) and reduce turning left.’
- 7) ‘Adjust the corners at the beginning of the C- and F-piers.’
- 13) ‘Improve drainage.’

8.6 Conclusion of the implementation strategy

This final chapter about implementation urgently advices to take the (near) future construction works into account, because this can save a large amount of money. The reason for this can be found because the corresponding area already is constructed differently for example as consequence of a terminal extension. Directly implementing for example improvement possibility 7, "adjusting the corners at the beginning of the C- and F-pier", together with this terminal construction, could result even in no additional construction costs and so only in for example designing costs.

Furthermore, stakeholders should be taken seriously when implementing improvement possibilities; for this reason a stakeholder mitigation strategy, together with the financial consequences and potential implementation risks are provided within this chapter, so the implementation of improvement possibilities will be approved, and possibly even supported (financially) by related stakeholders of AAS.

Regarding the time of implementation, it could be concluding that there are four potential short-term realization improvement possibilities, which could be implemented very quickly. One of the middle-term improvement possibilities, could also be of direct interest because of the large effectiveness, which is the "rerouting traffic using the viaducts more often".

9. Conclusion & recommendations

As is discussed in the previous chapter, the implementation of potential improvement possibilities should be prepared carefully, after analyzing all possible consequences and risks to avoid problems after implementation that could have been avoided. Within this final chapter the conclusion will be provided and different recommendations. The recommendations are divided into three different recommendations: general recommendations, recommendations for AS and recommendations for further research. Now first the main conclusion of this research is drawn in the next section.

9.1 Conclusion

The growing air transportation movements resulted in a detailed research of the traffic system on the airside of AAS. Using safety, robustness, reliability and utilization as the four main aspects, a clear overview is provided of the current situation of the traffic system on the airside. These aspects are also discussed in the objectives in the beginning of this document.

It appears that most collisions occurring at the beginning of the piers, with the D-pier as the location with the absolute most collisions, based on a safety analysis using the black spot methodology. The average cost of a collision on the airside is researched to be €*1612.99 euro per collision* (AAS, 2012). So a reduction of these collisions could results directly in financial savings, which is of large importance in these times of financial crisis, as discussed in section 1.3.1.

Regarding the robustness aspect it can be concluded that the complete traffic system should consist of a *2x2 single lanes structure*. For this reasons, it is proposed that lane extension should be constructed between the E- and F-piers. Preferably also an extra lane should be constructed between the D- and E-pier, although the current situation on the airside prevents this possibility because of limited space.

To maximize the utilization of the traffic system, it is researched if vehicles could be logically be rerouted along routes with low traffic volumes. From traffic volume measurements it appeared that the viaducts are used rather less compared to the rest of the system. Another measurement experiment, measuring the travel times over routes with and without the viaducts, resulted in the proposed improvement possibility to increase the maximum allowed driving speed from 30 to 50 km/h on the viaducts. In this way, the 'viaduct-route' will be used more often and the utilization of the complete system will be more optimal. Furthermore, rerouting vehicles will release pressure on the problem areas; the beginning of the piers as appears out of the safety analysis.

Besides the current situation, also the future situation, in terms of the year of 2018, is taken into account in this research. Using the traffic volume measurements together with literature, an extrapolation could be made in the number of vehicles driving around on the airside. With respect to capacity, the traffic system appears not able to handle the future amount of traffic, generating from the grown amount of plane handling. It should be mentioned that the used methodology to calculate capacity on the airside of AAS, is not adjusted to the specific traffic situation on the airside, with the many distracting junctions and large variety in vehicles. If the proposed improvement possibilities are (partly) implemented, new capacity calculation should be performed to analyze if the infrastructure at the airside is able to handle the traffic volumes in the future.

In the end of the research, a total of 15 improvement possibilities are proposed, of which the following five scored the highest score regarding **costs**, **effectiveness** (regarding the four aspects) and **stakeholder support**:

- Rerouting traffic over the viaducts to maximize the utilization of the network by achieving a increased used of the viaducts with almost 40%,
- Reduce the number of traffic signs to create more overview,

- Increase the cooperation between stakeholders (mostly AS and AA),
- Add an extra (safety related) training component for new users and
- Removing the green pedestrian crossings near the beginning of the D-pier.

Another interesting improvement possibility, which can be realized on a short-term, is to 'reduce the number of (new) registered vehicles'. In this way the inflow of vehicles will be reduced, which will lead to a reduced traffic volume and less dangerous traffic situations.

For all 15 proposed improvement possibilities the implementation strategy is provided, including for example if the improvement possibility could be combined with future construction works and more insight in the implementation risks. Also the role of related stakeholders is discussed and how to involve all companies so that they accept or even support the implemented improvement possibilities.

Concluding, it can be that the main objectives are fulfilled to the best extend and the main research question is answered as good as possible, both with regarding the available time and resources: ***"how safe, robust, reliable and utilized is the traffic system on the airside of Amsterdam Airport Schiphol and how can this traffic system be improved regarding safety, robustness, reliability and utilization?"***. More insight is gathered on all four aspects and together a complete overview could be provided of the traffic system of AAS. But as is common at performing research, also many additional questions appeared during this research. Both question needing more in depth research at specific elements within this research and also complete new questions evolved during the execution of this thesis. In the next chapter, all recommendations, both for AAS and for further research, and evolved questions are listed and discussed.

9.2 Recommendations

As is the case in most research, the performed research could be studied more in depth on several areas. Also more research can be performed on the methodology and other scientific related topics due to this research. In this chapter both the recommendations for AAS and for further research will be discussed.

General recommendations

The general recommendations consist of general advices; for instance adopting monitoring system to monitor the traffic on the airside of AAS. But also the more policy related improvement possibilities have large potential and are relatively simple to implement and / or start with. Another general recommendation is the importance that these types of research will be performed more often and at different locations within the world; in this way more comparison between researches could be adopted which will strengthen all research in this field. Currently, relative limited literature is available on optimizing traffic systems on the airside of larger airports. Besides general recommendations, also more specific recommendations are discussed and can be found in the next two sub-sections.

Recommendations for AAS

Seven recommendations are advised to AAS in this section, which arose during this research or possible opportunities that appeared from findings. Of all proposed improvement possibilities, more insight is provided regarding different implementation elements. It could be very interesting to test the actual quantitative effect of different proposed improvement possibilities for example by performing a (dynamic) simulation. Each improvement possibility can be simulated separately, but it could be also very interesting to combine different improvement possibilities with each other to see the results of combined improvement possibilities. Comparing to the principle of Integrated Network Management (INM) in which different separate measures could result in an even higher positive effect when they are combined with each other within the same network.

Another area of attention could be adjusting the capacity calculation methodology to specific traffic system as are located at airports. The capacity methodology now assumes straight roads with structured infrastructure, which is not the case on the airside of AAS. One could think of a correlation factor to reduce the amount of available capacity or even design a complete new methodology, taking the difficult infrastructure of for example airport into account.

Related to the travel time measurements held during this research, it could be recommended to extend these measurements by driving the same routes many extra times. This will result in higher reliability of the data and so more reliable statements. Taken into account that the measurements, both of travel times and traffic volumes, are held on working days between 9:30 and 16:00 O'clock; before and after these times, and during the weekends, no measurements are held. To get a complete overview of the complete system and more accurate data, these time frames and days should be taken also into account.

Also more research can be performed to a more suited type of asphalt that could cope better with the rainfall on the airside and is at the same time suitable for driving maximum 30 km/h; as ZOAB ("Seer Open Asfalt Beton": very open asphalt concrete) is not an ideal type of asphalt in this sense.

Regarding the environmental aspects at AAS, which is becoming more and more an important point on the general agenda nowadays, research could be performed to the implementation of electrical cars on the airside. Because of the many short distances, this could be really suitable for all type of vehicles, which can be equipped as electrical car. Already a small number of baggage trucks are electrical, because they have to enter the baggage basements where diesel trucks are not allowed, but this number could be increased largely.

With the knowledge of bicycles being one of the most vulnerable users within traffic systems, together with pedestrians, more attention could be paid to the bicycle policy on the airside of AAS. A few bicycles are seen nowadays within the system, mostly by users from the baggage halls / basements. The question raises if this should be tolerated and allowed or should be repulsed from the traffic system at the airside of AAS.

Regarding the scope of this research, a comparable project could be conducted on the four aspects regarding aircraft stands ('VOPs'); the most collisions occurring at these aircraft stands nowadays and so more attention could be paid and / or conducting another research to this different scope.

Finally, more in depth research could be performed on the junctions on the airside, by possibly simulate junction(s), for example using the research of Ruben Corthout on "Intersection modeling and marginal simulation in macroscopic dynamic network loading" (Corthout, May 2012).

Recommendations for further research

Besides the practical recommendations for next steps for AAS, also an advice could be provided for further research regarding scientific literature. The used methodology in this research, analyzing a traffic system at an airport using four aspects (safety, robustness, reliability and utilization), could be applied to other airports also. This could results in increased knowledge on which aspects are most suitable for this specific kind of study. It could be possible that the four aspects aforementioned are not sufficient enough to provide a complete overview of the situation at other airports, although it was experienced to be sufficient enough for AAS. Or on the other hand, it could be the case that one of the aspects is not necessary to create a complete overview of a traffic system, which will save time in performing the research. More information on this topic will results in a more in depth reflection on which aspects to use to be able to provide a clear overview of a traffic system at an airport.

Another point of attention could be the way the different aspects are defined. In some cases a clear definition lacked in literature, which could have result in a slightly different definitions. This could have lead to different perspectives on the same aspects. Adopting a clear definition within traffic management literature for utilization and/ or robustness for example would have created more transparency.

Regarding behavioral elements in this research, it could be recommended to study the driving behavior on the airside of airports in general even more, because of the rather limited available literature on this aspect currently. All currently available literature on driving behavior is related to public roads and is difficult to compare with the different attitude and behavior on the separate traffic system on airside with the large variety in vehicles and complex infrastructure.

Finally, this research mainly focused on infrastructural and behavioral improvements with minor attention to the policy and organizational related aspects. It could be worthwhile to research the policy side of study more in depth, in corporation also with the related stakeholders, so even more improvement possibilities could be designed. A positive side aspect of this recommendation will be that the improvement possibilities proposed in this research will probably be adopted more easily and maybe also in a shorter time-frame, because of the awareness of all involved stakeholders. Also more insight in the large organizational structure of airports will contribute during the implementation phase of improvement possibilities. Awareness of how organizations, in this case specifically airports, are structured and organized could add much value to a faster and more smooth implementation process mainly because stakeholders will have a positive attitude towards the improvement suggestions because they were involved in the process.

List of formulas

Resulting of chapter 3 Safety analysis of the traffic system

$P = A + 2 * B + C$ (1)

P = *Number of accident*
A = *Total number of unilateral collisions*
B = *Total number of collisions between vehicles*
C = *Total number of other collisions (involving people and / or animals)*

Resulting of chapter 6 Utilization analysis

$$Utilization = \frac{Operating\ hours}{Available\ hours} x\ 100\% \tag{2}$$

$$Breaking\ distance = Response\ time * Design\ speed - \frac{0.5 * Design\ speed^2}{Deceleration} \tag{3}$$

$$Breaking\ distance = 1.00 * 15.00 - \frac{0.5 * 15.00^2}{-7.00} = 5.41\ m/s^2 \tag{4}$$

$$Time\ between\ 2\ vehicles = \frac{Vehicle\ length + Breaking\ distance}{Design\ speed} \tag{5}$$

$$Time\ between\ 2\ vehicles = \frac{10.00 + 5.41}{15.00} = 3.70\ s. \tag{6}$$

$$Capacity = \frac{3600}{Time\ between\ 2\ vehicles} \tag{7}$$

$$Capacity = \frac{3600}{3.70} = 973.60\ pae/h/lane \tag{8}$$

Bibliography

AA For the road ahead (2009). *UK road sign review*. (The Automobile Association Limited 2010) Retrieved 11 09, 2012 from www.theaa.com: http://www.theaa.com/public_affairs/aa-populus-panel/aa-populus-too-many-road-signs.html

AirlineUpdate.com (2012). *International airline industry directories*. Retrieved Juni 19, 2012 from http://www.airlineupdate.com/content_subscription/gha/europe/netherlands.htm

Anna.Aero (2012). *Airline & Airport Industry Market Trends from Anna.Aero*. (P. P. Ltd, Producer) Retrieved 12 14, 2012 from Anna Aero: http://www.anna.aero/category/market-trends/

Annual report of the Schiphol Group 2009 and 2011 (2009). In *Jaarverslag Schiphol Group* (p. 260). Schiphol: Schiphol Group.

Ashford, N., Mumayiz, S., & Wright, P. (2011). *Airport Engineering, Planning, Design, and Development of 21st Century Airports* (Fourth edition ed.). Hoboken, New Jersey, United States of America: John Wiley & SOns, INC.

ASIS (2012). *Airside Informatie Systeem, luchthaven Schiphol.* The Schiphol Group.

Bootsma, P. (1997). *Airline Flight Schedule Development.* Utrecht: Elinkwijk B.V.

Business dictionary (2012). Retrieved June 4, 2012 from www.businessdictionary.com: http://www.businessdictionary.com/definition/safety.html

Cambridge Dictionaries Online (2011). Retrieved June 5, 2012 from Cambridge University Press: http://dictionary.cambridge.org/dictionary/british/congested

CBS (2012). Retrieved June 22, 2012 from Record number of travellers to and from Dutch airports in 2011: http://www.cbs.nl/en-GB/menu/themas/verkeer-vervoer/publicaties/artikelen/archief/2012/2012-3617-wm.htm

Cheapflights.com (n.d.). Retrieved June 4, 2012 from www.cheapflights.com

Corthout, R. (2012). *Intersection modelling and marginal simulation in macroscopic dynamic network loading.* Heverlee, Belgie: Katholieke Universiteit Leuven, Groep Wetenschap en Technology.

CPB.nl (2012). Retrieved June 5, 2012 from CPB: Matig herstel economie na 2012: http://www.cpb.nl/persbericht/3211418/cpb-matig-herstel-economie-na-2012

De Jong, P. (2004). *Hoe de capaciteit van wegen afneemt bij hogere rijsnelheden.* Delft: TU Delft.

Design mobility plan Flanders (2001). *Ministry of Flemish Government, Belgium*. Retrieved 07 19, 2012 from http://viwc.lin.vlaanderen.be/mobiliteit/

Elsevier (2012). Rijkswaterstaat: Aantal files neemt af door meer asfalt. *Elsevier* , p. 1.

Eurocontrol (2012). *Seven-years forecast.* Eurocontrol Statistics and Forecast Service. Europe: European Organisation for the Safety of Air Navigation.

Finance maps of World (2012). *Airline mergers and acquisitions*. (C. I. Ltd., Producer) Retrieved 12 14, 2012 from Finance.mapsofworld.com: http://finance.mapsofworld.com/merger-acquisition/airline.html

Geurts, K., & Wets, G. (2003). *Black Spot Analysis Methods.* Kennis Verkeersonveiligheid. Diepenbeek: Steunpunt Verkeersveiligheid bij stijgende mobiliteit.

Greenshield, B. (1934). *A study of highway capacity* (Vol. 14). Washington: Proceedings Highway Research Record.

Hillson & Simon (2007). *Practical Project Risk Management.* The ATOM Methodology.

Hoogendoorn, S. (2010). *Traffic Flow Theory and Simulation CT4821.* Delft: Delft University of Technology.

International Transport Forum (2008). Towards Zero, Ambitious Road Safety Targets and the Safe Sysem Approach. *Organisation for Economic Co-operation and Development.* Paris: OECD.

Lamm, R., Psarianos, B., & Mailaender, T. (1999). *Highway design and traffic safety engineering handbook.* New York: McGraw-Hill.

Lewis, E. (1994). *Introduction to Reliability Engineering.* Evanston, Illinois: John Wiley & Sons, Inc.

Lint, D. v. (2012). Capacity of the network will be determined by capacity of junctions. (B. Borsboom, Interviewer)

Meurs, H., & Van Wee, B. (2012). *Beter Benutten regionaal en landelijk uitgewerkt (VK 2/2012)*. Retrieved October 23, 2012 from www.verkeerskunde.nl: http://www.verkeerskunde.nl/internetartikelen/internetartikelen/beter-benutten-regionaal-en-landelijk-uitgewerkt.4.26862.lynkx

Ministerie van Financiën (1986). *Evaluatiemethoden.* Ministerie van Financiën, Afdeling Beleidsevaluatie en -instrumentatie. Delft: Staatsuitgeverij.

Ministerie van Verkeer en Waterstaat (2004). *Startnotitie Spitsstrook A1 Hoevelaken - Barneveld.* Directoraat-generaal RIjkswaterstaat, Rijkswaterstaat Utrecht. Nieuwegein: Rijkswaterstaat Utrecht.

MOT (2012). *Beheer en onderhoud verkeersborden*. Retrieved 11 09, 2012 from www.Opleidenmot.nl: http://www.opleidenmot.nl/index.php?view_node_10027

Schiphol Development Plan 2013-2017 (2012).

Schiphol Group (2012). *Toekomst Mainport Schiphol.* Schiphol: Schiphol Group & KLM.

