OPTIMISATION OF THE AIRSIDE ROAD TRAFFIC SYSTEM AROUND THE PIERS OF AMSTERDAM AIRPORT SCHIPHOL

Msc Thesis Transport, Infrastructure & Logistics
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OPTIMISATION OF THE AIRSIDE ROAD TRAFFIC SYSTEM AROUND THE PIERS OF AMSTERDAM AIRPORT SCHIPHOL

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SUMMARY

Located near Amsterdam in the Netherlands, Amsterdam Airport Schiphol (AAS) has the ambition to be Europe's most preferred airport. In 2014, 58 million passengers departed from the airport to 295 destinations, 1.6 million tonnes of cargo was transported, and 451,000 flight movements were carried out. The number of passengers and flight movements still grows each year. The airside of AAS is the area where aircrafts take off, land, and are handled at the platforms and gates. The handling process is serviced by handling vehicles which use the airside road traffic system along with Airport Authority, Customs and the '*Koninklijke Marechaussee' (KMar*). The airside road traffic system is a non-public road traffic system, consisting of a main road and service roads around the piers. The problems experienced at the road traffic system of the service roads are delays and traffic accidents.

The focus of this research is on finding the infrastructural design that improves the effectiveness of the airside road traffic system of the service roads around the piers of AAS. The objective of this research is a systematic approach to apply the effects of the infrastructural designs on airside road traffic systems of all kinds. Effectiveness is tested on travel time, travel distance, robustness, safety, surface used, and costs. The end product of this research is an advice for the Schiphol Group on what infrastructural design improves the road traffic system of the service roads around the piers. The main research question is: "*How can the design of the airside road traffic system around the piers of Amsterdam Airport Schiphol be improved in terms of travel time, travel distance, robustness, safety, surface used and costs?*"

In this thesis the characteristics of the entire airside road traffic system in the base situation and the stakeholder involved on airside are analysed first. Second, literature on public road designs and road traffic systems is studied to base infrastructural design alternatives on. Third, a literature study on available simulation models narrows down the choice of a simulation model. Fourth, the design alternatives are simulated on the airside road traffic system of one pier and general configurations of the same pier, as a case study for the entire airside road traffic system. Fifth, the results of the simulations on the six aspects are analysed and compared with the results of the design of the base situation. Sixth, an assessment of the design alternatives is performed with a multi criteria analysis and the implementation steps for the design alternatives are also discussed.

The road traffic system of AAS has the same traffic rules, road markings, and traffic signs found on public roads, however cycling is not allowed and pedestrians do not have priority. The speed limit on airside is 30 km/h. The different sizes of aircraft stands at AAS determine the type of aircraft that can be docked to the gates and the number of vehicles needed for the handling process. Passengers are also taken to and from the aircrafts with buses that travel between the terminal building and the remote aircraft stand. The road traffic system is connected to an underground complex network of baggage halls with multiple entrances and exits. The bus, catering truck, fuel dispenser, cleaning services truck, toilet/water service truck, baggage trains, pallet trains, push-back truck, and ramp snake found on the road traffic system have diverse speeds, lengths, widths, and turning radii. When implementing new designs on the infrastructure of the airside road traffic system organisational stakeholders and road users are involved, all with their own interests and resources. The organisational stakeholders are the departments Process Management Airside (PMA), Analysis, Development, and Innovations (ADI), Construction & Maintenance Control (CMC), Maintenance Operations (MO), and Development. The bus company, handling companies, authority officers, kMar, Customs, and emergency services are the users of the road traffic system. The kMar, Customs, and the department Development have to be kept satisfied. The departments PMA, ADI, and CMC, the authority officers, the bus company, and the handling companies are the key stakeholders.

Pier B is chosen as a case study because the pier has the most uniform shape and length, has a bus station, and houses a home base for technical services. The pier has three junctions with the main road and is an integral part of the road traffic system for through traffic and destination traffic. The passage road through the pier offers multiple routes for the destination traffic.

A literature study on road designs found on public roads, at the airside of AAS, and at the airsides of other airports resulted in three road section designs and five junction designs. Design variations of these designs had to take the non-removable elements and road users in to account, and comply with the rules and regulation to pass. The road section variations that passed are two-way, one-way with two lanes, one-way with parking bays, one-way with extended aircraft stands, and shared space. The junction design variations that passed are equal crossings, equal crossings with turning lanes, and the *voorrangsplein.* These five road section designs and three junction designs are combined into twelve design alternatives, the

combinations of one-way designs with the *voorrangsplein* are not part of this research. The surface used and costs of a design alternative are part of the design specifications of an alternative.

The performance of the design alternatives is measured on the aspects travel time, travel distance, robustness, and safety in simulation models of the alternatives. VISSIM is chosen as a simulation program because it offers a detailed study of individual vehicles on different road section and junction designs. VISSIM works with dynamic assignment, provides the appropriate aspect outputs, and has detailed driving behaviour parameters. The road traffic systems of the design alternatives are implemented according to their specifications using the tools available in VISSIM. To determine robustness the total travel time in an accident scenario is measured and compared to the total travel time under normal circumstances. VISSIM cannot determine the effects on safety, therefore the application SSAM is used to analyse simulated vehicle trajectories for conflicts. The traffic flow of the airside road traffic system is simulated for an average day with an average number of flight movements. The flight planning data of Thursday November 19 2015 is combined with static handling times and the number of vehicles needed in a handling process into an origin destination matrix (OD matrix). The OD matrix is multiplied by a matrix factor to account for the difference between the amount of vehicles in 2015 and 2025. A period of 3 hours and 40 minutes containing 2 peak moments is simulated.

The effects on travel time, travel distance, robustness, and safety are determined with the simulation results and the SSAM analysis. Designs of the road traffic system that allows traffic movement in both ways around the pier result in better travel times, travel distances, and robustness. When traffic is only allowed to travel in one direction around the pier the number of conflicts is the lowest. More complicated road section designs with overtaking areas lead to better travel time and worse safety in comparison with alternatives that have one lane per direction. The effects of a junction design are smaller in comparison with the effects of a road section design. Turning lanes result in better travel times, travel distances, and safety results. The *voorrangsplein* has the best robustness results. There is no alternative that has the best result in all aspects, and there is no alternative that improves all aspects of the base situation. The one-way with two lanes and equal crossings with turning lanes has significantly different results compared to the design of the base situation, but most of them are negative. The two-way with the *voorrangsplein* design and the one-way with equal crossings design are significantly different from the results of the base design on all aspects but one.

The effects on travel time, travel distance, robustness, and safety are tested on five design alternatives applied to two general road traffic system configurations. Other configurations found on the airside of AAS are piers that are independent road traffic subsystems attached to the main road, with or without passage roads through the pier. The configuration of the road traffic system influences the number of possible routes a road user can take. Traffic has multiple route options from their origin to their destinations when the pier is an integral part of the road traffic system, under normal circumstances and when an accident occurs. When the pier is an independent subsystem attached to the main road there is only one route for through traffic, and depending on the configuration of the independent subsystem there are multiple or single routes for the destination traffic. The road section design with the best performances does not change when the configuration of the road traffic system changes. But the best junction designs for the aspects travel distance and robustness do change. Changing the functionalities of a pier has an evenly spread effect on the design alternatives, and would therefore not change the outcome.

The stakeholders involved in the decision making process for the design of the airside road traffic system are divided into four groups. The four stakeholder groups find different aspects more important than others. Their position on the aspects is determined with the Analytical Hierarchy Process (AHP) method, on which the weights of assessment are based. The departments PMA, ADI, and CMC, the bus company, handling companies, the authority officers, the kMar, and Customs mostly have the same preferences in the aspects. The two-way design with the *voorrangsplein* is the most effective design alternative for pier B for the first three stakeholder groups. The fourth group, the department Development, has different preferences and therefore a different advice. The base design is the most effective for this group, but if the base design is taken out of the equation the shared space with equal crossing and turning lanes alternative is the most effective. In the general pier configurations the design of the base situation is the most effective for all stakeholder groups. The design alternatives suggested in this research only require small infrastructural interventions, when the budget is made available the process can be completed within a couple of months.

The main conclusion of this research is that the infrastructural design alternatives tested in this research all improved at least one aspect of the research aspects compared to the base situation. There was no design alternative that improved all aspects. Based on the assessments of the majority of the stakeholder groups the two-way design with the *voorrangsplein* is the best design for pier B. And the shared space design and equal crossing with turning lanes or the *voorrangsplein* also score better than the base design in the assessments. So the advice for the Schiphol Group is to further investigate these three designs, and especially the two-way design with the *voorrangsplein*. In the general pier configurations the design of the base situation is the best, and the second best results are for the two-way design and equal crossings.