Schiphol Group, (2012). *Traffic review 2011.* Schiphol Amsterdam Airport.

Schoemaker, T. (2002). *Samenhang in vervoer- en verkeerssystemen.* (S. Rienks, Ed.) Bussum, Nederland: Uitgeverij Coutinho.

Schoemaker, T., Koolstra, K., & Bovy, P. (1999). Traffic in the 21st century - a scenario analysis for the traffic market in 2030. In M. Weijnen, & E. t. Heuvelhof, *The infrastructure playing field in 2030* (pp. 175-194). Delft: Delft University Press.

Sita Aero (2012). Retrieved June 6, 2012 from www.site.aero.com: http://www.sita.aero/knowledge-innovation/industry-surveys-reports/airport-it-trends-survey-2011

Snelder, M., Immers, B., & Wilmink, I. (2004). *De begrippen betrouwbaarheid en robuustheid nader verklaard.* TNO, Inro. Delft: TNO Inro.

Støwer, T., Bjerkaas, H.-T., & Eliassen, A. (2012). *Weather statistics for Amsterdam Airport Schiphol, North Holland (Netherlands)*. (A. j. Norwegian, Producer) Retrieved October 31, 2012 from www.yr.no: http://www.yr.no/place/Netherlands/North_Holland/Amsterdam_Airport_Schiphol/statistics.html

Taale, H. (2011). Witteveen & Bos, Rijkswaterstaat, Dienst Verkeer en Scheepvaart.

The Schiphol Group. (2012). *Incidentenrapportage AOVO.* The Schiphol Group.

Van Dale woordenboek. (2012). *Botsing*. Retrieved July 19, 2012 from Van Dale woordenboek: http://www.vandale.nl/opzoeken?pattern=botsing&lang=nn

Van der Leek, K. (2012). Interview. (M. Borsboom, Interviewer) Schiphol.

Van der Leek, K. (2012). Veiligheidsdoelstellingen AO. Schiphol, Nederland: Airside Operations.

Van der Meer, D. (2012). Security operations. (M. Borsboom, Interviewer)

Van Kooten, J., & Adams, K. (2011). *Gebiedsgericht Benutten Plus, Handboek Verkeersmanagement.* CROW, kennisplatform voor infrastructuur, verkeer, vervoer en openbare ruimte. Ede: CROW.

Van Wee, P. (2010). "Hoe lossen we de files op?". *Technologie Debat 29 maart.* Den Haag: Technische Universiteit Delft.

Verhaar, P. (2012). *E-pier one-directional in AutoCAD.* Schiphol Group, Schiphol.

Weng, L. (2010). *Concept Design and Evaluation of Traffic Management in Beijing.* TU Delft, Faculty of Civil Engineering and Geosciences. Delft: ITS Edulab.

www.luchtverkeersleiding.nl. (2012). Retrieved Mei 24, 2012 from Luchtverkeersleiding: www.luchtverkeersleiding.nl

www.Schiphol.nl. (2012). Retrieved Mei 24, 2012 from Banenstelsel Schiphol Airport: http://www.schiphol.nl/InDeSamenleving/Junior/SchipholNu/Banenstelsel1.htm

www.Schiphol.nl. (2012). Retrieved Mei 24, 2012 from Afhandeling van Vliegtuigen: http://www.schiphol.nl/InDeSamenleving/Junior/SchipholNu/AfhandelingVanVliegtuigen.htm

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Appendix A Practical aspects

A.1 Assignment

As already discussed this research will focus on the traffic system on the airside at AAS. The question arises within the Schiphol Group what the current status of this traffic system is, for example how many incidents are occurring, what happens if an accident occurs regarding delays and inconvenience for the other road users, what is the capacity of the traffic system etcetera. The assignment is formulated as follows by the Schiphol Group;

“Research to the robustness of the traffic system on the airside

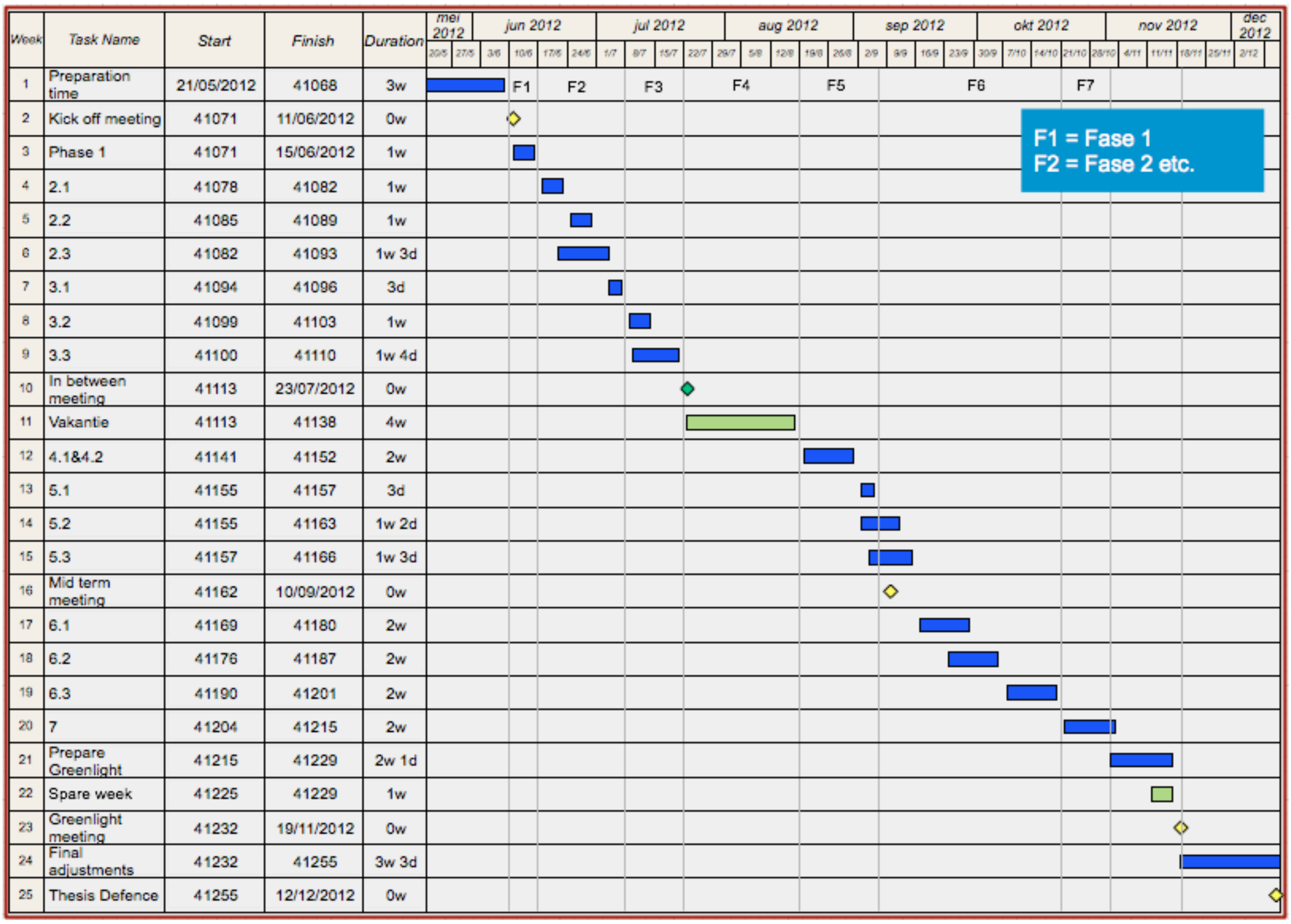
Since the opening of Schiphol centrum in 1967 there is also traffic system located at AAS. Roughly this system consists of the ‘Rinse Hofstraweg’ artery and subsequent hatching perimeter roads along the piers.

This traffic has the primary purpose of facilitating the ground handling traffic (aircraft tractors, baggage tractors, water trucks, tank trucks, catering trucks, etc.) to be able to make the flight operations possible. Basically the traffic to Airside did not experience many changes, but the air traffic has increased through the years. The question arises whether the current traffic system is still sufficiently robust, reliable and safe, in the review of:

1) The increase in air traffic,
2) The pressure to shorten throughput time of airplanes at the gate,
3) The extensions related to the future master plan,
4) More and more vehicles on airside will use other fuels than gasoline or diesel in the future.”

This formulated assignment resulted in the main research question and sub question, which are discussed in the first chapter of the report.

A.2 Gantt chart



Week	Task Name	Start	Finish	Duration
1	Preparation time	21/05/2012	41068	3w
2	Kick off meeting	41071	11/06/2012	0w
3	Phase 1	41071	15/06/2012	1w
4	2.1	41078	41082	1w
5	2.2	41085	41089	1w
6	2.3	41082	41093	1w 3d
7	3.1	41094	41096	3d
8	3.2	41099	41103	1w
9	3.3	41100	41110	1w 4d
10	In between meeting	41113	23/07/2012	0w
11	Vakantie	41113	41138	4w
12	4.1&4.2	41141	41152	2w
13	5.1	41155	41157	3d
14	5.2	41155	41163	1w 2d
15	5.3	41157	41166	1w 3d
16	Mid term meeting	41162	10/09/2012	0w
17	6.1	41169	41180	2w
18	6.2	41176	41187	2w
19	6.3	41190	41201	2w
20	7	41204	41215	2w
21	Prepare Greenlight	41215	41229	2w 1d
22	Spare week	41225	41229	1w
23	Greenlight meeting	41232	19/11/2012	0w
24	Final adjustments	41232	41255	3w 3d
25	Thesis Defence	41255	12/12/2012	0w

Figure A.1; Gantt chart Master Thesis M. Borsboom, executed at Amsterdam Airport Schiphol

A.3 Goal tree

Table A.2; Goal tree to indicate all planned activities and deliverables for this research at AAS

Goals	Sub goals	Activities	Deliverables
Phase 1:* Improve the traffic system (TS)** at the airside at AAS; ***SQ1	This improvement can be considered in terms of four main aspects: - Robustness - Reliable - Safe - Costs ***(Appendix B.1)*** ***Duration= 1 week***	Question if the definition for safety, robustness, reliability, and utilization is correct/ useful and if not, redefine robustness for this research Define if and how the four main aspects are related to each other	Definition safety, robustness, reliability and utilization. Interrelation between the four main aspects
***Phase 2*: Current situation of the TS** **SQ2**	2.1 Gather insight in the current situation ***(Appendix C)*** ***Duration= 1 week***	Indicate the definition and the (physical) boundaries of the traffic system	**Scope of the research (definition and boundaries of the TS)**
		Identify which companies and who exactly is using the system ***(Appendix C.2.4.2)***	**Stakeholder analysis**
	2.2 Gather insight in the current traffic flows ***Duration= 1 week***	Describe types of vehicles are used ***(Appendix C.2.4.3)***	Ext. stakeholder analysis
		Describe main important origins and destinations of different vehicles	TS analysis (1/3)
		Research how traffic flows are going through the TS	TS analysis (2/3)
		Research the amount of traffic flows through TS	TS analysis (3/3)
		Identify capacity of the TS (supply) ***(Appendix B2-B4)***	Capacity of the TS
		What is the demand of the TS (demand)	**Demand** of the TS
	2.3 Gather insight in the future developments of AAS ***Duration= 0,5 week***	Identify the future developments (masterplan) of AAS ***(Appendix D)***	Future changes at AAS (new masterplan)
		Identify the consequences of the future plans regarding the traffic flows in the traffic system at AAS.	Consequences of the new masterplan
Phase 3: **Frame of Reference (FoR) for the TS** **SQ3**	3.1 Identify the vision/ strategy of the Schiphol Group ***Duration= 0,5 week***	Formulate the vision/ strategy of the Schiphol Group in terms of this research	Vision/ strategy Schiphol Group (regarding traffic system)
	3.2 Literature study ***Duration= 0,5 week***	Searching for relevant literature to define the four main aspects more in detail/ depth	Literature for traffic flows and airport related topics
	3.3 Define (MCA) more in depth criteria/norms/standards to quantify different levels of the traffic system. ***Duration= 1,5 week***	More in depth criteria for the MCA/ the tool	More in depth criteria (besides the four main criteria)
		Conduct the right norms to be able to compare	Correct and relevant norms
		Search for standards to create a relevant frame of reference	Correct and relevant standards
		Gather data from other airports to conduct a more reliable framework	Useful data
		Compare acquired data to ADP (Paris/London). E.g. incidents (safety)	More reliable FoR + Complete the tool
Phase 4: **SQ4**	4.2 Identify main causes ***Duration= 1 week***	Identify for each bottleneck why and by what the bottleneck is caused	(main) Causes of the bottlenecks
Phase 5: **Improvement possibility scenarios** *Duration=* *2 weeks* **SQ5**	5.1 Know where improvement possibilitys for the bottlenecks can be found	Define improvement possibility space for these bottlenecks	Definition of the improvement possibility space
	5.2 Know in which direction in the defined area improvement possibilitys can be found	Define improvement possibility directions for these bottlenecks	Different improvement possibility(s) (directions)
	6.1 Translate scenarios into improvement possibilitys to be able to compare them ***Duration= 2 weeks***	Quantify the different scenarios in terms of improvement possibilitys aspects to get a realistic comparison	Different improvement possibilitys ready
Phase 6: **Testing the scenarios** **SQ6**	6.2 Compare different scenarios ***Duration= 2 weeks***	Compare of the different improvement possibilitys and analyse the outputs	Results for each scenario
	6.3 Evaluate the findings ***Duration= 1 week***	Evaluate the outcomes and draw conclusions from it	Comparison of scenarios
	Conclude the complete research and formulate recommendations	Formulate conclusions & recommendations	Conclusions & recommendations

Appendix B Context of the airside transportation system of AAS

B.1 The entrances and exits of the baggage halls / basements at the airside of AAS

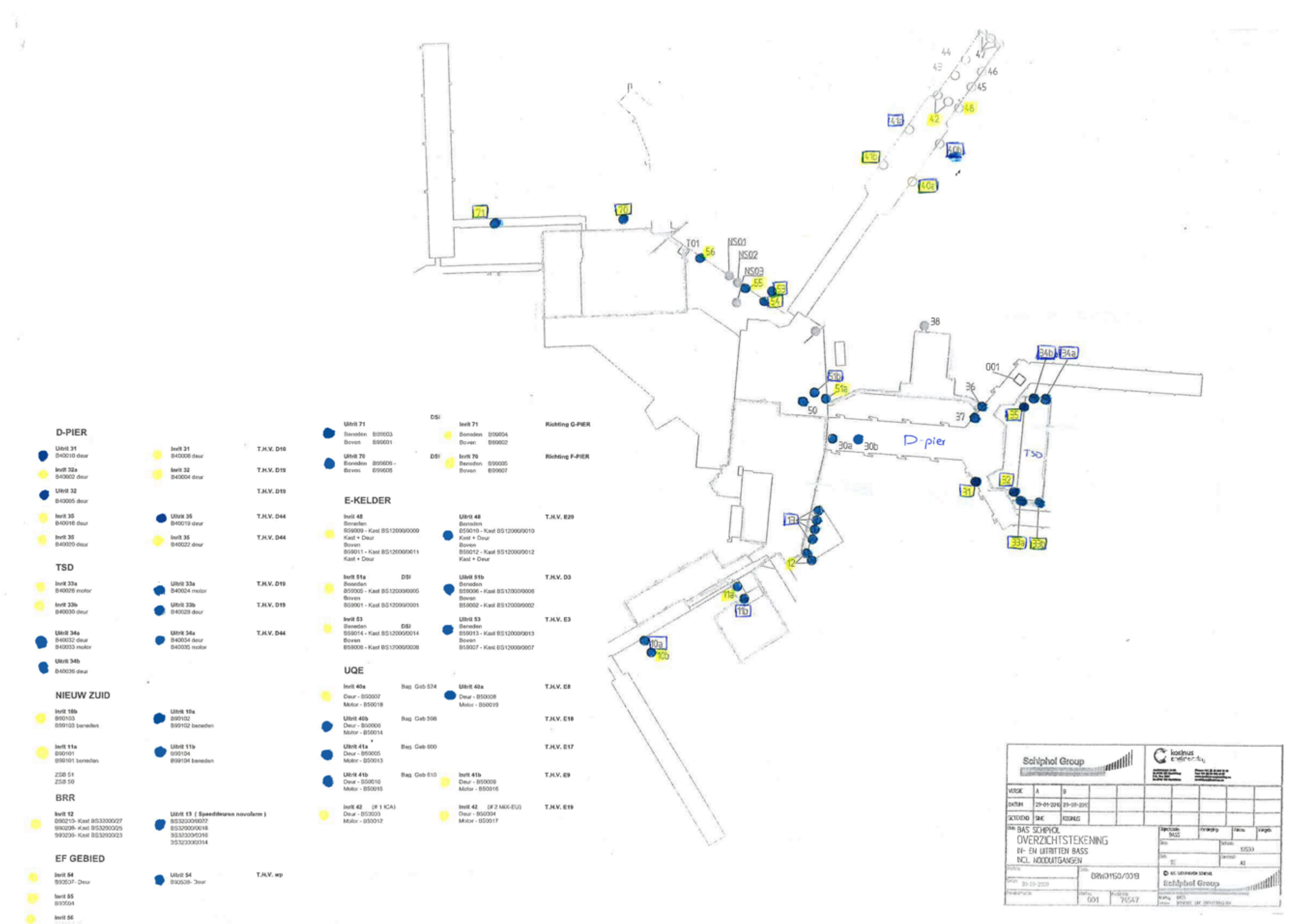


Figure B.3; Entrances and exits of the baggage halls/ basements at airside of AAS

B.2 Type of gate (narrow or wide body) per gate number at AAS

Table B.1; Different type of gates at AAS (WB=Widebody, NB=Narrowbody, aircraft stand='Vliegtuigopstelplaats')

Pier	Gatenumber	Type
A	A31-A35,A41,A43,A45,A46,A48,A49	NB gates
B	B13,B15,B17,B23,B27,B31,B35	NB gates
	B16,B20,B24,B28,B32,B36, B51-B56,B61-B66,B71-B76,B81-B85,B91-B95	NB gates
C	C4-C16,C18	NB gates
D	D2,D4(D62),D3,D7,D8(D64),D43(D73), D47,D49,D51(A+B),D53,D55,D57(A+B)	WB gates
	D5,D10,D12,D14,D16,D18,D21-D29,D31,D41 D44(D74),D46(D76),D48(D78),D50,D52(D82),D54(D84),D56(D86)	NB gates
	D88,D90,D92,D93,D94,D95	NB gates
E	E2-E9,E17-E20,E22,E24	WB gates
	E72,E75,E77	WB gates
F	F2-F9	WB gates
G	G3-G9	WB gates
	G2	NB gates

	G71-G80	WB gates
H	H1-H7	NB gates
J	J80-J87	
P	P1-P3,P10-P16	
R	R72,R74,R77,R80-R87	
S	S72,S74,S77,S79,S82-S85,S87-S94,S96	
Y	Y71-Y73	

B.3 The number and corresponding type of vehicles at airside

Table B.2; The number and corresponding type of vehicles at airside

Soort voertuig	#	%
Airco-unit	1	0%
Airstart-unit (jetstarter)	0	0%
Ambulance	0	0%
Bagage vehicles	20	2%
Van	124	12%
Container	6	1%
Containerdolly	29	3%
De-icingvehicle	3	0%
Dispenser	20	2%
GPU	3	0%
Lowerdeck-loader	5	0%
Maindeck-loader	12	1%
Motor vehicle	0	0%
Oil vehicle	1	0%
Other vehicles	96	9%
Pallet transporter	12	1%
Pallet van	29	3%
Passenger bus	91	9%
Passenger car	127	12%
Scissor vehicle (catering, cleaning service)	40	4%
Snow fleet vehicle	1	0%
Stairs (motorized or not)	26	3%
Fuelling truck	20	2%
Toiletservice-vehicle	13	1%
Transport conveyor	13	1%
Trucker (elektrical, disel)	237	23%
Push-back vehicle	13	1%
Push-back vehicle towbarloos	24	2%
Forklift	1	0%
Truck	52	5%
Waterservice-vehicle	5	0%
Totaal	**1024**	**100%**

Appendix C Safety analysis of the traffic system

C.1 Companies involvement in collisions 2005-June 2012

Table C.1; Companies involvement in collisions 2005-June 2012, both the amount and percentage

Companies involved in collisions 2005-June 2012	#	%
AAS/AMS	7	1%
AAS/OPS/AO/AA	12	1%
AERO Groundservices	7	1%
Aiport Cargo B.V.	1	0%
ASITO Aviation B.V.	11	1%
Aviapartner	28	3%
British Midland	0	0%
China Airlines	0	0%
Combined Refuelling Service (CRS)	6	1%
Connexxion N.V.	1	0%
CSU Airport Services	2	0%
Falck Airport Security	1	0%
Gansewinkel B.V.	7	1%
Gate Gourmet Amsterdam B.V.	9	1%
Gezamelijke Tankdienst Schiphol B.V. (GTS)	8	1%
HTM Specials B.V.	54	6%
ICTS-NAS B.V.	1	0%
Intergom uitzendbureau	0	0%
KLM	229	25%
KLM Catering Services Schiphol B.V. (SPL/HZ)	20	2%
KLM Equipment Services B.V. (KES - SPL/TN)	19	2%
KLUH Service Management Nederland B.V.	16	2%
Kmar (Koninklijke Marechausse)	10	1%
Lavos B.V.	13	1%
Malaysia Airlines	0	0%
Martinair Holland N.V.	18	2%
Menzies Aviation (LCC)	32	3%
Menzies World Cargo B.V.	11	1%
MET & CO B.V.	2	0%
Nayak Netherlands B.V.	8	1%
NBG (Nederlandse Beveiligingsgroep)	2	0%
North West Airlines	0	0%
Olympic Airways	0	0%
Overige	346	37%
Pro-Check International B.V.	1	0%
RMM Truck Cleaning	1	0%
Santifort Aircraft Maintenance (SAM)	0	0%
Servisair Amsterdam BV	34	4%
TCR Nederland B.V.	12	1%
Transavia Airlines	2	0%
Turkish Airlines	1	0%
Total	**932**	**100%**

C.2 Top 5 causes with corresponding percentage of the total top 5 causes

Table C.2; Top 5 causes with corresponding percentage of the total top 5 causes

Oorzaaksoort	#	%
Bedienen installatie / apparatuur (verkeerd, onbevoegd)	23	2%
Bedrijfsmiddelen en materieel (onderhoud, defect)	91	9%
Kennis en gedrag	386	36%
Overig / Niet bekend	208	20%

Verkeersveiligheid	348	33%
Weersinvloeden	5	0%
Totaal	**1061**	**100%**

C.3 Type of causes with corresponding percentages of the total amount of causes

Table C.3; Type of causes with corresponding percentages of the total amount of causes

Oorzaaktype	#	%
Afgevallen lading	10	1%
Communicatie	4	0%
Geen voorrang verlenen	140	13%
Fout in bedieningsinstructie	0	0%
Menselijk falen	288	27%
Gebrek infrastructuur AAS	5	0%
Gladheid	2	0%
Kop-staart botsing	61	6%
Nalatig gedrag / ongemotiveerd	47	4%
Onbevoegd bedienen	0	0%
Onvoldoende instructie / opleiding	5	0%
Onvoldoende onderhoud bedrijfsmiddelen AAS	2	0%
Onvoldoende onderhoud materieel	6	1%
Onvoldoende onderhoud voertuig	4	0%
Overig / Niet bekend	208	20%
Regelgeving veiligheid niet gevolgd	31	3%
Slingerend voertuig	21	2%
Technisch defect materieel	38	4%
Technisch defect voertuig	35	3%
Tegen geparkeerd/stilstaand voertuig	116	11%
Tijdsdruk	11	1%
Verkeerd bedienen	23	2%
Wind	1	0%
Totaal	**1058**	**100%**

C.4 Number of collisions per pier

Table C.4; Number of collisions per type per problem area in 2005

Problem areas in 2005	Unilateral & other collisions									Collisions between vehicles								
	2005	2006	2007	2008	2009	2010	2011	2012	Total	2005	2006	2007	2008	2009	2010	2011	2012	Total
B-pier	11	10	7	7	11	6	4	2	58	20	32	22	21	23	15	20	4	157
C-pier	7	5	3	6	2	7	2	2	34	17	30	11	10	9	5	8	3	93
D-pier	21	13	19	14	12	7	7	2	95	33	26	26	28	21	22	12	4	172
E-pier	4	6	6	2	2	3	7	1	31	11	15	19	22	8	8	8	5	96
F-pier	4	4	5	6	0	4	1	0	24	9	8	9	11	5	4	6	4	56
Total	**47**	**38**	**40**	**35**	**27**	**27**	**21**	**7**	**242**	**90**	**111**	**87**	**92**	**66**	**54**	**54**	**20**	**574**

Appendix D Travel time reliability analysis of the traffic system

D.1 Measurement plan 'Reliability at airside'

Research question: How reliable is the travel time on airside of AAS and will provide the relative new viaducts a realistic alternative regarding travel times?

Sub-questions

- How reliable is the travel time on airside and if a deviation occurs, how large will this deviation be and what is the norm set to be reliable or not?

- Does the viaducts offer a realistic alternative for the traffic originating from Schiphol East/ the 'Kaagbaantunnel' or the Cargo Platform R?

    - Is there a (large) difference in travel time using the viaducts or not, when the same destination is taken?
    - When are the viaducts a realistic route? What is the set norm for his?
    - How does the actual users assess the current and future situation?

What should be happen now

- Measuring travel times starting from the 'DSL', since almost all cargo vehicles using it (custom control) and here also the buses are stationed, which again is positioned within the top of most incidents causers. The destination can vary: for example, F / G and D-pier pier.
- Measuring track disturbance during the measurement and after every ride note special activities or incidents.
- Measuring the standard determines whether the 'viaducts route' is a worthy alternative when the maximum of 20% of the average travel time on top of the travel time is not exceeded (Snelder, Immers, & Wilmink, 2004); if the average 'normal-route along the B-platform' time is 10 minutes, the viaduct will be a worthy alternative if the average travel time of the 'viaducts-route' does not exceed 12 minutes.

- Process the measurements outcomes:

    - Take the quickest time as 'shortest travel time possible'.
    - Take averages of: measured travel times, deviations of the 'shortest travel time possible' and make use of: average travel times and deviations of the travel times.
    - Compare outcomes with the norms, which will results in reliable travel times, or not, and will determine the average deviation will be.
    - Compare the measurements of the 'viaducts route' with the 'normal route along the B-platform' and draw conclusions and answer the research question.

Measurement (research) restrictions

- The maximum speed of 30 km/h should always be tried to reach if the traffic situation allows this, because of the consistency of the measurements.
- The measured travel times will be noted within the logbook.

Way of performing the measurements

- The beginning of all measurements is located at the 'DSL', and destination will vary from D-, E- and F-piers.
- Every route will be driven as many times as possible between 09.30-15.00h.
- The measurements will be performed with the same stopwatch.

D.2 Data gathered from the travel time measurements on the airside of AAS

Table D.1; Log of travel time measurements on the airside of AAS on Monday 10-09-2012

Trip nr.	Start location	End location	Viaduct?	Start time (h)	Duration (min)
	DSL	E-pier	N	9:34	5.80
	E-pier	DSL	Y	9:44	8.47
	DSL	D-pier	Y	9:55	11.58
	D-pier	DSL	N	10:10	6.75
	DSL	F-pier	N	10:19	5.27
	F-pier	DSL	Y	10:27	5.77
	DSL	E-pier	Y	10:55	8.05
	E-pier	DSL	N	11:06	5.95
	DSL	D-pier	N	11:13	5.77
	D-pier	DSL	Y	11:21	9.97
	DSL	F-pier	Y	11:32	5.85
	F-pier	DSL	N	11:40	5.23
B.1	DSL	E-pier	N	13:21	5.23
B.2	E-pier	DSL	Y	13:28	7.35
B.3	DSL	D-pier	Y	13:36	9.03
B.4	D-pier	DSL	N	13:48	7.20
B.5	DSL	F-pier	N	13:57	5.43
B.6	F-pier	DSL	Y	14:06	6.07
B.7	DSL	E-pier	Y	14:13	7.58
B.8	E-pier	DSL	N	14:23	5.43
B.9	DSL	D-pier	N	14:30	5.28
B.10	D-pier	DSL	Y	14:37	8.30
B.11	DSL	F-pier	Y	14:53	5.90
B.12	F-pier	DSL	N	14:58	5.77

Table D.2; Log of travel time measurements on the airside of AAS on Wednesday 12-09-2012

Trip nr.	Start location	End location	Viaduct?	Start time (h)	Duration (min)
A.1	DSL	E-pier	N	8:41	5:55
A.2	E-pier	DSL	Y	8:47	6:53
A.3	DSL	D-pier	Y	8:56	8:12
A.4	D-pier	DSL	N	9:05	5:52
A.5	DSL	F-pier	N	9:12	7:00
A.6	F-pier	DSL	Y	9:20	5:40
A.7	DSL	E-pier	Y	10:51	7:13
A.8	E-pier	DSL	N	10:59	5:35
A.9	DSL	D-pier	N	11:06	5:51
A.10	D-pier	DSL	Y	11:12	8:08
A.11	DSL	F-pier	Y	11:21	5:45
A.12	F-pier	DSL	N	11:28	5:40
B.1	DSL	E-pier	N	12:11	5:50
B.2	E-pier	DSL	Y	12:17	7:26
B.3	DSL	D-pier	Y	12:25	8:10
B.4	D-pier	DSL	N	12:34	5:40
B.5	DSL	F-pier	N	12:40	4:57
B.6	F-pier	DSL	Y	12:46	5:45
B.7	DSL	E-pier	Y	13:09	7:16
B.8	E-pier	DSL	N	13:17	6:15
B.9	DSL	D-pier	N	13:25	6:00
B.10	D-pier	DSL	Y	13:32	9:03
B.11	DSL	F-pier	Y	13:52	6:04
B.12	F-pier	DSL	N	13:59	5:11
C.1	DSL	E-pier	N	14:08	5:18
C.2	E-pier	DSL	Y	14:14	6:23
C.3	DSL	D-pier	Y	14:31	7:47
C.4	D-pier	DSL	N	14:40	5:43
C.5	DSL	F-pier	N	14:48	5:10
C.6	F-pier	DSL	Y	14:53	5:44
C.7	DSL	E-pier	Y	15:00	7:24
C.8	E-pier	DSL	N	15:08	9:07
C.9	DSL	D-pier	N	15:18	5:15
C.10	D-pier	DSL	Y	15:24	7:55
C.11	DSL	F-pier	Y	15:33	5:50
C.12	F-pier	DSL	N	15:52	6:26

Table D.3; Log of travel time measurements on the airside of AAS on Friday 14-09-2012

Trip nr.	Start location	End location	Viaduct?	Start time (h)	Duration (min)
A.1	DSL	E-pier	N	9:36	5.78
A.2	E-pier	DSL	Y	9:44	7.78
A.3	DSL	D-pier	Y	9:52	8.30
A.4	D-pier	DSL	N	10:01	5.73
A.5	DSL	F-pier	N	10:09	6.60
A.6	F-pier	DSL	Y	10:17	6.68
A.7	DSL	E-pier	Y	10:24	7.12
A.8	E-pier	DSL	N	10:33	5.52
A.9	DSL	D-pier	N	10:39	5.25
A.10	D-pier	DSL	Y	10:44	8.98
A.11	DSL	F-pier	Y	10:54	5.83
A.12	F-pier	DSL	N	11:01	6.28
B.1	DSL	E-pier	N	11:12	5.33
B.2	E-pier	DSL	Y	11:26	7.08
B.3	DSL	D-pier	Y	11:34	8.00
B.4	D-pier	DSL	N	11:42	6.75
B.5	DSL	F-pier	N	11:51	5.73
B.6	F-pier	DSL	Y	11:58	5.98
B.7	DSL	E-pier	Y	12:19	7.33
B.8	E-pier	DSL	N	12:27	5.37
B.9	DSL	D-pier	N	12:32	5.13
B.10	D-pier	DSL	Y	12:38	7.77
B.11	DSL	F-pier	Y	12:50	5.72
B.12	F-pier	DSL	N	12:57	6.07
C.1	DSL	E-pier	N	13:17	5.10
C.2	E-pier	DSL	Y	14:16	6.55
C.3	DSL	D-pier	Y	14:23	7.62
C.4	D-pier	DSL	N	14:31	4.85
C.5	DSL	F-pier	N	14:37	5.82
C.6	F-pier	DSL	Y	14:44	5.72
C.7	DSL	E-pier	Y	14:50	7.00
C.8	E-pier	DSL	N	14:58	5.75
C.9	DSL	D-pier	N	15:12	5.42
C.10	D-pier	DSL	Y	15:18	8.07
C.11	DSL	F-pier	Y	15:26	5.47
C.12	F-pier	DSL	N	15:32	6.85

Table D.4; Log of travel time measurements on the airside of AAS on Tuesday 18-09-2012