Further research should focus on the driving conditions on airside and their translations into simulation studies, and the application of shared space in simulation models. A broader concept of costs and policy alternatives should be part of further research on the airside road traffic system of AAS.

SAMENVATTING

Amsterdam Airport Schiphol (AAS), een vliegveld dichtbij Amsterdam in Nederland, heeft de ambitie om het meest geprefereerde vliegveld van Europa te zijn. In 2014 zijn er 55 miljoen passagiers vertrokken naar 296 bestemmingen, is er 1,6 miljoen ton aan cargo getransporteerd, en zijn er 438.000 vluchtbewegingen uitgevoerd. Het aantal passagiers en vliegbewegingen groeit nog steeds elk jaar. De luchtzijde van AAS is het gebied waar vliegtuigen landen, opstijgen en worden afgehandeld op de platformen en aan de gates. De gebruikers van afhandelingsvoertuigen, samen met de *Airport authority*, de Douane en de '*Koninklijke Marechaussee' (KMar*) gebruiken het luchtzijdige wegverkeerssysteem. Het luchtzijdige wegverkeerssysteem is een niet-publiek wegverkeerssysteem, bestaande uit een hoofdweg en randwegen rondom de pieren. De problemen die ondervonden worden op het luchtzijdige wegverkeerssysteem zijn vertragingen en verkeersongelukken.

De focus van dit onderzoek is op het vinden van een infrastructurele ontwerp dat het luchtzijdige wegverkeerssysteem van de randwegen rondom de pieren van AAS verbetert. Het doel van dit onderzoek is een systematische aanpak om de effecten van de infrastructurele ontwerpen toe te passen op luchtzijdige wegverkeerssysteem van alle soorten. Effectiviteit wordt getest op reistijd, reisafstand, robuustheid, veiligheid, ruimtegebruik en kosten. Het eindproduct van dit onderzoek is een advies aan de Schiphol Group over het meest effectieve ontwerp voor de randwegen rondom de pieren. De hoofd onderzoeksvraag is: "Hoe kan het ontwerp van het luchtzijdige wegverkeerssysteem rondom de pieren van Amsterdam Airport Schiphol worden verbeterd op het gebied van reistijd, reisafstand, robuustheid, veiligheid, ruimtegebruik en kosten?"

In dit rapport worden eerst de karakteristieken van het volledige luchtzijdige wegverkeerssysteem in de basissituatie en de actoren die erbij betrokken zijn geanalyseerd. Als tweede wordt literatuur over ontwerpen van de openbare weg en wegverkeerssystemen bestudeerd om infrastructurele ontwerpalternatieven op te baseren. Als derde wordt de keuze van een simulatiemodel bepaald met een literatuur studie naar beschikbare simulatie modellen. Daarna worden de ontwerpalternatieven gesimuleerd op het luchtzijdige wegverkeerssysteem van een pier en generieke configuraties van dezelfde pier als casestudy voor het gehele luchtzijdige wegverkeerssysteem. Als vijfde worden de aspectresultaten van de simulaties geanalyseerd en vergeleken met de resultaten van het ontwerp van de basissituatie. En als laatste is een beoordeling van de ontwerpalternatieven met een multi criteria analyse (MCA) en de implementatiestappen van de ontwerpalternatieven worden ook besproken.

Karakteristieken van het luchtzijdige wegverkeerssysteem en actoren

De karakteristieken van het gehele luchtzijdige wegverkeerssysteem worden geanalyseerd om inzicht te geven in de mogelijkheden en beperkingen van het wegverkeerssysteem. Het luchtzijdige wegverkeerssysteem van AAS heeft dezelfde verkeersregels, wegmarkering en verkeersborden als op de publieke weg. Echter, fietsen is verboden en voetgangers hebben geen voorrang. Het snelheidslimiet op het luchtzijdige wegverkeerssysteem is 30 km/h. De karakteristieken van het wegverkeerssysteem zijn divers, de configuratie en functionaliteiten van een pier hebben invloed op de karakteristieken. De wegbreedtes liggen tussen 7 en 12 meter. De verschillende groottes van de vliegtuig opstelplaatsen bepalen het type vliegtuig dat kan worden aangesloten op de gates en het aantal voertuigen dat nodig is over het afhandelingsproces. Passagiers worden ook gebracht naar en gehaald van de vliegtuigen met bussen die tussen de terminal en de platformen rijden. Het luchtzijdige wegverkeerssysteem is verbonden met een complex ondergronds netwerk van bagagehallen met meerdere in- en uitgangen. De bussen, cateringwagens, brandstofverdelers, schoonmaakbusjes, toilet/water-busjes, bagage treintjes, pallettreintjes, push-back wagens en rolbandhellingen die te vinden zijn op het luchtzijdige wegverkeerssysteem hebben verschillende snelheden, lengtes, breedtes en draaihoeken. De bussen op luchtzijde hebben deuren aan de rechterzijde, waardoor bus parkeerplaatsen zich alleen aan de rechterkant van de weg mogen bevinden. De meeste ongelukken vinden plaats bij de kruispunten van hoofdweg en randweg. Oorzaken van ongelukken op luchtzijde zijn menselijk falen, geen voorrang verlenen, botsen tegen een geparkeerd voertuig, gebrek aan heldere infrastructuur, slechte opleiding, tijdsdruk en gebrek aan handhaving.

Bij het veranderen van de infrastructuur zijn veel actoren bij betrokken, ieder met eigen belangen en middelen. De actoren in het besluitvormingsproces zijn te onderscheiden als organisatorische actoren en gebruikers. De afdelingen Process Management Airside (PMA), Analysis, Development, and Innovations (ADI), Construction & Maintenance Control (CMC), Maintenance Operations (MO) en Development zijn organisatorische actoren in het besluitvormingsproces. De gebruikers van het luchtzijdige

wegverkeerssysteem zijn het busbedrijf, de *authority officers*, de kMar, de Douane, de hulpdiensten en de afhandelaren. De hulpdiensten en afdeling MO moeten geïnformeerd worden tijdens het proces. De afdeling Development, de kMar en de Douane moeten tevreden worden gesteld. De afdelingen PMA, ADI en CMC, de *authority officers*, het busbedrijf en de afhandelaren zijn de belangrijkste deelnemers.

B-pier is gekozen als een voorbeeldstudie omdat deze pier de meest uniforme vorm, uniforme lengte, een busstation, en een thuisbasis voor een technische dienst heeft. De randwegen rondom de pier hebben drie aansluitingen met de hoofdweg en is een integraal deel van het gehele wegverkeerssysteem voor doorgaand verkeer en bestemmingsverkeer. De weg door de doorgang in de pier biedt meerdere routes voor bestemmingsverkeer op de pier.

Infrastructurele ontwerpalternatieven

Een literatuurstudie van de wegontwerpen op de publieke weg, de luchtzijde van AAS en de luchtzijde van andere vliegvelden heeft geresulteerd in drie wegsectie ontwerpen en vijf knooppuntontwerpen. Tweerichtingswegen, eenrichtingswegen, shared zones, gelijke kruisingen, gelijke kruisingen met aparte afslagen en rotondes worden al toegepast op luchtzijdige wegverkeerssystemen. Het voorrangsplein komt al wel voor op de publieke weg, maar wordt nog niet toegepast op de luchtzijde van vliegvelden.

Ontwerpvarianten van deze acht ontwerpen moeten rekening houden met de niet-verwijderbare elementen en weggebruikers, en voldoen aan de regels en regulatie om te worden toegepast. De bussen kunnen niet rijden en parkeren aan de gevel in alle eenrichting varianten met tegen de klok rijdend verkeer, de rotonde is te groot of voldoet niet aan de dimensie-eisen bij een kleinere variant, en varianten met een hele strook voor parkeren voldoen niet aan de regels. De wegsectie ontwerpvarianten tweerichting, eenrichting, eenrichting met parkeerhavens, eenrichting met verlengde vliegtuig opstelplaatsen en *shared space* voldoen. De knooppunt ontwerpvarianten gelijke kruising, gelijke kruising met aparte afslagen en het voorrangsplein voldoen. De wegsectie ontwerpen en knooppuntontwerpen die voldoen worden met elkaar gecombineerd tot twaalf ontwerpalternatieven, de combinaties tussen eenrichting verkeer en voorrangsplein zijn geen onderdeel van het verdere onderzoek.