Trip nr.	Start location	End location	Viaduct?	Start time (h)	Duration (min)
	DSL	E-pier	N	9:37	5.50
	E-pier	DSL	Y	9:43	6.90
	DSL	D-pier	Y	9:51	9.97
	D-pier	DSL	N	10:01	5.48
	DSL	F-pier	N	10:07	5.22
	F-pier	DSL	Y	10:13	5.62
	DSL	E-pier	Y	10:20	6.92
	E-pier	DSL	N	10:28	6.05
	DSL	D-pier	N	10:35	5.78
	D-pier	DSL	Y	10:41	7.72
	DSL	F-pier	Y	10:49	5.33
	F-pier	DSL	N	10:55	5.30
B.1	DSL	E-pier	N	12:20	6.87
B.2	E-pier	DSL	Y	12:26	6.48
B.3	DSL	D-pier	Y	12:36	8.62
B.4	D-pier	DSL	N	12:45	5.88
B.5	DSL	F-pier	N	12:51	5.98
B.6	F-pier	DSL	Y	12:57	5.52
B.7	DSL	E-pier	Y	13:18	7.80
B.8	E-pier	DSL	N	13:28	5.32
B.9	DSL	D-pier	N	13:33	6.17
B.10	D-pier	DSL	Y	13:40	8.20
B.11	DSL	F-pier	Y	13:48	5.55
B.12	F-pier	DSL	N	13:55	5.58
	DSL	E-pier	N	14:13	5.62
	E-pier	DSL	Y	14:18	7.32
	DSL	D-pier	Y	14:26	7.67
	D-pier	DSL	N	14:34	5.67
	DSL	F-pier	N	14:42	5.22
	F-pier	DSL	Y	14:48	5.03
	DSL	E-pier	Y	14:53	6.83
	E-pier	DSL	N	15:01	6.25
	DSL	D-pier	N	15:15	5.27
	D-pier	DSL	Y	15:21	7.30
	DSL	F-pier	Y	15:33	4.97
	F-pier	DSL	N	15:39	5.17

Table D.5; Log of travel time measurements on the airside of AAS on Thursday 20-09-2012

Trip nr.	Start location	End location	Viaduct?	Start time	Duration
A.1	DSL	E-pier	N	9:35	5.70
A.2	E-pier	DSL	Y	9:42	7.02
A.3	DSL	D-pier	Y	10:06	7.68
A.4	D-pier	DSL	N	10:15	5.85
A.5	DSL	F-pier	N	10:37	5.52
A.6	F-pier	DSL	Y	10:43	5.93
A.7	DSL	E-pier	Y	10:49	7.00
A.8	E-pier	DSL	N	10:57	5.62
A.9	DSL	D-pier	N	10:21	5.98
A.10	D-pier	DSL	Y	10:28	7.58
A.11	DSL	F-pier	Y	9:49	5.52
A.12	F-pier	DSL	N	9:56	6.17
B.1	DSL	E-pier	N	11:19	4.97
B.2	E-pier	DSL	Y	11:25	6.52
B.3	DSL	D-pier	Y	11:32	8.87
B.4	D-pier	DSL	N	11:42	5.27
B.5	DSL	F-pier	N	11:47	6.88
B.6	F-pier	DSL	Y	11:54	5.65
B.7	DSL	E-pier	Y	12:01	6.80
B.8	E-pier	DSL	N	12:09	5.75
B.9	DSL	D-pier	N	12:28	5.52
B.10	D-pier	DSL	Y	12:33	7.60
B.11	DSL	F-pier	Y	12:41	5.72
B.12	F-pier	DSL	N	12:48	6.25
C.1	DSL	E-pier	N	13:21	5.35
C.2	E-pier	DSL	Y	13:26	6.82
C.3	DSL	D-pier	Y	13:34	8.02
C.4	D-pier	DSL	N	13:55	5.32
C.5	DSL	F-pier	N	14:04	5.15
C.6	F-pier	DSL	Y	14:10	5.83
C.7	DSL	E-pier	Y	14:17	7.03
C.8	E-pier	DSL	N	14:25	5.68
C.9	DSL	D-pier	N	14:30	6.75
C.10	D-pier	DSL	Y	14:38	8.13
C.11	DSL	F-pier	Y	14:46	5.72
C.12	F-pier	DSL	N	14:53	5.92

Appendix E Utilization analysis of the traffic system

E.1 Sensitivity analysis regarding road capacity

First the sensitivity analysis will be discussed, with displaying both the consequences for the traffic system with the current amount of traffic volume and the future (extrapolated) traffic volume. After this analysis, the deceleration sensitivity will be discussed.

Sensitivity of design speed and response time on road capacity

Within this sensitivity analysis four different scenarios are used to analyse the influence of the different parameters. The following parameters are given by literature: deceleration speed of -7m/s², reaction time of 1 s. (Lamm et al., 1999) and car length of 10 m. (De Jong, 2004). The other two parameters, design speed and response time, are adjusted to see their effects and so the influences. Table E.1 illustrates the four different options of changing these parameters. It is decided to vary in design speed with 30 and 15 km/h, respectively the allowed maximum speed and the individual maximum speed (for a few vehicles on airside). The response time is varied between 0.50 s., used in the research of De Jong (2004), and 1.00 s., the generally accepted value researched by Lamm et al. (1999).

Table E.1; The square diagram with the adjusted parameters and their two-level values

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Design speed (km/h)	30	15	30	15
Response time (s.)	0.50	0.50	1.00	1.00

Table E.2 below displays the different parameter values of the four different scenarios. The values in the first scenario are close to the analysis of De Jong (2004). In scenario 2 only the design speed is adjusted from 30.00 to 15.00 km/h, resulting in a decreased capacity of 443 pae/h/lane. Scenario 3 uses the original design speed of 30 km/h again, but now the response time adjusted to 1.00 s. The capacity is decreased with 281 pae/h/lane, which implicates the influence of design speed on the capacity is relatively larger than the influence of the response time. In the final scenario both the design speed and response time are adjusted to 15.00 km/h and 1.00 s. respectively, resulting in a decreased capacity compared to the first scenario with 595 pae/h/lane. A remark with these calculations is the fact that the summed up amount of decreased capacity is larger than the decreased capacity when both values are adjusted at the same time.

Table E.2; Four different scenarios to test the influence of the parameters

Parameters	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Design speed (km/h)	30.00	15.00	30.00	15.00
Design speed (m/s)	8.33	4.17	8.33	4.17
Deceleration (m/s²)	(7.00)	(7.00)	(7.00)	(7.00)
Response time (s)	0.50	0.50	1.00	1.00
Braking distance (m)	9.13	3.32	13.29	5.41
Vehicle length (m)	10.00	10.00	10.00	10.00
Time between 2 vehicles (s)	2.30	3.20	2.80	3.70
Capacity (pae/h) one lane road	**1,568.46**	**1,125.84**	**1,287.90**	**973.60**

The capacity is determined as explain in chapter 6. The four different scenarios in the sensitivity analysis all have their own related capacity, all displayed in table E.3.

Table E.3; Capacity of the four different scenarios of the sensitivity analysis in pae/h/lane

Amount of traffic volume	Capacity pae/h/lane
Scenario 1	1,568.46
Scenario 2	1,125.84
Scenario 3	1,287.90
Scenario 4	973.60

Now the parameters and capacities are known, the consequences on the traffic system could be researched. When these four scenarios are assessed, by comparing these road capacities to the traffic volumes, table E.4, E.5 and E.6 can be found. Taking into account the congestion levels of these I/C ratios (Ministerie van Verkeer en Waterstaat, 2004), it can be seen that all traffic flows will be handled well and without congestion, besides the table of scenario 4. Because this scenario will be closest to reality, this scenario will be used in this research and will be discussed in detail in chapter 6.3. Both the traffic volumes of the current situation (table E.4, E.5 and E.6) as in the future situation (extrapolated) will be displayed (table E.7, E.8 and E.9). The colours are corresponding with the legend in chapter 6.

Current situation

Table E.4; Measured traffic intensities per hour and the I/C-ratio of location 1: beginning of the E-pier on 19-09-2012 (De Jong, 2004).

Amount of traffic volume	Location 1: E-pier	I/C			
	Intensity	Sc.1	Sc.2	Sc.3	Sc.4
10.30-11:30	810	0.52	0.72	0.63	0.83
11:30-12:30	922	0.59	0.82	0.72	0.95
12:30-13:30	923	0.59	0.82	0.72	0.95
13.30-14:30	843	0.54	0.75	0.65	0.87
14:30-15:30	695	0.44	0.62	0.54	0.71
15:30-16:30	685	0.44	0.61	0.53	0.70
16:30-17:00	322	0.21	0.29	0.25	0.33
Total	**5,200**				

Table E.5; Measured traffic intensities per hour and the I/C-ratio of location 2: 'ACC-building' on 19-09-2012 (De Jong, 2004) .

Amount of traffic volume	Location 2: ACC-building	I/C			
	Intensity	Sc.1	Sc.2	Sc.3	Sc.4
10.30-11:30	557	0.36	0.49	0.43	0.57
11:30-12:30	751	0.48	0.67	0.58	0.77
12:30-13:30	551	0.35	0.49	0.43	0.57
13.30-14:30	672	0.43	0.60	0.52	0.69
14:30-15:30	561	0.36	0.50	0.44	0.58
15:30-16:30	683	0.44	0.61	0.53	0.70
16:30-17:00	261	0.33		0.20	0.27
Total	**4,036**				

Table E.6; Measured traffic intensities per hour and the I/C-ratio of location 3: roundabout on 19-09-2012 (De Jong, 2004).

Amount of traffic volume	Location 3: roundabout DSL	I/C			
	Intensity	Sc.1	Sc.2	Sc.3	Sc.4
10.30-11:30	303	0.19	0.27	0.24	0.31
11:30-12:30	292	0.19	0.26	0.23	0.30
12:30-13:30	321	0.20	0.29	0.25	0.33
13.30-14:30	318	0.20	0.28	0.25	0.33
14:30-15:30	260	0.17	0.23	0.20	0.27
15:30-16:30	215	0.14	0.19	0.17	0.22
16:30-17:00	121	0.15	0.21	0.09	0.12
Total	**1,830**				

Future situation

Table E.7; Future traffic intensities per hour and the I/C-ratio of location 1: beginning of the E-pier on 19-09-2012 (De Jong, 2004).

Amount of future traffic volume	Location 1: E-pier		I/C		
	Intensity	Sc.1	Sc.2	Sc.3	Sc.4
10.30-11:30	924	0.59	0.82	0.72	0.95
11:30-12:30	1052	0.67	0.93	0.82	1.08
12:30-13:30	1053	0.67	0.94	0.82	1.08
13.30-14:30	962	0.61	0.85	0.75	0.99
14:30-15:30	793	0.51	0.70	0.62	0.81
15:30-16:30	781	0.50	0.69	0.61	0.80
16:30-17:00	367	0.23	0.33	0.28	0.38
Total	**5,932**				

Table E.8; Future traffic intensities per hour and the I/C-ratio of location 2: 'ACC-building' on 19-09-2012 (De Jong, 2004) .

Amount of future traffic volume	Location 2: ACC-building		I/C		
	Intensity	Sc.1	Sc.2	Sc.3	Sc.4
10.30-11:30	924	0.41	0.56	0.49	0.65
11:30-12:30	1052	0.55	0.76	0.67	0.88
12:30-13:30	1053	0.40	0.56	0.49	0.65
13.30-14:30	962	0.49	0.68	0.59	0.79
14:30-15:30	793	0.41	0.57	0.50	0.66
15:30-16:30	781	0.50	0.69	0.60	0.80
16:30-17:00	367	0.38	0.53	0.46	0.61
Total	**4,604**				

Table E.9; Future traffic intensities per hour and the I/C-ratio of location 3: roundabout on 19-09-2012 (De Jong, 2004).

Amount of future traffic volume	Location 3: roundabout DSL		I/C		
	Intensity	Sc.1	Sc.2	Sc.3	Sc.4
10.30-11:30	924	0.22	0.31	0.27	0.36
11:30-12:30	1052	0.21	0.30	0.26	0.34
12:30-13:30	1053	0.23	0.33	0.28	0.38
13.30-14:30	962	0.23	0.32	0.28	0.37
14:30-15:30	793	0.19	0.26	0.23	0.31
15:30-16:30	781	0.16	0.22	0.19	0.25
16:30-17:00	367	0.18	0.25	0.21	0.28
Total	**2,088**				

Sensitivity of the deceleration on road capacity

For this quick analysis, deceleration values of 5.2 and 7 m/s² are used. Figure E.1 and E.2 display the differences in capacity with a deceleration of 5.2 m/s² (minimum as is set by law) and a deceleration of 7 m/s² (assumed to be a normal deceleration value). The reaction time (0.5s.) and the distance between vehicles (10m.) are kept constant. It can be seen in both figures that the maximum capacity of a single lane increases when a higher deceleration value is used. Also the fact that the graph shifts (to the right) towards higher driving speeds. Nowadays, a deceleration of 7 m/s² is used as generally accepted.

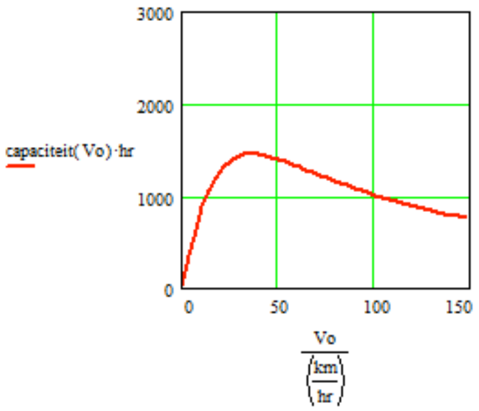


Figure E.1; The capacity of a single lane with a deceleration of 5.2 m/s²

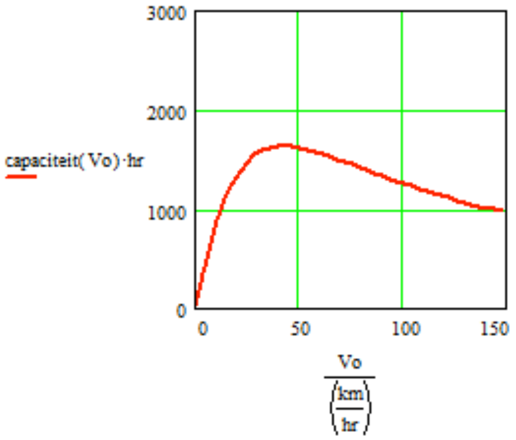
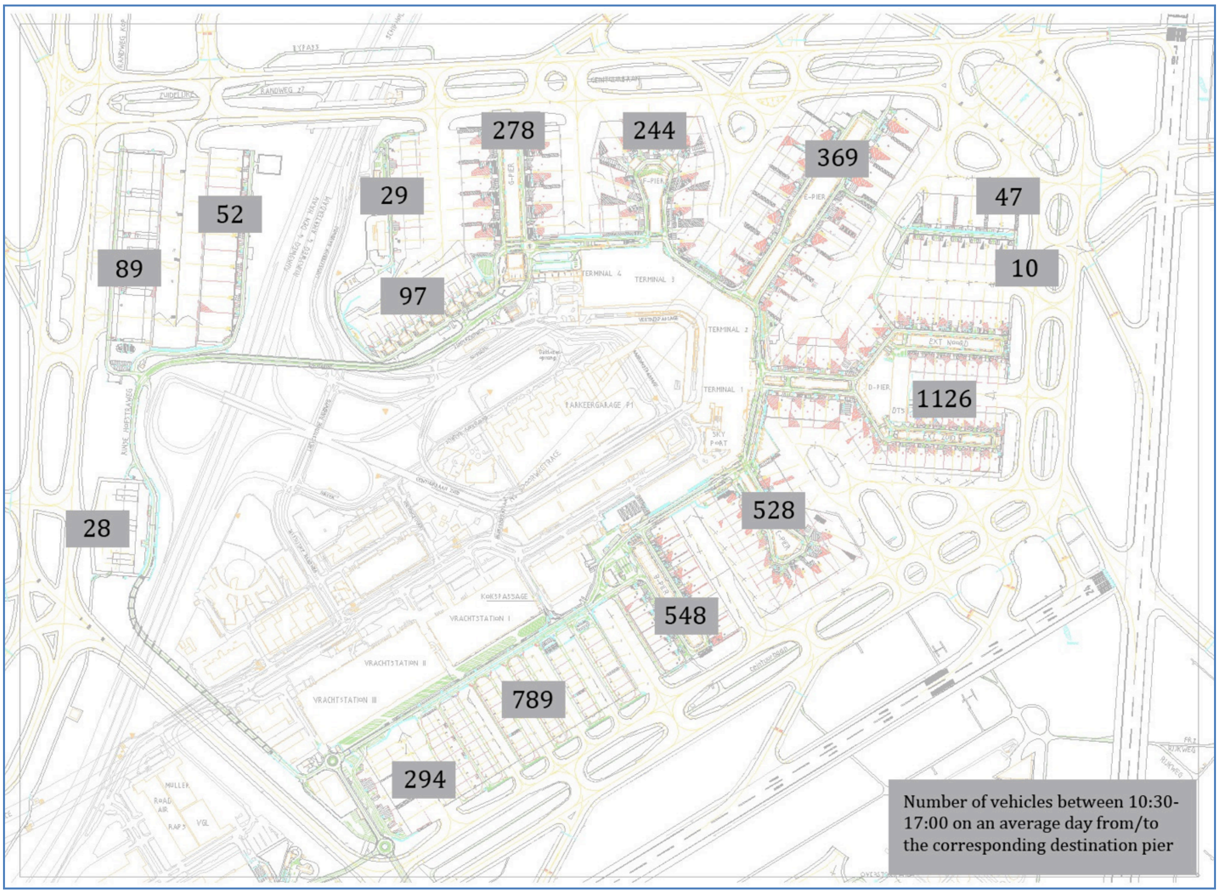


Figure E.2; The capacity of a single lane with a deceleration of 5.2 m/s²

E.2 Theoretical traffic intensity measurements (2011 and 2018)

Table E.30; Theoretical traffic intensity measurements by theoretical calculating the generated traffic per plane, times the average number of planes per day (2012)

Direction flows	2011 (movements 420249)	2018 (movements 479431)
A-buffer	294	335
B-buffer	789	900
B-pier	548	625
C-pier	528	602
D-pier	1126	1285
D-buffer	10	11
E-pier	369	421
F-pier	244	278
G-pier	278	317
G-buffer	29	33
H-pier	97	111
J-buffer	89	102
P-buffer	52	59
Y-buffer	28	32
Total	**4528**	**5166**

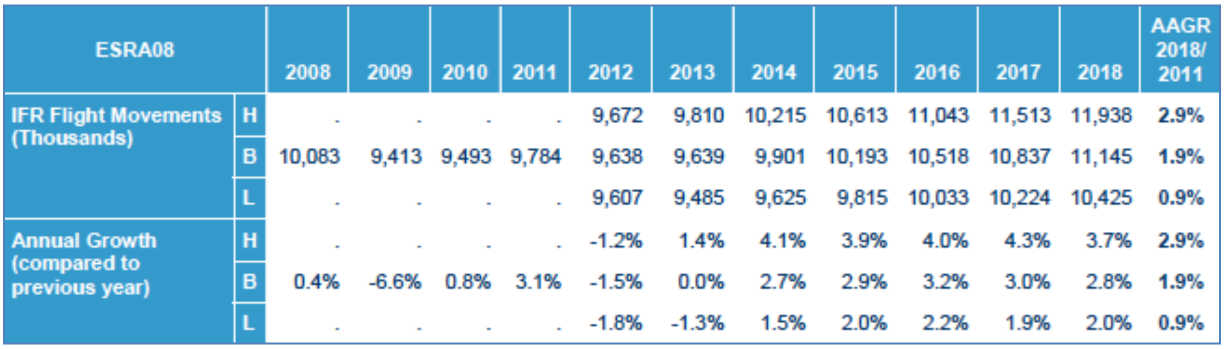


Number of vehicles between 10:30-17:00 on an average day from/to the corresponding destination pier

Figure E.3;Theoretical traffic intensities, calculated by the generation traffic per handled plane

E.3 Eurocontrol medium-term prediction 2012-2018

The air traffic flight movements predicted by Eurocontrol for the medium-term period of 2012-2018 can be seen in figure E.4 (Eurocontrol, September 2012).