Ruimtegebruik en kosten van de ontwerpalternatieven zijn onderdeel van de ontwerpspecificaties. Het ontwerp van het knooppunt in een alternatief heeft geen invloed op het ruimtegebruik. De tweerichting-, eenrichting-, en *shared space* alternatieven hebben hetzelfde ruimtegebruik. De eenrichting met parkeerhavens alternatieven en de eenrichting met verlengde vliegtuig opstelplaatsen alternatieven hebben een kleiner wegoppervlakte, en gebruiken minder ruimte voor de functie verkeer. De constructiekosten van een nieuw wegsectie ontwerp zijn laag. De constructiekosten voor een gelijke kruising zonder aparte afslagen zijn het drievoudige, en de constructiekosten voor een voorrangsplein zijn het viervoudige.

Simulatiemodel

De prestaties op de aspecten reistijd, reisafstand, robuustheid en veiligheid van de ontwerpalternatieven wordt gemeten met simulatie modellen van de alternatieven. Er is een keuze gemaakt uit 17 simulatieprogramma's. VISSIM is gekozen als simulatie programma omdat het een uitgebreide studie van individuele voertuigen op verschillende wegsectie- en knooppuntontwerpen biedt. VISSIM werkt met dynamische toewijzing van voertuigen, levert de gewenste uitkomst en heeft gedetailleerde rijgedrag parameters.

Het luchtzijdige wegverkeerssysteem van de ontwerpalternatieven worden geïmplementeerd in VISSIM volgens de ontwerpspecificaties. Zes voertuigtypes met verschillende lengte, breedtes en snelden zijn geïmplementeerd. Om de robuustheid van een ontwerpalternatief te bepalen wordt de totale reistijd in een ongeluksscenario gemeten en vergeleken met de totale reistijd onder de normale omstandigheden. VISSIM kan niet de effecten op veiligheid bepalen, daarom wordt de applicatie SSAM gebruikt om de gesimuleerde voertuigtrajecten te analyseren op conflicten. De verkeerstromen op het luchtzijdige wegverkeerssysteem worden gesimuleerd voor een gewone dag met een gemiddeld aantal vliegtuigbewegingen. De vluchtplanning data van donderdag 19 november 2015 wordt gecombineerd met statische afhandelingstijden en het aantal voertuigen nodig voor het afhandelingsproces in herkomst bestemming matrices (OD matrices). Er zijn twee voertuigcomposities en twee sets OD matrices, een voor de bus en een voor het afhandelingsverkeer. De OD matrices worden vermenigvuldigd met een matrix factor om de rekening te houden met de verschillen tussen het aantal voertuigen tussen 2015 en 2025. Een periode van 3 uur en 40 minuten, waarin twee piekmomenten zitten, wordt gesimuleerd.

Effecten van ontwerpalternatieven

De effecten op reistijd, reisafstand, robuustheid en veiligheid zijn bepaald met de simulatieresultaten en de SSAM analyse. Ontwerpen van wegverkeerssystemen die verkeer in meerdere richtingen rondom de pier toelaten hebben betere resultaten voor reistijd, reisafstand en robuustheid. De *shared space* alternatieven hebben de laagste totale reistijd en extra reistijd in he ongeluk scenario. Voertuigen in de tweerichting alternatieven leggen de minste reisafstand af. Bij eenrichting ontwerpen, waar verkeer maar in één richting rondom de pier kan reizen, is het aantal conflicten het laagst. De eenrichting alternatieven hebben de beste veiligheid. Gecompliceerde wegsectie ontwerpen met inhaalgebieden leiden tot betere reistijdresultaten en slechtere veiligheidsresultaten in vergelijking met wegsectie ontwerpen die één strook hebben per richting. Gelijke kruisingen met aparte afslagen resulteren in betere reistijd, reisafstand en veiligheid resultaten. Het voorrangsplein heeft de beste robuustheid resultaten.

Er is geen enkel alternatief dat voor elk aspect het beste resultaat heeft, en er is geen enkel alternatief dat alle aspecten van de basis situatie verbetert. *Shared space* gecombineerd met gelijke kruisingen met aparte afslagen alternatief heeft een lagere reistijd dan de basissituatie. De reisafstand van de basissituatie is het kortst, en kan niet worden verbetert. De andere tweerichting alternatieven en alle *shared space* alternatieven hebben een lager percentage extra reistijd in het ongeluk scenario, en zijn meer robuust. Er is groot aantal alternatieven dat het aantal conflicten verminderd. Door te kiezen voor een van de twee andere tweerichting alternatieven, de eenrichting alternatieven, het *shared space* met gelijke kruisingen alternatief of het *shared space* met voorrangsplein alternatief wordt de veiligheid verbeterd.

Het eenrichting ontwerp in combinatie met gelijke kruisingen met aparte afslagen heeft significant andere resultaten dan het ontwerp in de basis situatie, maar het grootste deel van de resultaten verschild negatief. Het ontwerp van tweerichting met het voorrangsplein en het eenrichtingsontwerp met gelijke kruisingen zijn significant anders op vijf van de zes aspecten. Het gebruik van andere parameters voor rijgedrag heeft geen significante invloed op de resultaten.

Generieke applicatie

Het wegverkeerssysteem aan de luchtzijde van AAS bestaat uit een hoofdweg met vijf pieren die verbonden zijn met de hoofdweg als onafhankelijke subsystemen en twee pieren die een integraal onderdeel zijn van het gehele systeem. Pier B is een integraal onderdeel van het gehele systeem, om de effecten van reistijd, reisafstand, robuustheid en veiligheid te bepalen voor de andere pieren zijn vijf ontwerpalternatieven getest op twee generieke pier configuraties.

De configuratie van het wegverkeerssysteem heeft invloed op het aantal mogelijke routes voor een weggebruiker. Verkeer heeft meerdere route opties van herkomst naar bestemming wanneer de pier een integraal onderdeel is van het wegverkeerssysteem, zowel onder normale omstandigheden als wanneer er een verkeersongeluk plaatsvind. Als de pier een onafhankelijk subsysteem is, is er maar een route voor doorgaand verkeer. En afhankelijk van de configuratie en ontwerp van het subsysteem, zijn er één of meerdere routes voor het bestemmingsverkeer.

Het wegsectie ontwerp met de beste prestaties verandert niet als de configuratie van de pier verandert. De alternatieven van tweerichting en *shared space* hebben de beste resultaten voor reistijd, reisafstand en robuustheid. Bij eenrichting ontwerpen is de veiligheid het best. Maar voor de aspecten reisafstand en robuustheid veranderen de beste knooppuntontwerpen. Gelijke kruisingen met aparte afslagen resulteren in de beste reistijd-, robuustheid- en veiligheid resultaten, maar de reisafstand is beter wanneer een gelijke kruising zonder aparte afslagen wordt toegepast. Het veranderen van de functionaliteiten van de pier heeft een gelijkmatig verdeeld effect op de ontwerpalternatieven, en verandert de uitkomst van beste ontwerpalternatieven niet.

Beoordeling en implementatie

De effecten van de ontwerpen op de aspecten worden beoordeeld in een multi criteria analyse. De multi criteria analyse houdt rekening met de verschillende aspecten en laat gewichten toe in de beoordeling. De effecten van de ontwerpalternatieven zijn gestandaardiseerd met de methode van maximale standaardisatie. Het overzicht van gestandaardiseerde effect scores geeft een systematisch overzicht van de consequenties van het verschillende ontwerpen.

De actoren die betrokken zijn bij het besluitvormingsproces voor het ontwerp van het luchtzijdige wegverkeerssysteem zijn onder te verdelen in vier groepen. De afdelingen PMA, ADI en CMC zijn de eerste groep. Het busbedrijf en de afhandelaren zijn de tweede groep. De *authority officers*, de kMar en de Douane zijn de derde groep. En de vierde groep bestaat uit de afdeling Development. Hoe belangrijk zij aspecten vinden bepaald hun set van gewichten.

De vier sets van gewichten en een set met gelijke gewichten worden toegepast in de beoordeling van de ontwerpalternatieven op basis van gestandaardiseerde effect scores. De totale effect scores laten zien dat het tweerichtings ontwerp met voorrangsplein het meest effectieve ontwerp is voor pier B voor drie van de vier actorgroepen. Voor de groep Development is het ontwerp van de basissituatie, tweerichting met gelijke kruisingen met aparte afslagen, het beste. Voor de generieke pier-configuraties is het ontwerp van de basissituatie het meest effectief.

De ontwerpalternatieven die zijn besproken en toegepast in dit onderzoek vereisen kleine infrastructurele ingrepen. Deze ingrepen zouden gepland moeten worden binnen al geplande werkzaamheden waar mogelijk. Wanneer er voldoende budget is vrijgemaakt kan het ontwerp in een paar maanden geïmplementeerd zijn.

Conclusie

De hoofdvraag van dit onderzoek is hoe het ontwerp van het luchtzijdige wegverkeerssysteem kan worden verbeterd. Het ontwerp in de basis situatie rond pier B is tweerichting en gelijke kruisingen met aparte afslagen. Het tweerichting met gelijke kruisingen alternatief verbeterd de robuustheid en veiligheid in alle pier-configuraties, en verbeterde de reisafstand in de onafhankelijke subsystemen. Het twee richting alternatief met voorrangspleinen verbetert de robuustheid in alle configuraties en de veiligheid voor pier B. Het eenrichting met gelijke kruisingen alternatief verbetert de veiligheid wanneer deze is toegepast op pier B, en is niet toegepast op andere configuraties. Het eenrichting alternatief en gelijke kruisingen met aparte afslagen verbetert de veiligheid in alle pier configuraties. De eenrichting alternatieven met parkeerhavens en verlengde vliegtuig opstelplaatsen zijn alleen toegepast op pier B, en verbeterden allemaal het ruimtegebruik. De *shared space* alternatieven met gelijke kruisingen en voorrangsplein verbeterden de robuustheid, maar zijn alleen getest op pier B. Het *shared space* en gelijke kruisingen met aparte afslagen alternatief verbeterde de reistijd en robuustheid voor alle pier configuraties.

De hoofdconclusie van dit onderzoek is dat de twaalf infrastructurele ontwerpalternatieven besproken en toegepast in dit onderzoek allemaal ten minste één van de zes aspect verbeteren ten opzichte van de basissituatie. Er was geen ontwerpalternatief dat alle aspecten verbeterde. Op basis van de beoordeling van de meerderheid van de actorengroepen is het tweerichtingsverkeer ontwerp met voorrangsplein het beste ontwerp voor pier B. En de *shared space* en gelijke kruisingen met aparte afslagen of voorrangspleinen scoren ook beter dan het basisontwerp in de MCA beoordeling. Dus het advies voor de Schiphol Group is om verder onderzoek te doen naar deze drie ontwerpen, en in het bijzonder het tweerichtingsverkeer ontwerp met voorrangsplein. In de generieke pier configuratie is het huidige ontwerp het beste, met daarna het tweerichtingsverkeer ontwerp met gelijke kruisingen.

Nader onderzoek moet zich richten op de rijomstandigheden aan de luchtzijde en hoe deze moeten worden vertaald naar simulatie studies. En de applicatie van *shared space* in simulatie modellen. Een breder beeld van alle kosten en beleidsalternatieven moeten deel uitmaken van verder onderzoek naar het luchtzijdige wegverkeerssysteem van AAS.

NOTATION

Aircraft stand: Area where aircraft are handled. In Dutch: *Vliegtuigopstelplaats* (VOP).

Airside road traffic system: The road traffic system on airside, at AAS the airside road traffic system consists of the main road (the Rinse Hofstraweg) and the service roads around the piers.

Bus@gate: The concept provides bus transport from arriving gates towards security filters at the terminal building for non-clean passengers.

Configuration (of the pier road traffic system): Shape and function of pier within the airside road traffic system.

Lane: Single road in one direction.

Non-clean passengers: Passengers of the flights originating from countries that have a lower security screening level than EU legislation prescribes.

Robustness: The ability to fulfil the function for which the network is designed, even in non-regular situations which differ strongly from regular user conditions.

Roundabout: A traffic square where the traffic on the square has priority, and the roads connect radially.

Safety: The methods and measures for reducing the risk of a person using the road network being killed or seriously injured.

Shared space: Traffic concept where all users are equal and respect other users. The design and layout has a balance of traffic, human exchange, and other spatial functions.

Slow vehicles: Vehicles that are incapable of driving faster than 15 km/h.

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

Voorrangsplein: A junction with elements of a priority crossing and a roundabout that promotes lower speeds at junctions.

ABBREVIATIONS

AAS	Amsterdam Airport Schiphol
ADI	Analysis, development, and innovations (department at Schiphol Group)
AHP	Analytical Hierarchy Process
CMC	Construction & maintenance control (department at Schiphol Group)
GPU	Ground power unit
ICAO	International civil aviation organisation
EASA	European aviation safety agency
kMar	*Koninklijke Marechaussee*
MCA	Multi criteria analysis
MO	Maintenance operations (department at Schiphol Group)
PET	Post-encroachment time
PMA	Process management airside (department at Schiphol Group)
TCT	Time-to-collision

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1 INTRODUCTION

The focus of this research is on finding the infrastructural design that improves the effectiveness of the airside road traffic system of the service roads around the piers of Amsterdam Airport Schiphol (AAS). Effectiveness is tested on travel time, travel distance, robustness, safety, surface used, and costs. The end product of this research is an advice for the Schiphol Group on what the most effective design is for the service roads around the piers.

First the context of the research is provided, after which earlier research is discussed, and the problem is stated. Second, the aim and objective of this research are formulated. Third, the objectives are translated into the research question and the sub questions. Fourth, the limitations of this research are defined with the scope. Fifth, effectiveness is defined. And last, the approach shows how the sub questions and products are interrelated and what the planning for this research is.

1.1 BACKGROUND AMSTERDAM AIRPORT SCHIPHOL

Located near Amsterdam in the Netherlands, Amsterdam Airport Schiphol (AAS) has the ambition to be Europe's most preferred airport. In 2015, 319 destinations were available, of which 295 were available to passengers. The number of passengers has grown with 6.0% to 58 million, there were 451,000 flight movements, and 1.6 million tonnes of cargo was transported (Schiphol Group, 2016).

Air France – KLM is the home carrier of AAS, providing a large part of the flight movements at the airport. More than 500 companies are located at Schiphol, providing employment to 65,000 people. The aviation sector of KLM and Schiphol represents 3% of the national income of the Dutch economy.

The terrain on which AAS is located is 2,787 hectares and consists of six runways and 222 aircraft stands. The runways are located towards different wind directions around the terminal building. There is one terminal building with several piers.

1.1.1 SCHIPHOL GROUP

The core activity of the Schiphol Group is the exploitation of AAS. The enterprise also has full ownership of Rotterdam The Hague Airport and Lelystad Airport and has a majority interest of 51% in Eindhoven Airport. The enterprise has a strategic collaboration with foreign airports including of Aéroports de Paris, John F. Kennedy Airport, Incheon Airport, and Brisbane Airport, and the Schiphol Group is active at the airports of Hong Kong and Aruba (Schiphol Group, 2016). Schiphol Group has four stakeholders: the '*Staat der Nederlanden*' (69.8%), the municipality of Amsterdam (20.0%), the municipality of Rotterdam (2.2%), and Aéroports de Paris (8.0%).

The Schiphol Group (2016) wants to improve the processes and make them more efficient. The reliability and efficiency of the (handling) process also have to improve. They want to increase and better exploit the capacity available. A goal is to have more flexible facilities so they can adjust the facilities to the wishes of the airline.

1.1.2 AIRSIDE SERVICE ROADS

Airside is the area where aircrafts take off, land, and are handled at the platforms. The handling services, enforcers, and other personnel use the airside service roads to travel between aircraft stands and their offices. Roads on airside are non-public, and have their own system. The service roads are located around terminal buildings, and their configuration depends on the type of airport. AAS is one of the only airports in the world with a one-terminal concept with piers. Most airports have multiple terminal buildings that are only connected with the service roads. The one-terminal concept of AAS leads to the unique road traffic system configuration of one main road and multiple road subsystems for the piers.

The handling process at AAS is serviced by ground vehicles for baggage, cargo and passenger handling, water refreshment, fuelling, catering services, and others which use the airside road traffic system along with Airport Authority, Customs and the '*Koninklijke Marechaussee' (KMar*).

The airside road traffic system of the service roads is a non-public road traffic system. The Masterplan of 2020-2025 includes a new pier, with the working name pier A, Southwest of the current pier B. For this research the Masterplan is assumed to be completed, and the road traffic system of 2025 is used as the base situation. The road traffic system consists of the main service road called the *Rinse Hofstraweg*, service roads around the six major piers A to G that connect to the main service road, and service roads along pier H and towards the platforms.

1.2 PROBLEM DEFINITION

The airside road traffic system of AAS is a small-scale non-public road network consisting of one main road with multiple independent road traffic subsystems that loop back to the main road. Origins and destinations (aircraft stands, baggage halls, bus stations, service points, etc.) are mostly on these independent subsystems, the main road is mostly for throughput. The network is used by a high diversity of vehicles.