ESRA08		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	AAGR 2018/ 2011
IFR Flight Movements (Thousands)	H	.	.	.	.	9,672	9,810	10,215	10,613	11,043	11,513	11,938	**2.9%**
	B	10,083	9,413	9,493	9,784	9,638	9,639	9,901	10,193	10,518	10,837	11,145	**1.9%**
	L	.	.	.	.	9,607	9,485	9,625	9,815	10,033	10,224	10,425	**0.9%**
Annual Growth (compared to previous year)	H	.	.	.	.	-1.2%	1.4%	4.1%	3.9%	4.0%	4.3%	3.7%	**2.9%**
	B	0.4%	-6.6%	0.8%	3.1%	-1.5%	0.0%	2.7%	2.9%	3.2%	3.0%	2.8%	**1.9%**
	L	.	.	.	.	-1.8%	-1.3%	1.5%	2.0%	2.2%	1.9%	2.0%	**0.9%**

Figure E.4; The flight movements and annual growth prediction for the period 2012-2018 (Eurocontrol, September 2012)

E.4 Actual traffic intensity measurements extrapolated (2011 and 2018)

Table E.11; Current (2012) and predicted (2018) traffic intensity, using a growth prediction of 1.14% per year (Eurocontrol, September 2012), with origins and destinations at airside of AAS

Traffic intensity measurements (2012)	Direction flows	2011 (movements: 420249)	2018 (movements: 479431)
Traffic intensity E-pier	To F	1847	2107
	From F	1536	1752
	To D	1681	1918
	From D	2047	2335
	To E-even	800	913
	From E-even	558	637
	To E-odd	427	487
	From E-odd	704	803
	To baggage	445	508
	From baggage	355	405
Traffic intensity C-pier	To D	1672	1907
	From D	1824	2081
	To B	1805	2059
	From B	1832	2090
	To C	566	646
	From C	297	339
Traffic intensity roundabout	To viaduct	192	219
	From viaduct	239	273
	To RH	731	834
	From RH	663	756
	To Tunnel	627	715
	From tunnel	586	669

Appendix F Improvement possibilitys

F.1 Not applicable improvement possibilitys

Eliminated improvement possibilitys, which are not applicable for the AAS region, partly resulting out of the GGB+ methodology (Kooten & Adams, August 2011), including the reason(s) why not applicable;

- Divide traffic flows by construct bicycle lanes: not space
- Junctions on different levels of height: terminals have to be reconstructed and costs
- Dynamic (maximum) speed: creates too much disturbances within the already busy system
- Dynamic road signs: creates too much disturbances within the already busy system
- Ramp metering: VRI systems are avoided for a long time if not necessary
- Flexible unravelling: creates too much disturbances within the already busy system
- Homogenise traffic flow: different equipment is needed to handle planes
- Optimise the VRI settings: only one VRI system is present; no interconnection possible
- Use supporting roads to for example spread the traffic: destinations are fixed and the radial structure at airside prevents this improvement possibility
- Create equal driving speeds on all types of road: already applied
- Create flexible turning sections on the road: no space
- Reduce the number of junctions and/or limit the connecting roads: the number of roads is already minimum because of the small amount of available space.

F.2 Calculations of the consequences of improvement possibility 5

F.2.1 Estimation of number of planes E2 and E4 (improvement possibility 5)

The gate planning of two days (24 hours) is analyses to get more insight in the number of arriving and leaving planes on VOP E2 and E4. An overview is provided in table F.1, which results in an average of 4.5 planes per VOP per 24 hours.

Table F.1; The researched number of planes handled per 12 hour-day on stands E2 and E4

	E2	E4	Total (E2+E4)
19-09-2012	4	5	9
27-09-2012	5	4	9
Total	9	9	18
Average per dag	4.5	4.5	9

F.2.2 Calculation improvement possibility 5

The advantages and disadvantages of improvement possibility 5 are measured by time measurements. To measure the travel time that will be lost due to the new one-direction situation at the beginning of the E-pier, the travel time of two routes is measured. Both the ‘old situation route’ as the ‘new situation route’ has been driven for 3 times, which is displayed in figure F.1. Of these three measurements per route the average travel time will be taken. The ‘old situation route’ starts at VOP E02 and ends at VOP E03, using the RH-road. The ‘one-direction situation route’ also starts at VOP E02 and ends at VOP E03, but now passing E04 first, passing the terminal underneath, passing E05 and also ends in E03; because of the created one-direction situation, users cannot make use of the turning right lane from the RH-road, directly towards E03. Figure displays these two different routes.

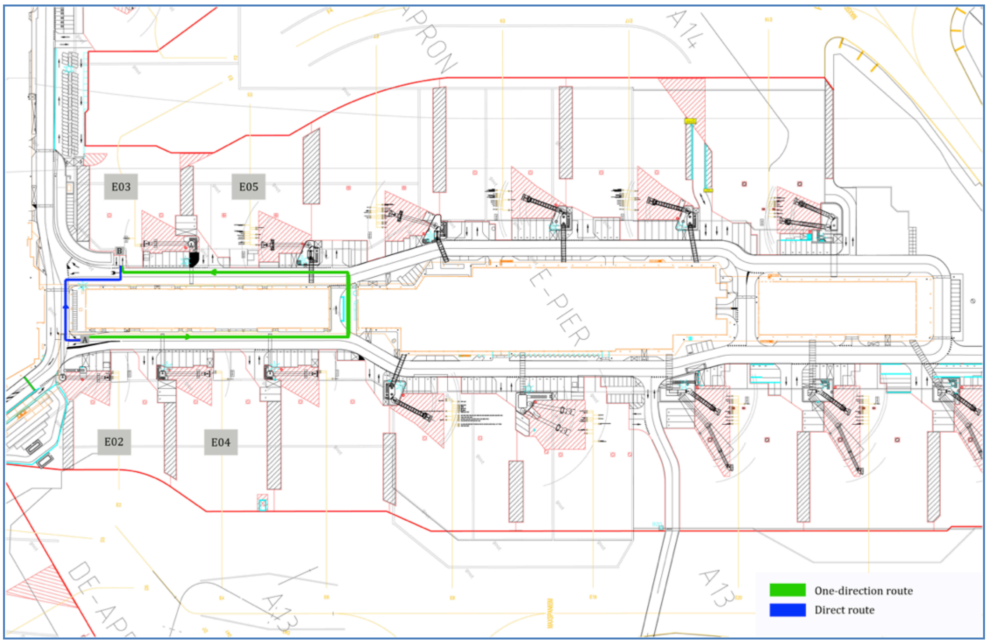


Figure F.1; Visualization of the way of measuring travel time delay for handlers due to the changed one-direction situation

The average travel time coming from the D-pier and destination E03 was in the first situation 16.67 s., an average based on three independent measurements. Changing the beginning of the E-pier to a one-direction situation will result in a travel time of 53 s. coming from the direction of the D-pier and having destination E03. This travel time is also an average based on three independent measurements, which are displayed in table F.2 So the users of the traffic system will experience 36.33 vehicle loss seconds on average because of implementing improvement possibility 5.

Table F.2; The independent travel time measurements to get more insight in the vehicle loss seconds experienced by users if implementing improvement possibility 5

Route	Time in seconds			Average (s.)
‘Old situation route’: From E02 to E03, using the RH-road	20	14	16	16.67
‘One-direction situation route’: From E02 to E03, passing E04 and E05	55	50	54	53.00

F.2.3 Calculation Theoretical traffic generation beginning of the E-pier

After analysing two different gates plannings (of Wednesday 19-09-2012 and Friday 28-09-2012) it is estimated that on average 9 planes arriving within 24 hours for both locations; 4.5 planes at E2 and 4.5 planes on E4. The estimation of these numbers can be found more in detail in the previous section. When this number of planes will be multiplied with the number of vehicles generated from 1 plane handling and the total delay in time, an overview could be provided for the consequences of improvement possibility 5. Table F.3 displays four different type of aircrafts: wide body from or to ICA-destinations, wide body from or to EUR-destinations, narrow body planes and narrow body planes handled on a buffer. It can be seen for example that narrow body planes generated the least traffic for handling (10.6 vehicles per plane), while a buffer handling generated the most traffic (13.6 vehicles per plane). On average, 12.1 vehicles are necessary to handle one aircraft at AAS.

Table F.3; Amount of generated traffic per aircraft type, divided

Transporter (palletizer)	1	1	0	0
Loader(s)	1.1	1.1	1.1	1.1
Transport band (rampsnake)	0	0	1.5	1.5
Catering truck	2	2	2	2
Dispencer (for fuelling)	1	1	0	0
Fuelling trucks	0	0	1	1
Stairs	1	1	1	1
Container dolleys	10	10	0	0
Container trains	2	2	0	0
Baggage carts	0	0	7	7
Baggage trains	0	0	2	2
Pallets	7.5	7.5	0	0
Pallet trains	2	2	0	0
Personnel van	0	0	0	1
Busses	0	0	0	2
Cleaning services	2	2	2	2
Total generated vehicles per plane	**12.1**	**12.1**	**10.6**	**13.6**

Combined with the 12.1 average amount of traffic which will be generated from one plane, a total of 9 planes x 12.1 average amount of traffic per plane handling x 36.33 vehicle loss seconds will results in 65.9 minutes average delay per day for **all users** of the beginning of the E-pier.