1.2.1 PROBLEM EXPLORATION

The airside road traffic system is secondary to the aircraft traffic system. The dimensions of the airside roads is the inverted space of the aircraft manoeuvring areas and aircraft stands, which means that the width of the road is not the same for each pier and can cause problems with broader vehicles. There have been incidents where vehicles had to partly divert to the aircraft stand to pass wide oncoming vehicles.

The large amount of handling processes of aircraft at AAS require a lot of vehicles to drive on the service roads to and from the aircraft stands on the independent subsystems of service roads. The high diversity of vehicles means that there are vast differences in width, length and speed of the vehicles using the roads. These two facts combined result in complex and large vehicle flows at the connection points of the main road and the service roads. This is reflected in the high number of incidents at the beginnings of the piers mostly caused by human error, as was reported by Borsboom (2012).

After pier F was converted from a two-directional traffic situation to a one-directional traffic situation, the number of incidents have decreased at the beginning of the pier according to an internal report of the Schiphol Group on incidents between 2005 and 2011 (Bolding, 2012).

The airside road traffic system as a concept is comparable to systems in distribution centres where there is one main axis and several independent subsystems, as seen in ports, mail sorting centres, warehouses, and baggage systems. These systems operate in a 24/7 climate under high time pressure, and are designed with possibilities of extension to accommodate future growth. There are differences between the type of systems and the system at AAS; the vehicles on the service roads stay a longer time period on the aircraft stand than on the road between points and the possibilities of extension are very limited. Problems experienced by these types of systems are with bringing down the travel time and using the available space optimally.

This leads to the following *problem statement*: *The airside road traffic system around the piers of Amsterdam Airport Schiphol suffers from delay and has traffic accidents.*

There have been two prior research studies done on the road traffic system of AAS. The research by Borsboom (2012) was an analysis on the safety, robustness, reliability, and utilisation of the airside road traffic system of the airside at AAS and provided improvement possibilities. The conclusion of this research was that in the current situation reducing the collisions at the beginning of the piers could result in financial savings, by having two lanes per direction the robustness should increase, and rerouting of traffic along the viaduct routes in the west should lead to a more optimal utilisation of the complete road system.

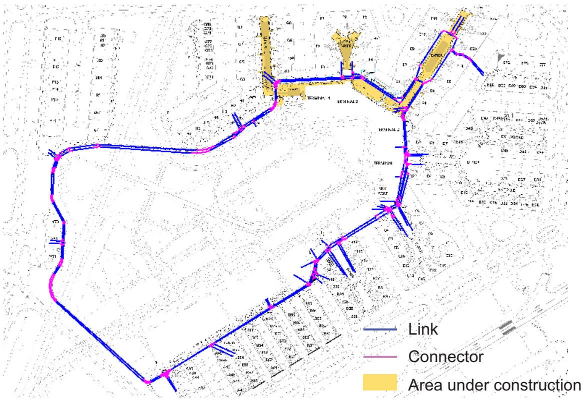


Figure 1: Layout of the road traffic system in a VISSIM by van der Horst (2014)

The research of van der Horst (2014) focused on network performance and traffic flow of the main road of the airside road traffic system using a VISSIM simulation model. The results of this research were practical solutions to the problems found on the main road, tested on network performance and traffic flow. The main conclusion of this research was that it is not too full on the traffic system. Other conclusions were that to increase network performance vehicles should be encouraged to drive via the west side, the number of slow vehicles on the network during peak hours should be decreased, and the number of accidents at piers should be decreased. Network performance did not change when the whole network had two lanes per direction.

1.2.2 KNOWLEDGE GAPS

Some research has already been done on the road traffic system of AAS, but the focus of the research has never been specifically on the service roads around the piers. Their function as access road requires more detailed solutions than suggested in the analysis of the entire system and other solutions than the previously assessed through road. To find the most optimal design of the service roads around the piers insight is needed into:

- Infrastructural design options that can be applied to the airside service roads of AAS: that take into account the non-removable elements and airside users, and complies to the rules and regulation;
- The type of simulation model needed to study the effects the designs of the road traffic system has on travel time, travel distance, robustness, and safety;
- The relation between the one-directional traffic situation and a decreasing number of incidents as was found on the redesigned pier F;
- The characteristic elements of pier road traffic systems affecting the optimal design choice for a design of the service road around a pier.

1.2.3 AIM AND OBJECTIVES

In this section the aim and objective are formulated. The *aim* is: *To optimise the* travel time, travel distance, robustness, safety, surface used, and costs *of the airside road traffic system of the service roads around the piers of AAS.*

The *scientific objective* is to develop a systematic approach to apply the effects that different infrastructural design alternatives have on the airside road traffic systems of the pier, depending on the characteristics of the airside road traffic system.

1.2.4 RESEARCH QUESTIONS

In this section the main research question and sub questions are formulated based on the aim and objectives of Section 2.

The *main research question* is:

"How can the design of the airside road traffic system around the piers of Amsterdam Airport Schiphol be improved in terms of travel time, travel distance, robustness, safety, surface used and costs?"

To answer this main research question the following sub questions (SQ's) have to be answered. Rising questions define the sub questions.

SQ 1. What are the characteristics of the airside road traffic system of the service roads around the piers in the base situation?
  - Which rules and what regulation are applied at the roads of airside, and what is the main difference with normal traffic regulation?
  - What are the characteristics of the service roads in the current situation?
  - What are the future developments of the service roads according to the Masterplan 2020-2025?
  - What types of ground vehicles drive on the service roads and what are their characteristics?
  - How is the airside road traffic system currently being used?
  - What are the characteristic elements of each pier?
  - What stakeholders are involved in the decision making process, and how?

SQ 2. Which infrastructural design alternatives can be applied to the airside road traffic system of the service roads around the piers?
  - Which designs of traffic systems are applied to public roads?
  - Which designs of road traffic systems can currently be found on airsides of airports with similar aircraft movements?
  - Which designs of road traffic systems can be applied to the service roads of AAS, and what are their specifications, surface used, and costs?

SQ 3. What type of model can be used for simulating the airside road traffic system?

- What types of model are available?
- Which types suit the model specifications of the base situation and the infrastructural design alternatives?

SQ 4. What are the effects of the infrastructural design alternatives on travel time, travel distance, robustness, and safety?

- What are the travel time, travel distance, robustness, and safety of the base situation?
- What are the travel time, travel distance, robustness, and safety of the infrastructural design alternatives when implementing them on the pier?

SQ 5. How do the characteristic elements of a pier relate to the effects of the design alternatives when applied on the airside road traffic system?

- What is the influence on travel time, travel distance, robustness, and safety in other pier configurations?
- How can the effects be applied to other piers with different characteristics?

1.3 SCOPE OF THE RESEARCH

In this section the geographical scope, time scale, user groups, design criteria, and definitions of effectiveness are defined.

Geographical scope

The scope of this research is on part of the road traffic system of the airside of AAS, and covers the service roads around the piers.

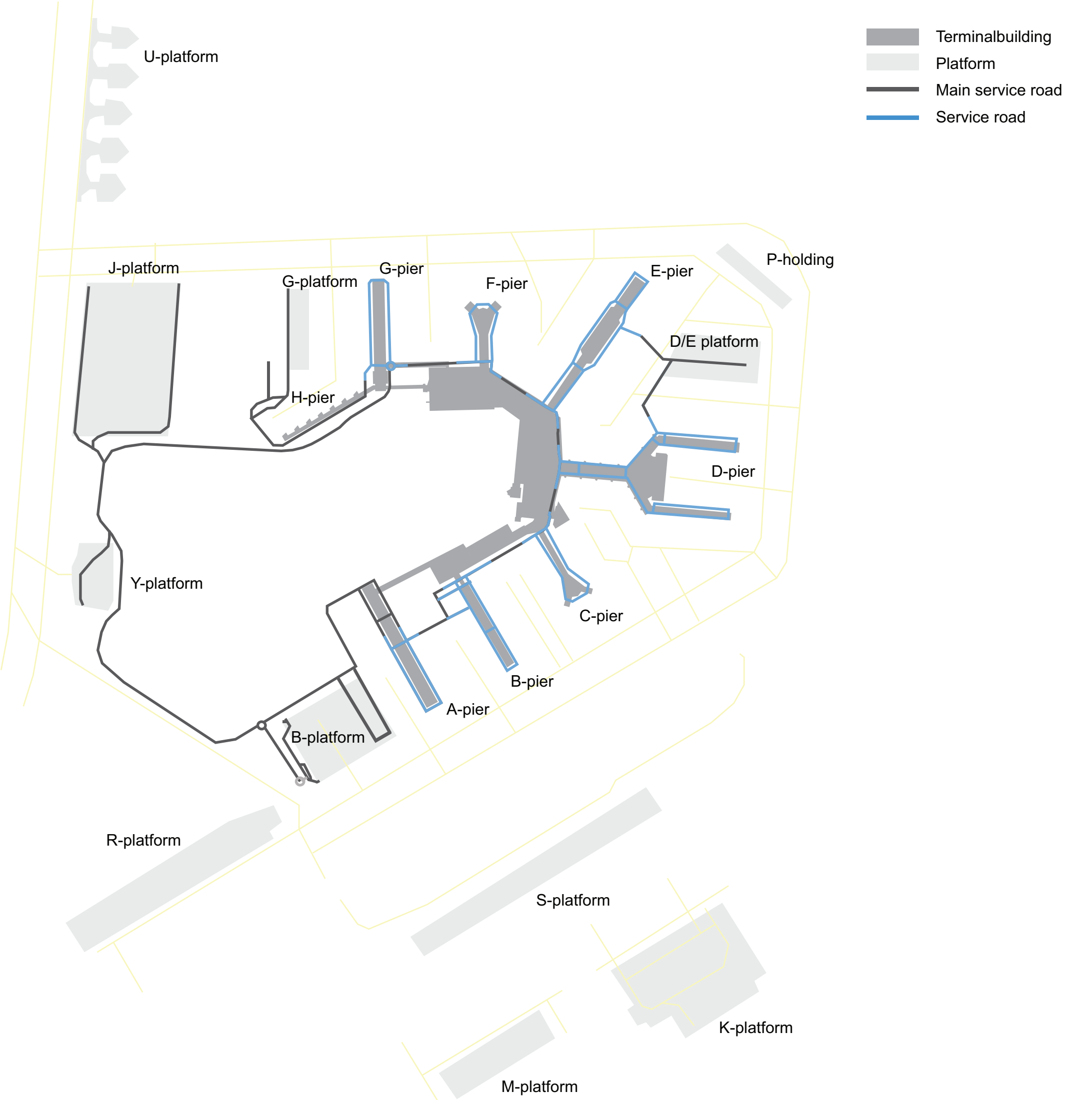


Figure 2: The airside road traffic system of the service roads of AAS

Runways, taxiways, the baggage handling system below the terminal, and the terminal are not be taken into account. The aim for this research is to find the optimal design of the service roads around the piers and the connection to the main service road. The road section design of the main service road is not part of the research. In Figure 2 an overview of the service roads and the main road in the base situation is given, the service roads in blue are the geographical scope. The service roads on and to pier H, platforms B, D/E, G, J, K, M, R, S, U, and Y and holding P are not within the scope, because these service roads are not situated around a pier.

The airside road traffic system of AAS consist of many piers, to improve the design of the entire system a case study is performed on one pier. The research on what design improves the base situation focuses on the road traffic system around one pier of AAS and generalised configurations around the same pier. The results of the case study and the general application can be applied to other piers at AAS, airside road traffic systems at other airports, or similar systems.

Time scale

The base situation for the airside road traffic system of this research takes the future developments of the Masterplan 2020-2025 with pier A and a new baggage hall into account. The planned pier A is located Southwest of the current pier B, connected to the terminal with an air bridge. The model used in this research is a simulation of an average day on the airside road traffic system. Extreme weather conditions are not be taken into account. An average day on AAS has peak hours for flights landing and departing, which coincide with the peak hours for the service vehicles. These peak hours are also part of the simulation.

User groups

Ground vehicles necessary for the handling process, busses, authority officers, and the *kMar* use the service roads of AAS airside, with a large variety of widths, lengths, speeds, and turning radii. It is not allowed to cycle on the service roads of airside. Pedestrians on airside are allowed on the platform and on the pedestrian paths, pavements, and crossings. When crossing the service road pedestrians never have priority (Schiphol Group, 2015). Therefore, for this research pedestrians and cyclists are not taken into account.

Design

To make a fair comparison the design alternatives are all infrastructural interventions. To determine which infrastructural design alternatives can be applied to the service roads of AAS the alternatives have to meet set criteria. Changing rules and regulation of the airside road traffic system is not allowed. Traffic management related design alternatives, policy related design alternatives, and autonomous vehicles are outside of the scope.

1.4 RESEARCH APPROACH

In this section the research approach, the steps of this research, and the used techniques are discussed. The approach of this research is visualised in Figure 3 as a conceptual model. The model shows the steps of this research, the products resulting from that step, and information flows of the research. The sub questions and chapters are also linked to the products of the steps. The model is based on the basic design cycle of analysis, synthesis, simulation, evaluation, and decision (Roozenburg & Eekels, 1995). The approach of this research differs slightly from the basic design cycle. In this research synthesis is not part of the cycle, the step design is used instead. This research adds problem definition and literature study to the basic design cycle as steps.

The *problem definition* defines the problem by looking at the current situation on the airside road traffic system, and consulting earlier research on the AAS airside road traffic system and similar systems. Placing the problem of the road traffic system in a broader context. The product of this phase is the problem statement, which defines the focus of this research.

The *literature study* first focuses on the different public road designs that exist, and the characteristics of those designs. Literature available on road traffic systems, road classifications, and public road designs is studied to base infrastructural design alternatives for the service roads on. The focus is then on the types of model that are available. Information on the types of simulation and analytical models is researched, documented and compared with the specifications needed for this research. The literature study is the base on which sub question 3 is answered.