F.2.4 Alternative options driving directions E-pier

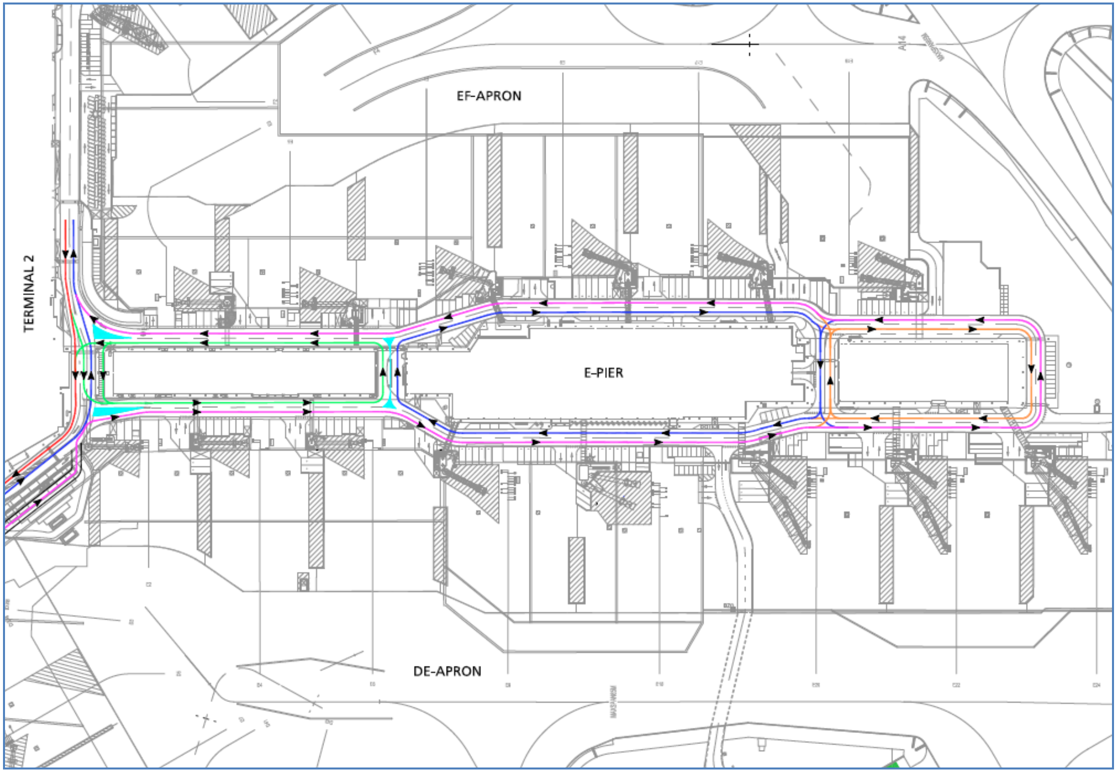


Figure F.2; Alternative option 1, not taken into account in the final proposal

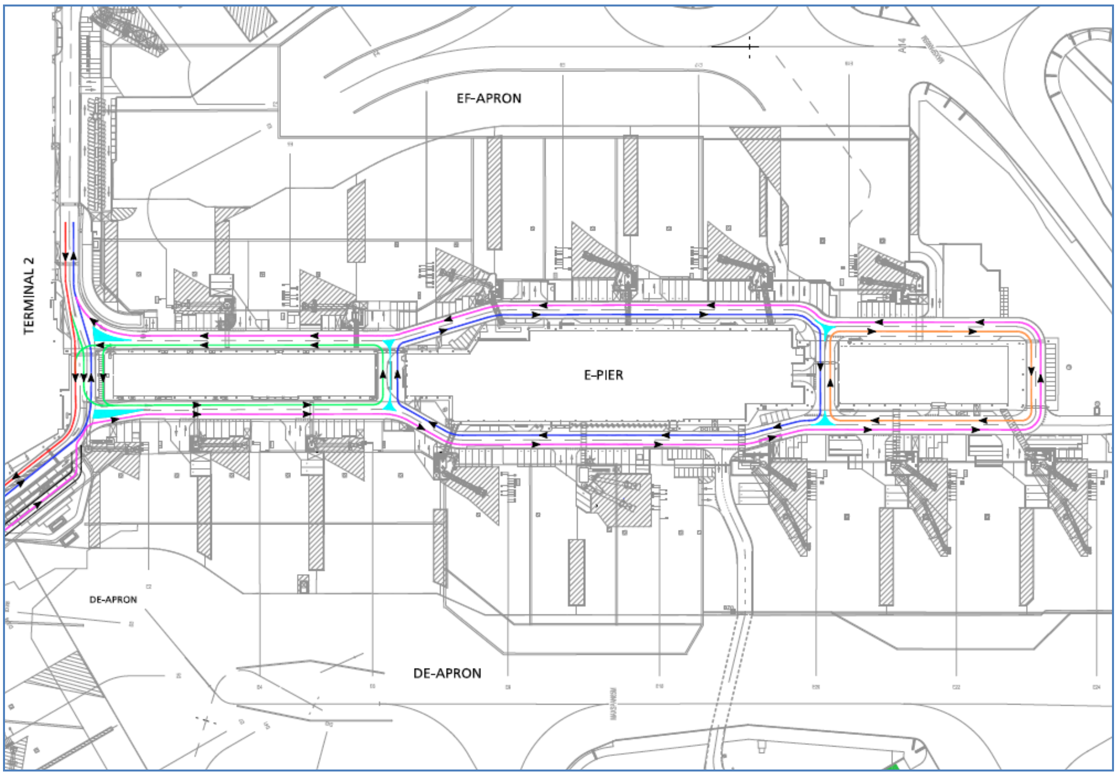


Figure F.3; Alternative option 2, not taken into account in the final proposal

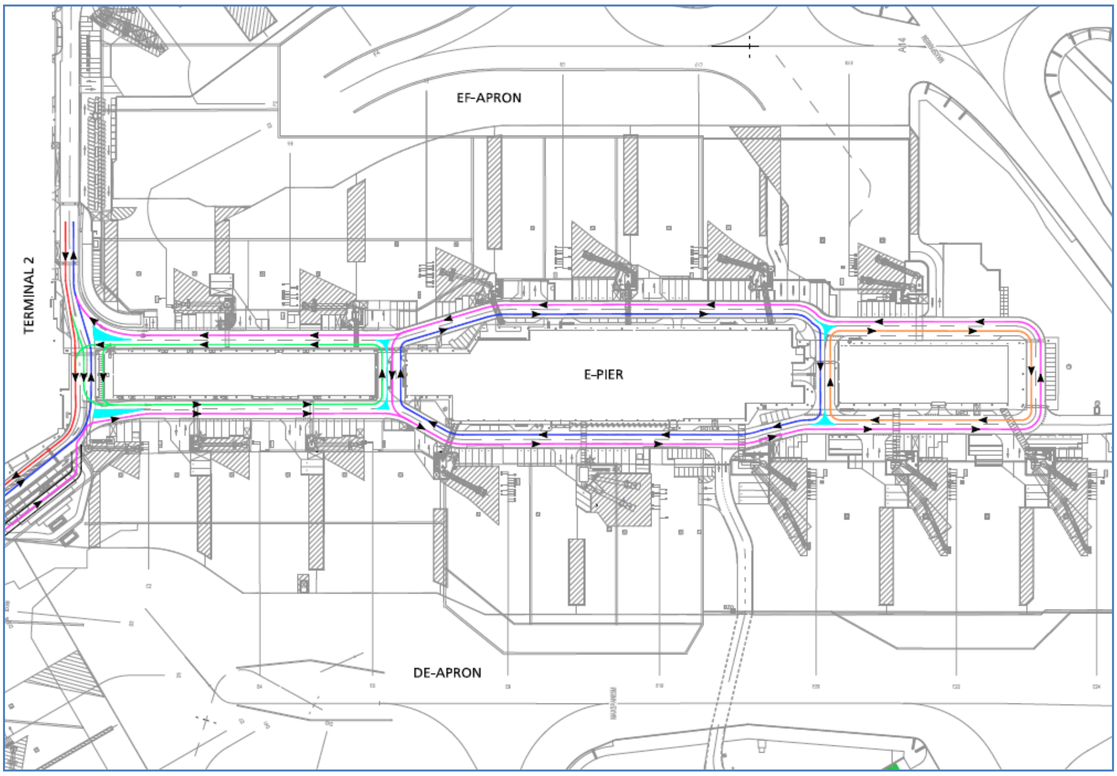


Figure F.4; Alternative option 3, not taken into account in the final proposal

F.3 Preliminary design of improvement possibility 6

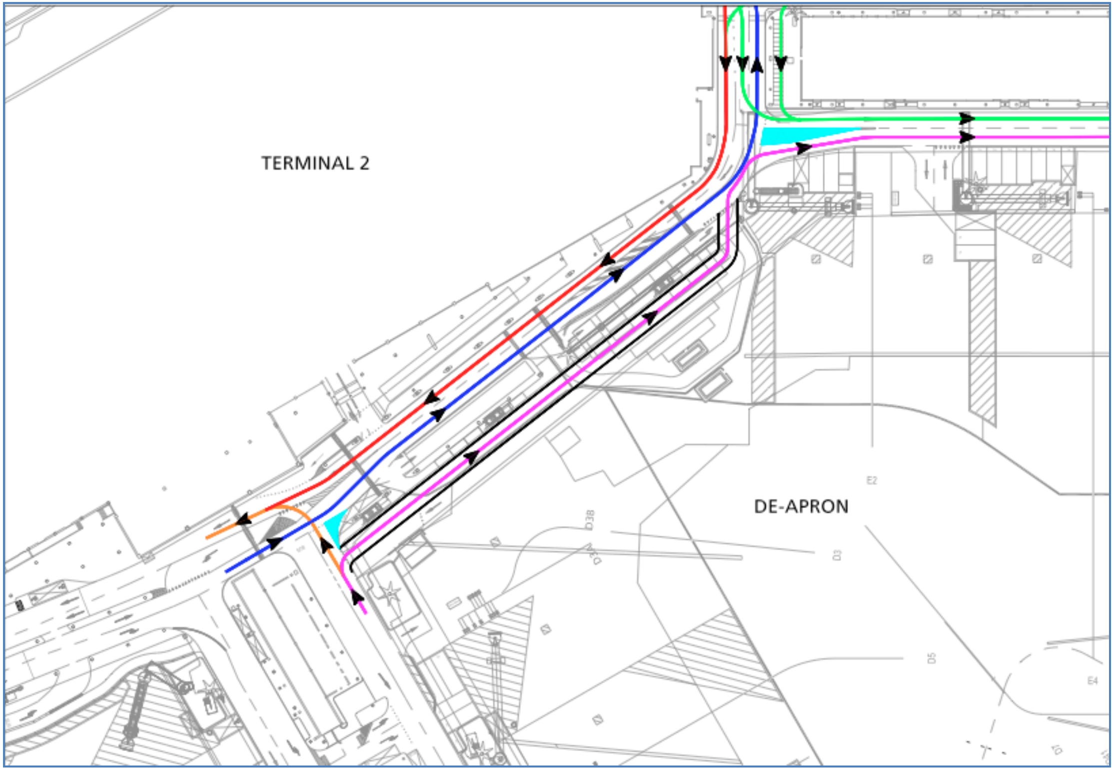


Figure F.5; Preliminary design of improvement possibility 6

F.4 Zoomed-in location of the physical lane barrier; improvement possibility 9

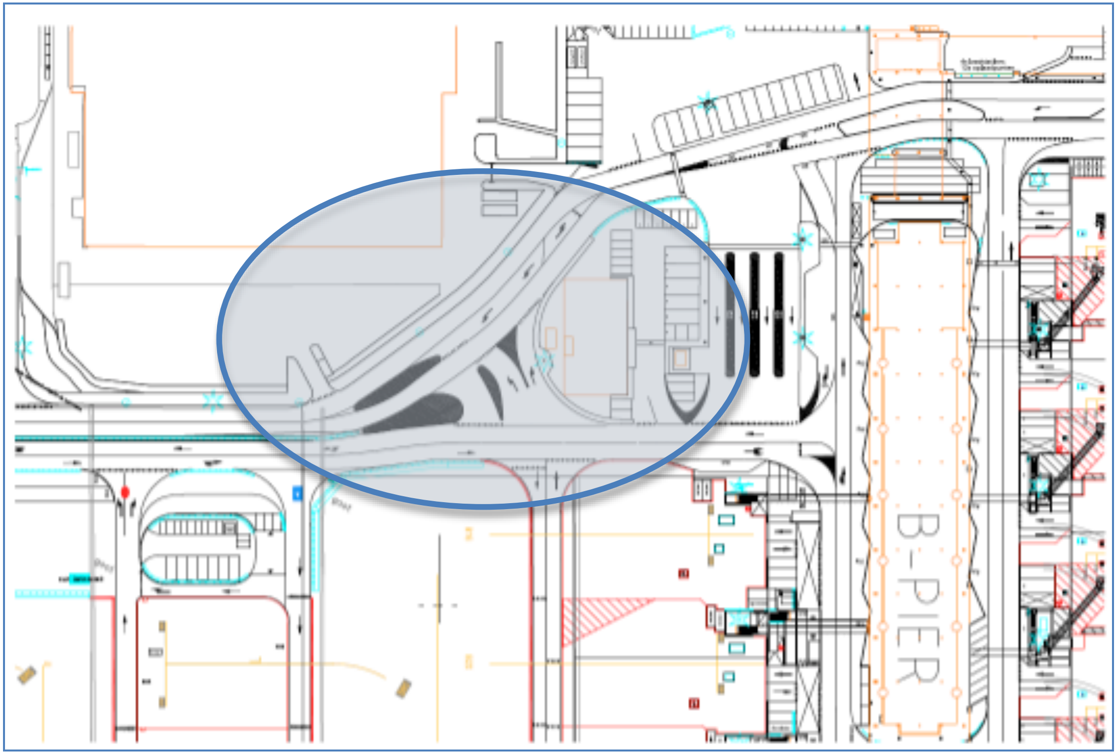


Figure F.4; Zoomed-in location of the proposed physical lane barrier

F.5 Goals poster improvement possibility 11

Figure F.6; Goals poster of the department Process Management Airside (PMA) at Schiphol, indicating the willingness of PMA to improve the communication with the continue shift

F.6 Sensitivity analysis with different weight factors

Table F.4; Different weights per aspect for the four different sensitivity alternatives

Alternatives						
1	1	2	2	3	3	🟦 Costs
1	1	1	1	1	1	🟪 Utilization
1	1	1	1	1	1	🟩 Reliability
1	1	1	1	1	2	🟥 Robustness
1	2	2	3	3	3	🟦 Safety

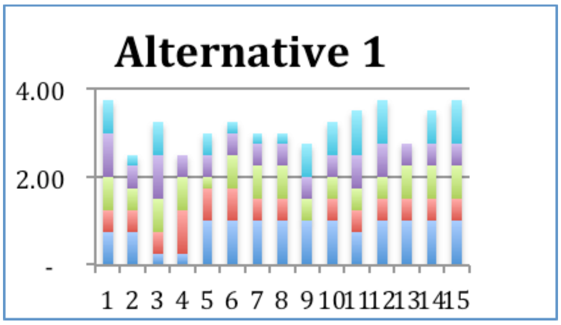


Figure F.7; Results of sensitivity alternative 1

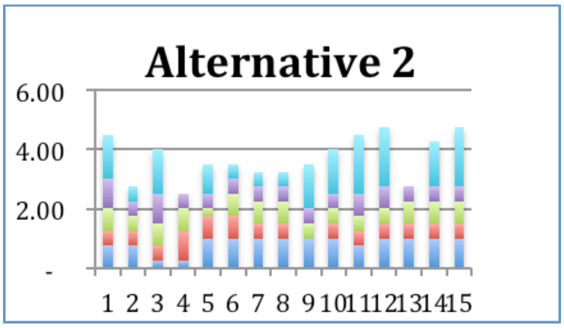


Figure F.8; Results of sensitivity alternative 2

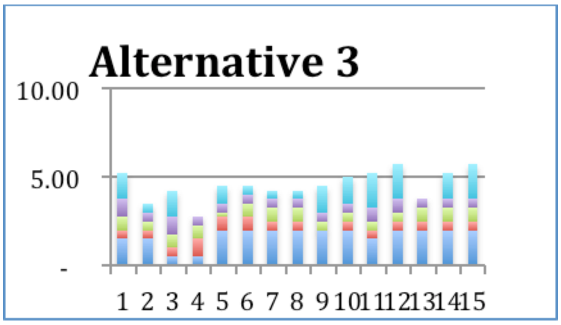


Figure F.9; Results of sensitivity alternative 3

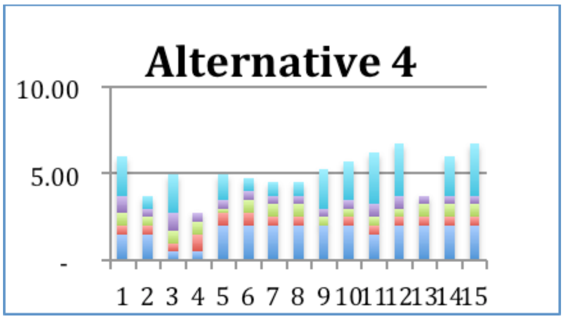


Figure F.10; Results of sensitivity alternative 4

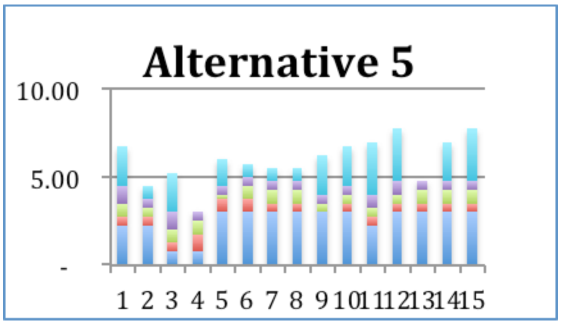


Figure F.11; Results of sensitivity alternative 5

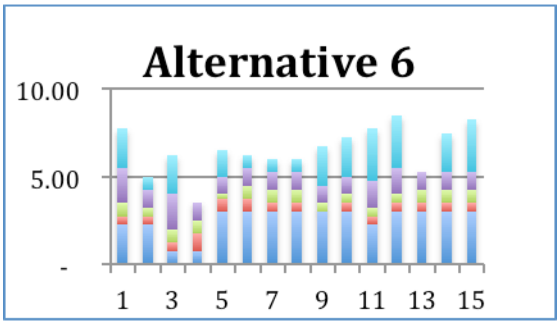


Figure F.12; Results of sensitivity alternative 6

Appendix G Interviews

For and during this research several interviews are held to get more information and insight in the situation at the traffic system at AAS.

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G.1 Interview Marco Bolding

Function: Airport Authority Officer
Date & Time: Tuesday 19th of June 2012, 13.00 – 15.30 O'clock
Location: ACC, Airside. Second floor, room 2013

Marco starts with advising to take the 'action radius' of each vehicle into account, which can be explained as the average area that specific vehicle will be most of the time.

Different stakeholders

Table G.1; List of different stakeholders at Schiphol Airport

Type of service	Companies
Technical Services ('Technische Dienst')	KLM TD D-pier
	KLM TD F-pier
	Alitalia TD
	CityJet TD
	Correndon TD
	DirectMaintenance TD
	Lufthansa TS
	Najak TD
	Transavia TD
Fuelling companies	KLM Fuelling
	CRS: Combi refuelling services
	GTS: 'Gezamelijk tank dienst'
	AFS: Aircraft fuel supply (maintenance hydrantsystems)
Cargo handling companies	KLM Cargo
	Aviapartner cargo
	Martinair cargo
	Menzies cargo
	SkyLink
	SwissPort
	WFS: Worldwide Flight Services
	DHL cargo
Passenger handling companies	KLM K.1 B-platform unit passenger handling
	Aviapartner Handling
	Martinair operations (passengers)
	BlueHandling (was Menzies)
	Menzies bagage
Airplanes (maintenance)	KLM General Aviation
	KLM Towing ('sleepdienst')
	KLM EFG-piers
	KLM D-pier
	KLM Aqua (fresh water, toilets, de-icing etc)
	Tech4Jets: Airplane maintenance Arkefly
Infrastructure (maintenance)	KLM bridge service
	VDM: Technical infrastructure structure: emergency services (electra/ water)
Catering companies	KLM catering
	GateGourmet
	TrusthouseFort

	Martinair
	Alpha
	Expert catering
	Eurest catering
Safety & Security	Douane
	KMar
	KLM Security
	Securitas Transport & Aviation
	Trigion
	Menzies sercurity services
Vehicle (Maintenance)	KES: KLM Equipment services
	K7: KLM Fleet (Wagenparkbeheer)
	ETS: testing & maintenance vehicles
	Spie Tech Maintenance
	SPS maintenance baggage carts
	TCR: Maintenance vehicles
Cleaning companies operations	Ecolos: cleaning spills (kerosene)
	RMM: cleaning spills (kerosene)
Special services	Axxicom: transporting disabled people
	VIP: driving VIP’s
	Met&co: driving crew members
	KLM Animal hotel
	KLM Postal (postkamer)
Cleaning companies	Lavos
	Asito
	Kluh
	Raggers
	ISS: cleaning offices on airside
Waste companies	Ganzenwinkel: dirt collector

Different vehicles

Table G.2; Different types of vehicles with their corresponding radius of action and different kinds of vehicles

Type of vehicles	Radius of action (large/middle/small)	Different kinds
'Normal' vehicles	Large	Trucks, vans, cars, bicycles
Pullers (trekkers)	Large	Electrical/ diesel
		Different sizes
		With or without baggage carts/ open or closed carts
		With or without dolly's
		Dolly's for ULD or horse-containers
Tractors	Small	With or without baggage carts
Airplane pullers (vliegtuigtrekkers)	Middle	Push-back/ push-forward/ combined
Deck loader	Small	Lower/ main/ high
Transportband (Conveyorband)	Middle	
Staartsteunen (tail support)	Small	
Stairs	Small	Statie stairs/ technical stairs
		Motorized/ non-motorized
GPU	Small	Moving/ fixed
Stikstofkar	Small	
Airstarter	Small	
Deicingtrucks	Small	
Heftrucks	Small	

Incidents and inspections have lead to five safety goals:

1) Runway incursions
2) Litter
3) Water pollution (de-icing/ leakages)
4) Construction traffic
5) Collisions

Results are for example that there are more collisions at the Narrow Body (NB) gates compared to the Wide Body (WB) gates. Also authority officers are different, so it depends on who covers which shift for the type of report of incidents by the Airport Authority. This unbalanced reporting is currently under development (risk based enforcement).
Improvement possibilitys can be clustered in three directions, according to Marco:

- Providing information/ education
- Infrastructure
- Enforcement and supervision

Traffic lights are only located in the middle of the system, implemented for the busses to provide them time to make a turn. Separated traffic flows are implemented here.