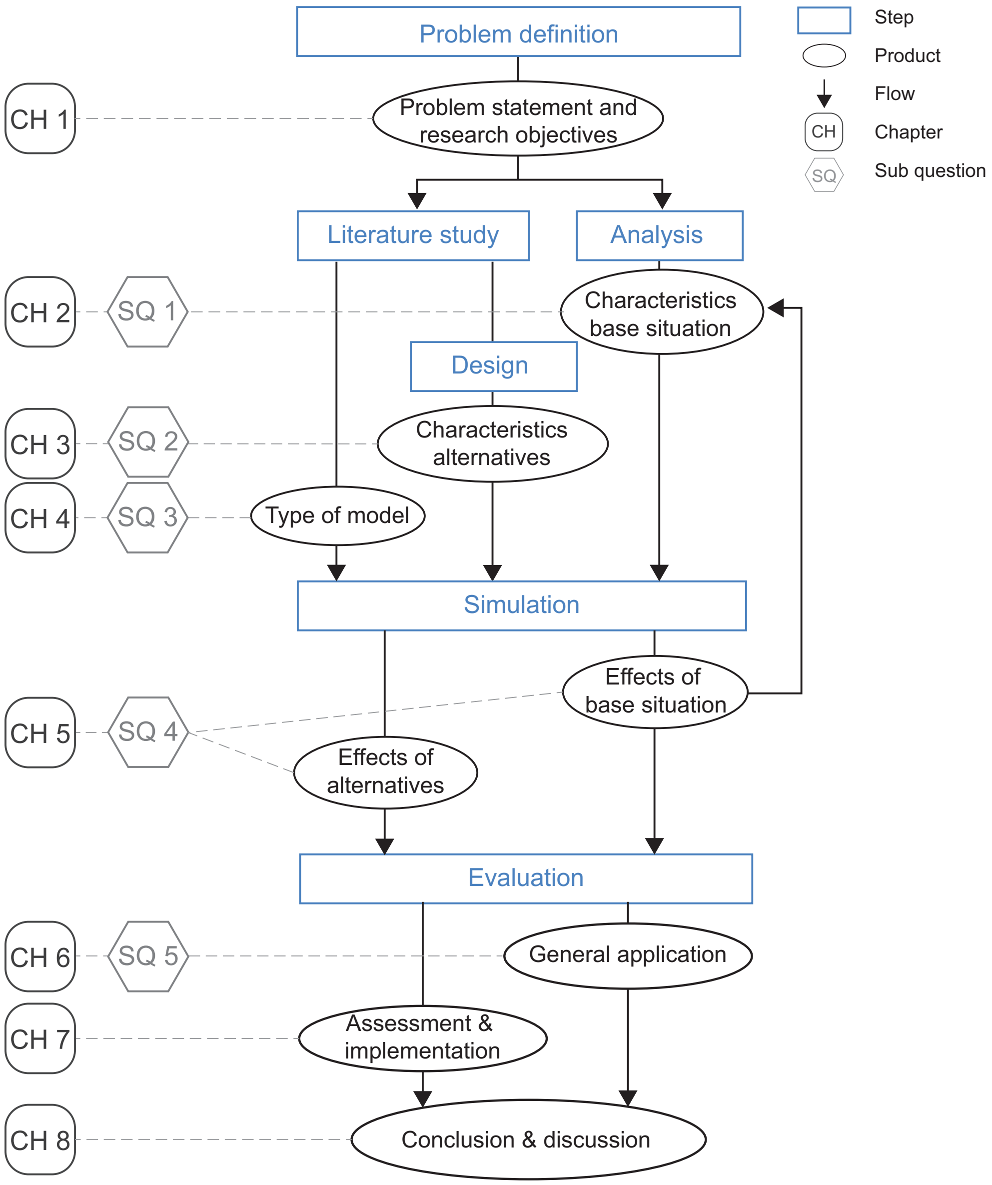


Figure 3: Conceptual model of the research approach

The *analysis* step is to better understand the base situation. With observations, maps, literature, and interviews the base situation is analysed. The rules and regulation, characteristics of the roads (length, entrances and exits of baggage storage, parking spaces, barriers, etc.), characteristics of ground vehicles (length, speed, turn radius), users and organisational stakeholder, and user experience are discussed. Part of the specifications of the model is drafted from the analysis. The product of this phase is the characteristics of the base situation, answering sub question 1. The analysis also specifies the specific characteristics of the individual piers, supporting the choice for the pier that is evaluated in the following steps. For this research the base situation and design alternatives on one pier.

In the step *design* provisional design proposals are based on the literature study on public road designs. To determine which infrastructural design alternatives can be applied to the service roads of AAS the alternatives have to meet set criteria. Part of the specifications of the model is drafted from the design. Physical characteristics of the infrastructural design alternatives, surface used and key figures for costs are the products of this step, answering sub question 2.

In the *simulation* step, a model calculates a part of the effectiveness data of the base situation and the infrastructural design alternatives on one pier. Pier B is chosen as a case study at the end of the analysis step because of its uniform shape and length, and it has a bus station and home base of technical services. The simulations produce the travel time, travel distance, the influence the incident scenario has on travel time (robustness), and conflicts by analysing vehicle trajectories (safety). According to Dijkstra et al. (2010) a micro simulation model is a suitable instrument that shows the effects of changed traffic flows on the road safety of the adopted measure. The data on effectiveness is generated for the base situation and compared to the actual characteristics for validation. After the model is validated, the infrastructural design alternatives with their characteristics are inserted into the model. Travel time, travel distance, robustness, and safety of the infrastructural design alternatives are compared with each other. Sensitivity of the results is determined and the significance of the results is tested. The effectiveness data is the product of this step, and answers sub question 4.

In the *evaluation* step, the effects and characteristics of the design alternatives on the different pier configurations are evaluated. The results of the evaluation relate characteristic elements of the road traffic system of piers to the effects, answering sub question 5. The effects and characteristics are also assessed based on the interests and power of the involved stakeholders in a multi criteria analysis (MCA). And the design and implementation process at AAS is discussed.

In the *conclusion & discussion* an answer to the research questions is given and the findings are discussed, concluding this research.

1.5 STRUCTURE OF THE REPORT

Figure 3 represents the approach of this research and the structure of this report. In *chapter 1* the problem is defined and the scientific objective and research questions are formulated. In *chapter 2* the characteristics of the base situation are described and the choice for the further researched pier is substantiated, answering sub question 1. *Chapter 3* describes possible infrastructural design on the public road and in airside conditions, answering sub question 2. The infrastructural designs that pass predetermined criteria are developed into design alternatives. *Chapter 4* first gives an overview on the available simulation models, after which a substantiated choice is made according to base situation and design characteristics. Which answers sub question 3. The data needed to operate the chosen model is also discussed, as well as face validity.

Chapter 5 presents the effects of each infrastructural design alternative implemented on pier B on the aspects travel time, travel distance, robustness, and safety, answering sub question 4. The results of all alternatives are compared with each other, and more specifically with the design of the base situation (one of the design alternatives). *Chapter 6* looks at a more general application of the infrastructural designs on other airport road traffic system configurations. Two smaller simulation studies provide the results of the design alternatives, which are compared to the advice on the best design alternative for pier B. This answers sub question 5. In *chapter 7* the effects and characteristics are assessed based on the interests and power of the involved stakeholders, this chapter also discussed the design and implementation process at AAS.

The final chapter of this research is the *conclusion and discussion*. Where the findings of this research are discussed, the main research question is answered, and recommendations for further research are given.

2 Characteristics of the base situation

In this chapter sub question 1 is answered: What are the characteristics of the airside road traffic system of the service roads around the piers in the base situation? First, the developments towards the Masterplan 2020-2025, which is considered the base situation, are presented. Second, more general information on rules and regulations is given. Third, characteristics of the service roads in the base situation are discussed, focusing on the design, boundaries, and obstacles. Fourth, the users of the service roads and their perception on the current road traffic system are discussed. Fifth, the characteristics of the ground vehicles are summed up. Sixth, safety on the road traffic system is discussed. Seventh, the organisational stakeholders that have influence on the design of the infrastructure are discusses. In the conclusion of this chapter an answer to the sub question is given.

2.1 Developments towards the base situation

The design of an airside road traffic system is a long-term decision. Therefore the base situation for this research is in the future, and takes future developments on the infrastructure into account. The base situation takes the developments on piers E and F and the Masterplan 2020-2025 design of the new pier A into account. In Figure 4 the airside road traffic system of the current situation is put side to side with the base situation of 2025.

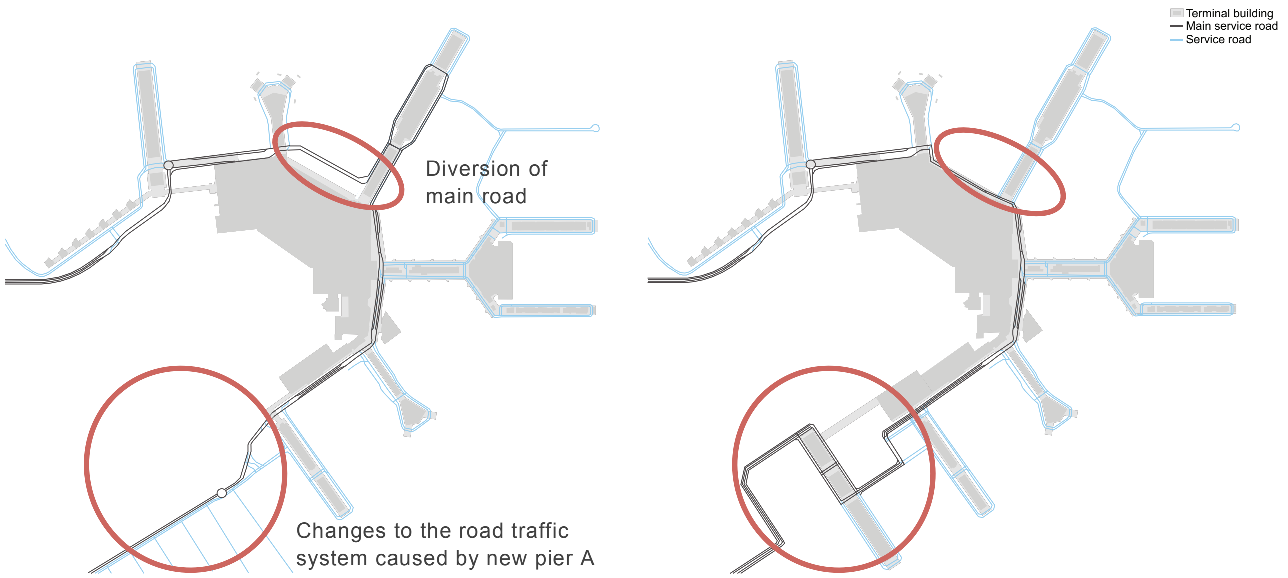


Figure 4: The current (left) and the base (right) situation of the airside road traffic system of AAS

The main service road, the *Rinse Hofstraweg*, is temporarily interrupted between the piers E and F in the current situation. The main service road is currently diverted around pier E because of construction works on the terminal building. In 2016, during this research, the main service road was restored.

The design of pier A and the service roads around the pier are from the second stage of the pier of the Masterplan 2020-2025. In the north part of the pier a bus station is located on ground level. The baggage facility *Sorteerhal Zuid* is extended towards the pier, and has extra exits and entrances. Platform B is partly relocated to make way for the new pier A, this relocation is not within the geographical scope of this research.