Tip: ask Paul van der Zwan to the research about safety and accidents (‘incidentenonderzoek’). His manager is Marco Koudijs and is part of the security-department (SHG 3rd floor, other side of SIM-location).

Tip2: ask Henk Duursma to (earlier performed) measurement with sensors on landsite.

The ‘Transpondersystem’ is only present in vehicles that are allowed to go on the maneuvering area and can be followed in this way by the Airport Authority.

Tip3: Call K7_ KLM Fleet (‘wagenparkbeheer’) for more information about their vehicles.

G.2 Interview Bob Gimberg

Function: Process and innovations
Date & Time: Tuesday 19th of June 2012, 16.00 – 17.15 O'clock
Location: ACC, Airside. Second floor, room 2013

Aircraft must fly → Schiphol provides the infrastructure → Quick handling is important for customers.

The growth of Schiphol expanded since 1967, adding different parts to AAS. Therefore, the complete traffic system is a system consisting of separate parts.

For the aspects (safety, robustness, reliability and efficiency) the KPIs should be met, both for AAS itself as for the customers (customer requirements). Measure Safety by using the number of incidents.

All processes 'serve' the turnaround time:
- Longer turnaround time: aircraft with AAS as 'home-base' → these aircraft require more activities → generating more traffic.
- Quick turnaround time: aircraft with 'home-base' other than AAS → these aircraft require minimal activity → generate little traffic.

Additional service AAS offers and generates traffic are the passenger buses.
Airlines decide what activities they do or do not want using their own time and expense policies.

IVAP → handling scheme: how long does each activity takes → handlers use these standards for their own planning of resources. These processes are closely linked to each other.

There are freight (full freighter), passenger (pax.) but also combi aircrafts at AAS, each type requires yet other services and thus generates another types of traffic. Traffic flows at AAS can be labelled as circular traffic.

Adjustments infrastructure

Various bypass be constructed, for example, between the C and D pier. There is also a separate vrachtweg at the Romeo / Bravo / new Alfa pier.

The traffic system was about 6 years ago mostly doubled regarding capacity, except between the D and E pier due to lack of space. Therefore it is tried to give 'hubverkeer' priority. Hubverkeer traffic is traffic that handles transfer cargo and pax. and therefore must be handled quickly.

Arguments to broadening the roads were:
- Relieve the center part of AAS
- Higher redundancy (by accident traffic still can be rerouted)

KLM is characterized by a wave pattern, enabling the occupation in peaks and valleys expires, which is arise because KLM mostly handled transfer traffic and these flights should be planned closely together (to provide a high quality of service). At other companies this aspect is more diversified.

Tip: ask Joan Kaijen for any previously performed traffic (engineering) research. Her predecessor was Saskia Shepherd.

Finally, it is good to take into account that traffic on the perimeter roads of the Airside behaves and act differently than on the public highway (different mentality).

G.3 Interview Gerard den Butter

Function: Koninklijke Marechaussee (KMar)
Date & Time: Monday 25th of June, 2012, 11.00 – 12.00 O'clock
Location: Back office KMar Schiphol Airport

The KMar primarily executes basis police functions and to secure the civil aviation. The traffic system at airside is a private traffic system, owned by Schiphol Airport, in contrast to the public road that is owned by the government and state. This is the case because there are different vehicles, different rules and restrictions (such as always drive with lights on your vehicle) etc.

On the public road the 'Wet Mulder' is used: the administrative enforcement of traffic regulations in which the most common traffic violations are covered. While on the airside, this law is not applicable, so rules and regulations will be enforced regarding the aviation law. The administrative operation of for example a speed ticket cost much more time and effort compared to the public road. This is the reason why the KMar focuses on the more serious violations such as: driving with alcohol, deadly accidents continue driving after an accident happens and dangerous driving behaviour.

Because of the quite serious consequences by Schiphol Airport, the rules and regulations will be followed quite well. The Airport Authority covers this part mainly and report every incident for Schiphol Airport; no criminal consequences will follow. One exception on this fact is that impede an airplane can be seen as criminal attempt.

On the bypasses the 'Verkeerswet' is active, using the RVV: 'Reglement Verkeersregels en – voorschriften. This law is administrative legal (so not criminal legal). Platforms are not specific indicated roads, so are not taken into account in the RVV. Incidents on the platforms are therefore seen as 'working incidents' ('arbeidsongevallen'); for example when a vehicle crashes an airplane wing.

Different peaks generate different amounts of traffic during the day; relatively much traffic; long vehicles; self-regulated system; compact system. KMar sometimes have to cross busy parts when an emergency happens, could results in dangerous situations. More places to overtake slow-vehicles could results in more smoother traffic flows. The road authority is Henk Duursma.

There is no real database, except the BPS police register, of all accidents; this is because the most accidents are not so heavy. In general 15 accidents happen on the airside whereby the KMar is involved and report about. More and more cooperation between the Airport Authoriy and the KMar is established; mutual understanding, sharing and exchange from tasks.

G.4 Interview Lotte Harbers

Function: AOM'er: teamleider Authority Officers
Date & Time: Friday 29th of June, 2012, 13.00 – 13.30 O'clock
Location: Schipholgebouw, third floor.

During their shift Authority Officers can take notice remarkable discrepancies in two types of documents:

- Check-it: all incidents or special notions or activities will be documented in this;
- ASIS: all incidents will be reported in this document
  → Paul van der Zwan (more severe incidents) and Pamela Lauwerse (all incidents)

Changes on piers:

- B-Pier (South): hydrant-charts → fuel machines (dispensers) placed fixed on VOPs;
- C-pier: 'hydrantisering': no more tanking trucks necessary any more;
- D-pier: not enough parking locations;
- F-pier: One-direction lanes can cause resistance with for example handling companies;
- G-pier: less vehicles of the KMar?

General note: not all vehicles on airside have a registration plate. It could be that there are too much unnecessary vehicles on airside, for e.g. construction works.

It could be of real interest to go with one of the airport authority officers to see problems on the bypass and to hear what kind of accidents happen. Just send a e-mail to '#Authority Officer' and mention Lotte. There are about 25 Authority officers.

Different perspective is interesting to take a look at:

- AO → safety and security
- KLM → more practical perspective, reliable system without too much delays

Officers work different shift, day and night. Mitigation of violation is executed with the use of a pointing system on all different areas.

G.5 Interview Jan-Kees Rem

Function: Sr. advisor Airport Authority
Date & Time: Tuesday 10th of July, 2012, 9.15 – 10.00 O'clock
Location: Triport 2, second floor, room 2319
Subject: Vehicle registration Schiphol Group on Airside

It could be very interesting to also take into account the area of Schiphol South-East, because of the 'Kaagbaantunnel' and the fact that driving behind the planes is a normal procedure over there. For more information ask the VPS ('Veiligheid Platform Schiphol'), via Fauzia Aouden.

Stickers on the windows of vehicles are called the vehicle pass ('Voertuigpas'). Also daily passes are possible. These passes are available and needed for every vehicle which will enter and leave the airside by passing one of the entry gates ('doorlaatposten').

The idea of having an overall 'APK' has been raised, but is not yet implemented.

Jan-Kees Rem advised to contact also **handling companies** to get more insight in their fleet. And also **security operations, via David van der Meer**; this department tracks all passing vehicles through the gates, and so know which vehicles enter and leave the traffic system, the amount of the daily flow and maybe even the directly they are going to. Finally, the maintenance companies (**KES, TCR and …)** also could provide a lot of information because they maintain all airside vehicles.

The data of all registered vehicles could be gained through ESM, to which we directly walked by, explained them about the research and asked them for the data, which they would provide soon.

G.6 Interview Paul van der Zwan

Function: Researcher incidents
Date & Time: Tuesday 10th of July, 2012, 13.00 – 14.00 O'clock
Location: SHG
Subject: Incidents at airside

Paul van der Zwan is incident research since 2005 at the Schiphol Group. The focus of his department (Airport Authority Office) is on incidents where or people are involved or infrastructural aspects.

The definition is of importance;
Incident = 'Een ongewenste gebeurtenis waarbij schade is ontstaan of dreigt te ontstaan'
Demage can be identified as safety, environment or health ('letsel, materiele schade of lekkages').

When an incident occurs, the airport authority will join the location and will report the incident in a specific system. The incidents researches get this information through and report monthly in the safety traffic meeting ('veiligheidsverkeer overleg'). For this reason (reporting) a lower and higher acceptance level is set so consistent conclusions can be drawn. These boundaries are indicated based on 5 years of data out of the past. An increased seasonal effect can be seen during the summer months. Every authority officers report their own incidents on their own way, which can cause inconsistancies.

<u>Defintions</u>

Safety → incidents
Reliability → ratio amount of incidents with amount of vehicle flow (#vehicles) for example.
The norm is set on 0,4 incidents per 1000 air movements.
An obstruction of the traffic can be: delays, detours. Mostly this is caused by another incident.

<u>Data system</u>

Every incident has its own number of reference. Not yet into the data set:

- # of deadly people
- # of injured people
- BZO: ´Bijzondere zicht omstandigheden´
- Weather conditions during the incident
- Weekly- quarterly

In the data set (in brackets the number in 2005):

- Five types of incidents
- Yearly- monthly
- Accident against airplane (#19)
- Accidents by (passenger-) bridge (#10)
- Accident by airplane (#3)
- One-sided airplane (#89)
- Other accidents (#7)
- Accidents between vehicles (#163)
- Total accidents = #291
- Every tab contains another year

Ask in the drawing room if they can locate the centre of gravity of certain accidents so X and Y coordinates can be determined. Then the drawing room can show the incidents on a map digitally. About 500 different locations will probably arise.

G.7 Interview Saskia Schaapherder

Function: Advisor (BHP)
Date & Time: Tuesday 10th of July, 2012, 13.30 – 14.30 O'clock
Location: Transview 418
Subject: Baggage handling process

Take into account that a horse trailer only drives with 10 km/h, so will cause a lot of delays on the traffic system. Departing from the animal hospital. Detour?

Further more, probably construction works will cause differences within incidents analysis can/. For example detouring the Rinse Hofstraweg at the D-pier, constructing alfa 1 caused several incidents.

Improvement possibility directions will be in infrastructural, policy and education.
Every reclaim has it own wharf ('loskade').
Bagage basements/ halls at D-pier, E-pier, South and OC (below terminal 3&4).

Use the terminal viewer on intranet or ask the drawing room for the entrances and exits of all baggage basements/halls.

Get more into detail on the flow, capacity and complexity of the traffic system.

Gateplanners are working on the 10th floor of the tower and know more about dragging movements ('sleepbewegingen'). The LVNL is located on the 15th floor.

The long-term advanced tactical gate planning is earlier made in the ACC building, could ask Joke van Dam (probably her past job) or Nick Struik for more information.

The handling companies know more about the number of dollays behind truckers. The airlines are having agreements with the handling companies and cluster their baggage into four categories:

- Arrival for Amsterdam
- Premium members (higher priority)
- Transfer EUR
- Transfer ICA

The supply of passengers is very different on a daily bases different transfers ICA/EUR/AMS. Also difference between planes arriving at wide body gates (mostly containers) and planes arriving at narrow body gates (bulk baggage). The occupation level of airplanes also differs every day.

KLM is handling mostly its own baggage. Passenger service did Bluetooth counts in one of the terminals in the past.

Schiphol Groups' cargo department is located on SHG A.3, but is very different from baggage. Cargo does not have a system to exploit, while baggage has a complete baggage sorting system to operate. Airport operations manage this cargo part (e.g. Kees van der Leek).

Handling companies, such as KLM, have cargo and baggage in their own management.

KES and TCR are maintaining the airside vehicles. Probably the fact is that vehicles that are not allowed to leave airside are also not allowed to enter the normal road at landside.

At the B-pier a bus stop is located for passenger buses to load and unload passengers, at this side passengers arrive at the gate, but because they are 'non-Schengen' passengers, they have to be transported by bus to the 'non-Schengen' area, where they can depart the bus and enter the terminal.

G.8 Interview Marco Stoltenberg

Function: Advisor
Date & Time: Tuesday 10th of July, 2012, 15.30 – 16.30 O'clock
Location: SHG
Subject: Masterplan AAS 2020

LVNL has initiated a simulation research at the moment to a research company (to-70); both Koos Noordeloos and Rob ten Hoven know more about this research.

The new Backbone will connect the currently three baggage halls/ basements with each other: South, D- and E- piers.

The boundaries of growth:

- 510 k. of airplane movements until 2020
- 580 k. of airplane movements until 2030

Consequences of the new masterplan:

- Less trucks on the road, because baggage is transported by the new Backbone.
- At the current locations of the A-piers, now KLM Airplanes are handled. When new piers are constructed, less traffic movement are needed which will result in less traffic.
- The Airplane taxiway Q will be constructed straight about the A4 (instead of oblique nowadays). The road will be constructed below the normal road height, because of the new piers. The RH-road will probably also moved a little northwards.
- Moving the cargo of KLM also to the Schiphol South-East, together with the other cargo handling and halls will cause less traffic movements because cargo is handled locally there. Also more separated traffic flows will be the consequences.
- The consequences will be that there are fewer fuel tanks on the road.

Different phased of the new masterplan (every 2 years 1 pier):

1) 2/3 of the new A-pier will be constructed and finished in 2015.
2) Complete A-pier will be constructed and finished in 2018.

The cargo of KLM first should be moved towards the South area. Half of the pier is EUR and half will be OC-ICA (Other Carriers – International) pier.

Together with the new terminal (the OC-terminal), located on the current Transview building, also a new baggage basement will be constructed.

The G-pier is now an OC pier, while when ready, the KLM will take over the G-pier and the OC will be moved towards the new A-pier.

Now there is a lack of capacity, which results in remote handling that uses busses to transport the passengers. One ICA-airplane requires about 6 busses, which causes a lot of traffic movements.

Fuelling

- At the C-pier a hydrant-system is constructed now, which will be finished in 2014.
- Together with constructing each new (A-) pier, directly the hydrant system will be constructed.
- The consequences will be that there are fewer fuel tanks on the road.

G.9 Interview Paul (P.J.W.M.) van der Lans

Function: Airside Authority Officer
Date & Time: Monday 3rd of September, 2012, 10.00 – 11.00 O'clock
Location: ACC, airside

Because airside authority officers (AAO's) are daily users of the traffic system, an interview is held with on of these AAO's, namely Paul van der Lans. He indicates, during a tour around airside, AAS has a really specific ground area; for example at other airport, the aircraft stands are not lined at all. He also indicates that there are two traffic control signs, located near the G-pier and along the B-buffer on the RH-road.

During the interview Paul is mentioning several improvement ideas:

- Keep the F-pier one-directional
- Make also the C-pier one-directional
- Traffic lights at the de-icing platforms near the J-buffer
- Traffic signs at the fuelling platform near the B-pier
- Reroute traffic over the viaducts, although KLM will argue it is too far
- A lot of pedestrian warning signs
- Create a meeting with AAO to discuss potential improvement ideas at airside
- Place more mirrors
- If construction works are planned for the long-term, place also long-term traffic signs instead of temporarily signs
- Dangerous corner at the beginning of the F-pier
- Green pedestrian crossings
- Crossings at the baggage basement of the D-pier
- Parking places along the road, which attracts even more traffic
- There is too much traffic, too many vehicles are standing in the way doing nothing

Current problem areas that Paul indicates:

- The beginning of the D-pier, partly because of the bus-detour there
- The covered parts of the traffic system at the D- and E-piers

Paul indicates that the most accidents happen by far on the aircraft stands or at the on-or off-ramps of the stands and so not on traffic system.

G.10 Interview J. van den Boogaart

Function: Coordinator HTM busses
Date & Time: Wednesday 12th of September 2012, 14.00 – 14.45 O'clock
Location: Tender square, airside.
E-mail: J.van.den.Boogaart@htm.nl

The bus coordinator of HTM, the company that delivers the busses to handle passengers at airside, was shortly available to answer some questions about the bus handling of airplanes. There are 52 busses, which are all registered at the AAS registration. The peak hours for busses can be identified as follows:

- 7:00 - 10:00 O'clock
- 11:00 – 14:00 O'clock
- 15:00 – 17:00 O'clock

75% of all busses are operating on the B-platforms and –buffers. Via the G-buffer to the E-buffer the busses are already on the road to and will use the viaducts.

G.11 Interview David van der Meer

Function: Aviation Security Manager, A/SSE/Security Policy
Date & Time: Wednesday 12th of September 2012, 10.00 – 11.00 O'clock
Location: Terminal 2, landside.

David van der Meer is responsible for the security at airside, which helped a lot while executing the measurements at AAS using the cameras. Also the security process at the gates is discussed and created more awareness of the security side of the airport. David van der Meer indicates that the willing number of registered vehicles is around 3500, to keep airside usable for all users of the traffic system without too many unnecessary vehicles; while the number of registered vehicles is now already more than 3900. He points out that it is also the aim of security to reduce the number of registered vehicles.

In 2007 the RFID chip is implemented within the vehicle badge on the windows of registered vehicles. In 2008 security started realizing the number of registered vehicles should be limited as much as possible.

Rene Korevaar is the expert related to Six Sigma of the security gates and is optimizing the utilization, flows and intensity of the gates.

David van der Meer indicates two main peak moments at the security gates:

- 6:30 – 9:00 O'clock
- 14:00 – 16:00 O'clock

G.12 Interview Daphne Schets and Erna Leerling

Function: Shift leader APC (traffic tower) and gate planner
Date & Time: Thursday 27th of September, 2012, 10.00 – 17.00 O'clock
Location: APC (traffic tower), landside
E-mail: leerling_e@schiphol.nl

The complete day joining a gate planner of AAS resulted in a lot of information about how the gate planning at Schiphol is made. It could be said that the gate planners are aware of the consequences of their planning to the traffic flow at airside, but this is not one of the main goals for a gate planner.

The day of a gate planner start with going through the construction works of the next day. It is assumed that it will take 45 minutes to let all passengers out of the plane and it will take 1.5 hours to let all passengers enter the plane and load the plane at the same time.

Two times a year the complete planning of LVNL is loaded into the CIS-system.

The C-pier is an Schengen area, and the E- and F-piers are ICA areas. The D-pier is split up into two parts: the top level of the terminal is a Schengen-area, while the lower level is non-Schengen area.

Furthermore, the E- and F-piers are moreover KLM piers, while the combi-aircrafts are placed mostly on the G-pier.

Erna Leerling indicated the departing peak hours as follows:

- 9:30 – 11:00 O'clock
- 13:00 O'clock
- (18:00 O'clock)
- 21:00 O'clock

The 'fluco' that day was Gean van Erp of KLM: Gean-van.erp@klm.com

G.13 Interview Maarten van der Scheer

Function: AAS
Date & Time: Thursday 1st of November, 2012, 10.00 – 11.00 O'clock
Location: Terminal C, 'Bassregie', Airside

Stakeholder communication

Maarten points out that the communication between the office and the operation could be improved, both in regular situations as in (un) planned construction works. Now both parties are experiencing negative consequences because of the lack of communication. Also the direct counter partner KLM is not involved within the process.

An example Maarten mentions is the construction crane which is placed already four times at random positions at airside, to replace cooling systems n the terminal; these random positions belong in this case to KLM, which results in logistical problems. His idea is to improve the communication with operations, because several other, suitable locations could be pointed out instead of the equipment buffer of KLM.

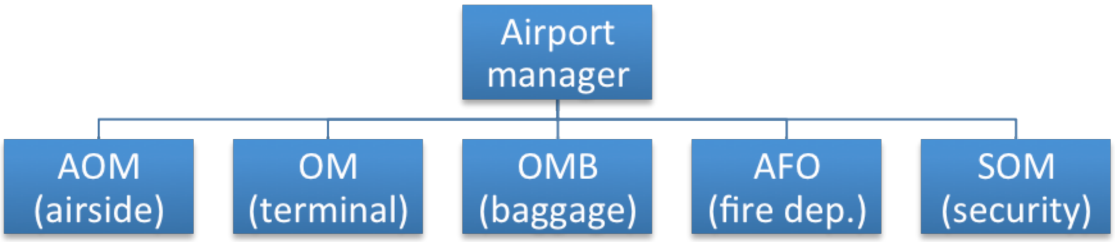


Figure G.1; The organizational structure of AAS between which more communication is preferred

Nowadays, the day shift of Airside Operations (AO) will be contacted if special elements will occur that day. Airside operations then will let the current Airside Operation Manager-person (AOM) at airside know what the special activities are, which again will tell the OMB. The day shift of AO will probably inform the day shift of KLM. The day shift of baggage is not informed in most cases and will experience the discrepancies during its shift, which is not in favour of handling these discrepancies.

Traffic flow directions

It is pointed out that the gate planning has a lot of influence on the traffic flows at airside.

In January, the new ‘backbone-system’ will be implemented, which will connect all main baggage systems in the terminal with each other. This new baggage handling system will also have its influence on the traffic flows; the South baggage basement at the B-pier will then be able to cope with all baggage from the EUR flight arriving at the A-, B- and C-piers, instead of driving all baggage to the E-pier to get to the ICA-flights or the D-pier for EUR-flights which is happening nowadays. This will relieve the traffic system at the main piers and will reduce the traffic intensity.

Now there are 4 baggage inflow locations at the E-pier and 5 at the D-pier. From January on there will be two extra inflow locations at the South baggage basement, which will results in additional capacity of 22.22%, so baggage vehicles could drop and collect their baggage at the south basement, instead of going to the D- (EUR-flights) or E-pier (ICA-flights).

Another idea that is discussed in this meeting is the fact of creating reclaim belts in the new terminal along the B-pier, to relieve the traffic flow at the busiest piers. In this way, the destination baggage, mostly from EUR-flights and so the A-, B- and C-piers, will not have to be transported all the way to the D-pier, but can be dropped at the South baggage basement.

Also the location of the busses at the beginning of the D-pier could be reconsidered, to avoid having busses at the busiest locations at airside. Within the new masterplan, these kinds of infrastructure elements should all be taken into account.

G.14 Interview Serge Wielemans

Function: KLM Process Manager BTS Platform
Date & Time: Wednesday 7st of November, 2012, 11.00 – 12.00 O'clock
Location: Terminal C, 'Bassregie', Airside

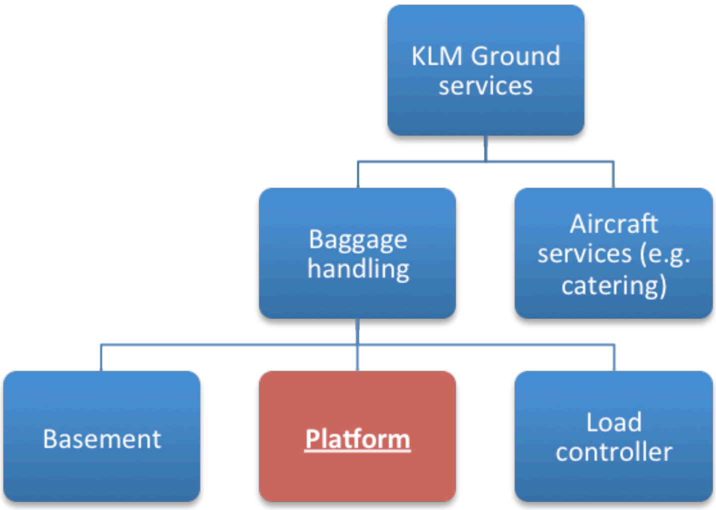


Figure G.2; The KLM structure as discussed in the interview with Serge Wielemans

Serge Wielemans starts with explaining the KLM organizational structure and where his position within this structure is located. An overview can be seen in figure F.2 of which Serge is fulfilling the function of KLM Process manager BTS Platform.

Vehicles could, and should according to Serge, into passenger cars and equipment. It would be interesting to label percentages to these two groups.

The planning to handle airplanes is set 24 hours before, although much information is not yet known then; this information will be released when the planes gets in the air from its origin location. The amount of traffic generated by both a wide body (WB) plane and narrow body (NB) plane is displayed in table F.3. Wide body planes are the Boeing 747 and 777 types, while narrow body planes can be indicted by the Boeing 737 types. Also the Embraers are indicated as narrow body planes.

Jan Jaap Hovings is an expert of handling airplanes at buffers, which is slightly different compared to normal handling locations (VOPs).

Table G3; Generated average traffic for both wide (WB) and narrow body (NB) planes

Transporter (palletizer)	1	1	-	-
Loader(s)	1.1	1.1	1.1	1.1
Transport band (rampsnake)	-	-	1.5	1.5
Catering truck	2	2	2	2
Dispenser (for fuelling)	1	1	-	-
Fuelling trucks	-	-	1	1
Stairs	1	1	1	1
Container dolleys	10	10	-	-
Container trains	2	2	-	-
Baggage carts	**-**	-	7	7
Baggage trains	**-**	-	2	2
Pallets	7.5	7.5	-	-
Pallet trains	2	2	-	-
Personnel van	**-**	-	-	2
Busses	**2**	2	2	2
Total generated vehicles per plane	**12.1**	**12.1**	**10.6**	**13.6**

Serge states that on average 10 container dolleys and 5 pallets are loaded into a 747 Wide Body plane, while on a general wide body plane also 10 container dolleys are loaded, but 12 pallets. On average this will results in a general amount of traffic for a wide body plane to be as follows: 1 transporter, 1 loader, 1 transport band, 2 catering trucks, 1 dispenser, 2 trucks with each 5 containers, 2 pallet trucks with both 4 containers; a total of 10 vehicles to handle one wide body plane. The 7.5 pallets are an average of 5 pallets for a passenger Boeing 747 wide body plane and 12 pallets for a Boeing 7474 Combi. A wide body plane from or to European destinations generates the same number of vehicles, only the 2 container trucks with each 5 dolleys are then replaced by two baggage trucks with 4 and 3 baggage carts.

KLM uses the average number of passengers which are on board are taken as a given parameter and are duplicated with 1.5 pieces of baggage on average per person, of which 40 pieces of baggage can be stacked on one baggage car.

Ordering new equipment can take more than 8 months.

In 2015/ 2016 the departure origin will be of importance, because travellers then should be split to their origins. Depending their origin they should pass a 100% check; e.g. Paramaribo and Curacao are now 100% check origins.

Table F.4; Netto available amount of equipment of KLM

Stairs EUR	46
Erma = transporter	23
Lowerdeckloader	22
CLT8 = combined loader and transporter (for Airbus A320, handled on the C-pier)	8
Conveyor Eur/ ICA	27
Maindeckloader = freight loader	5
Stairs K1	28
Conveyor K1	2
Powerstow = transporter	21
Rampsnake (incl HV) = transporter	35

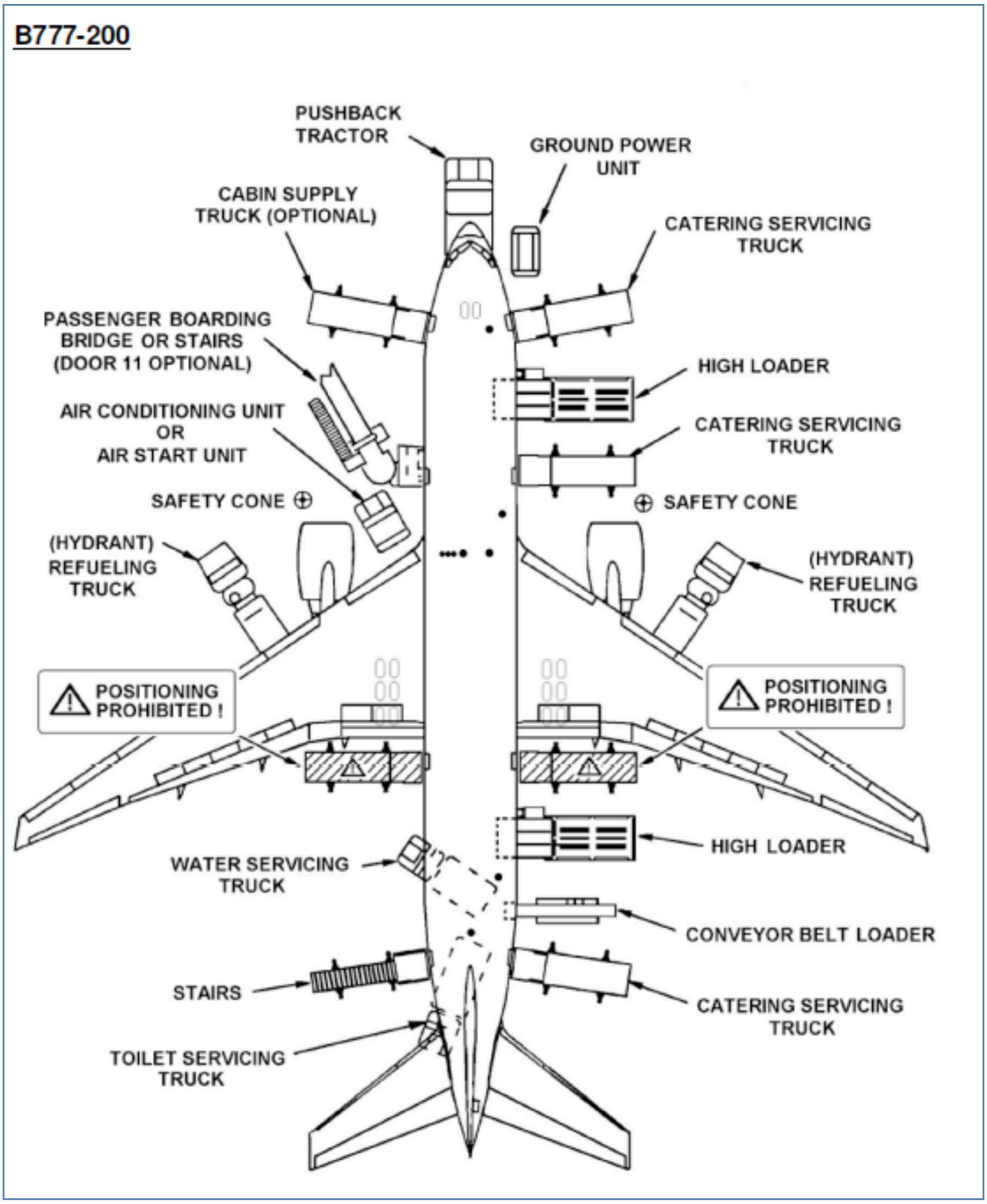
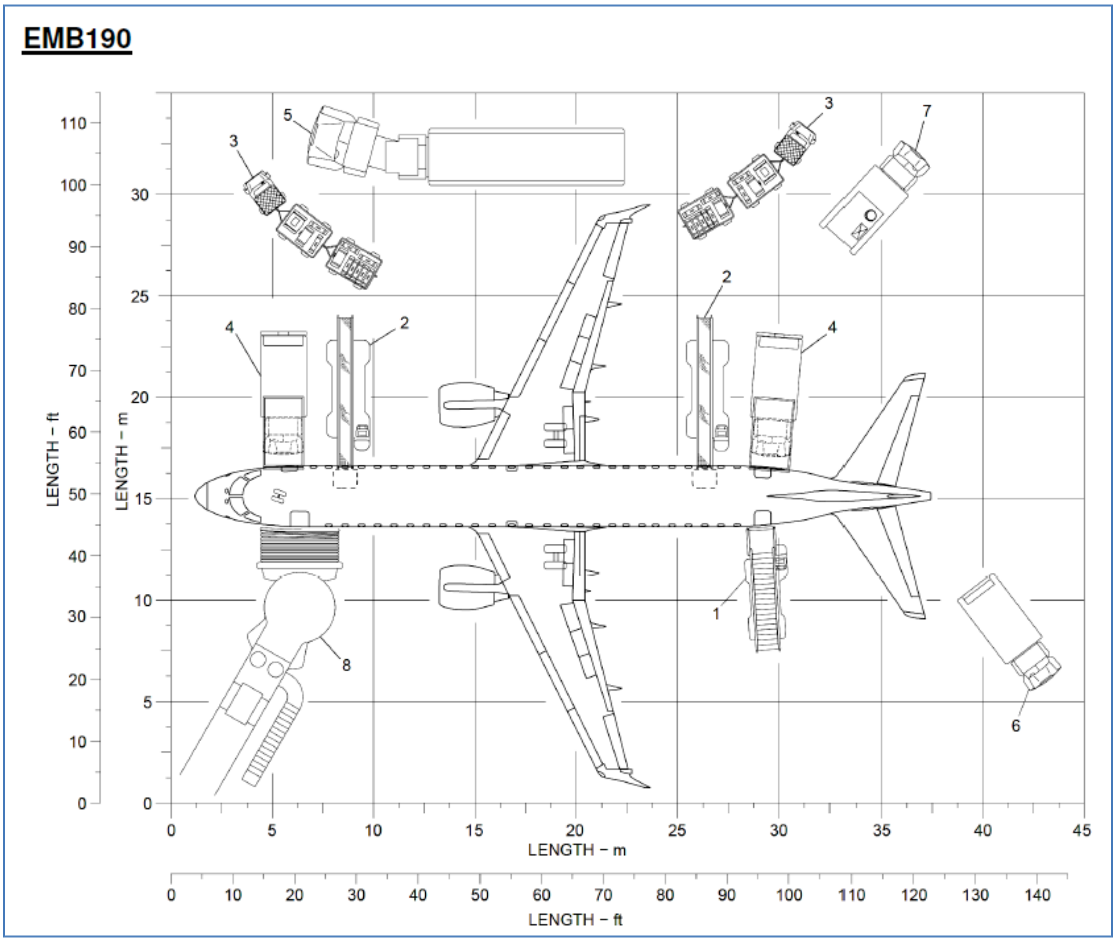


Figure G.3; Overview of the handling material for a wide body (WB) plane (B777-200 in this case)



EMB190

Figure G.4; Overview of the handling material for a narrow body (NB) plane (EMB190 in this case)