2.2 Rules and regulation

The road traffic system at AAS is a non-public road traffic system. On the Rinse Hofstraweg and the service roads, and in the baggage halls, parking facilities, and road tunnels the traffic rules of the *Reglement Verkeersregels en Verkeerstekens 1990* (Ministerie van Infrastructuur en Milieu, 1990) are declared applicable by AAS. The traffic signs and road markings also found on public roads are used on the airside roads, and the maximum speed of residential areas is maintained. But because of complexities of the airside some traffic rules are not applicable to the airside of AAS, the Schiphol rules (2015) contain more specific rules and regulation:

It is not allowed to cycle on airside: not on the road traffic system, the platform, or the runways. For pedestrians on airside it is mandatory to use the pedestrian paths, pavements, and crossings. The pedestrian crossings are indicated with yellow dots, and do not give priority to pedestrians. Pedestrians and cyclist are outside of the scope of this research. On the airside of AAS it is mandatory to give priority in the following order: Starting and landing aircraft, emergency vehicles with signal lights and sirens, taxiing aircraft and hovering helicopters with accompanying vehicles, passengers on foot who are guided to and from the aircraft, towed aircraft, other vehicles. Aircraft do not enter the road traffic system. Therefore, ground vehicles on the service roads only have to give priority to emergency vehicles and passengers.

Ground vehicles leaving the platform to enter the service road have to give priority to vehicles already on the service roads. Ground vehicles entering the main road have to give priority to vehicles already on the main service road.

The speed limit for vehicles on all roads on airside is 30 km/h. Baggage trains going down baggage halls, the viaducts on the *Rinse Hofstraweg*, the ramp to the *Kaagbaantunnel*, and the ramp to the tunnel at the R-platform have a speed limit of 15 km/h. But these ramps are not within the geographical scope.

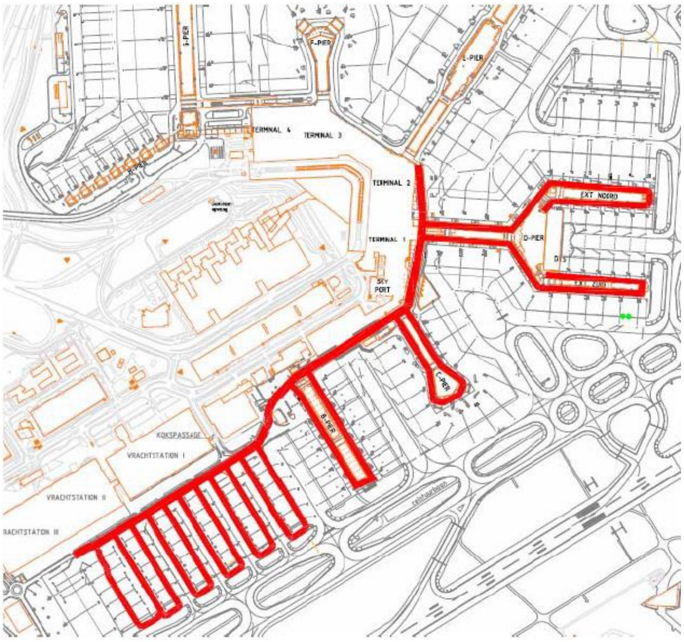


Figure 5: Route prohibited for vehicles wider than 3.90 meters (Amsterdam Airport Schiphol, 2015)

It is prohibited to drive a baggage train longer than 30 meters or 6 carts on all service roads. It is prohibited for vehicles wider than 3.75 meters and pushback trucks wider than 3.90 meters to drive between pier B and E (see Figure 5). It is not allowed for vehicles with a height of 3.80 or more to drive on the main road and service roads.

2.3 CHARACTERISTICS OF THE SERVICE ROADS AND IMMEDIATE SURROUNDINGS

The airside road traffic system of the base situation consists of the main service road called the *Rinse Hofstraweg* and service roads around the six major piers A to G that connect to the main road at two or more junctions. The service roads around the piers A, B, C, D, E, and G consist of single lanes in two directions on both sides of the piers. The service road around pier F consists of a one lane, partly two lane, one-directional road. The service roads are mainly used for destination traffic, while the main road is used by through traffic.

2.3.1 FUNCTIONAL CLASSIFICATION

The service roads of airside can be categorised according to the road types for public roads of CROW (2002).

The main service road, in black in Figure 4, is categorised as a distributor road (*gebiedsontsluitingsweg*) with a speed of 30 km/h instead of the common 50 km/h to 70 km/h. A distributor road has level crossings and is intended to connect rural or urban areas for public use. The main function of this type of road is distribution of traffic. Characteristics of a public distributor road are the double markings or physical barrier as a separation between the two directions. On the airside of AAS there are double markings.

The service roads, in blue in Figure 4, are categorised as an access road (*erftoegangsweg*) with a speed of 30 m/h. An access road is the most local type, with mixed slow traffic (bikes) and vehicular traffic travels without separation on public roads. The main function of this type of road is direct access for destination traffic. There is no separation between the two directions on the public access road. On the airside of AAS there are interrupted markings, and bikes are prohibited.

The airside road traffic system can be divided into links and nodes, where nodes connect the links to form a network. The network of the road traffic system of the service roads around the piers is a closed network. Entrances and exits to and from the network are the baggage halls, the bus stations, and the two entrances/exits at the edges of the scope.

2.3.2 AIRCRAFT STANDS

The service roads (*randwegen)* are situated between de aircraft stand and the terminal building, as can be seen at the top of Figure 6. Aircraft stands have aircraft clearing lines (6 in the figure) to mark the boundaries of an aircraft stand, vehicles are only allowed to pass these clearing lines when also handling a neighbouring stand. Vehicles are only allowed to enter and exit the aircraft stand at the service road, designated by road markings.

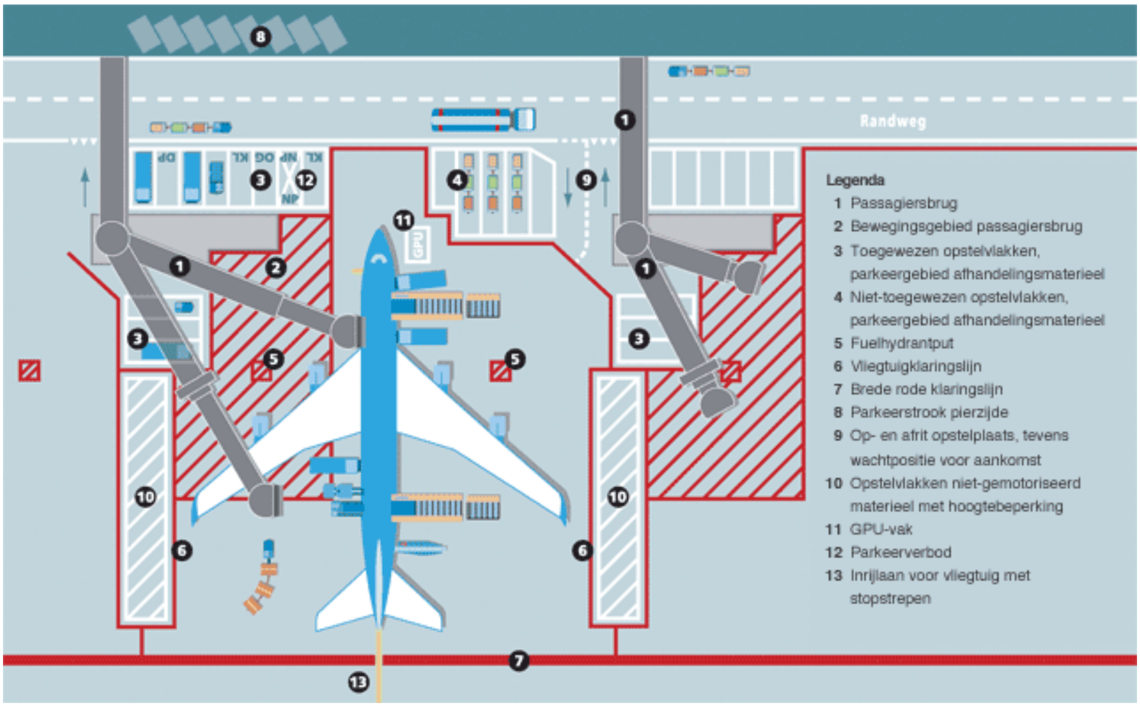


Figure 6: Schematic drawing of the situation on an aircraft stand (Schiphol Group, 2015)

At AAS there are aircraft stands for wide body aircraft and narrow body aircraft. The wide body aircraft stands at pier A and D are also used for narrow body aircraft, as can be seen in Figure 7. In the same figure the categorisation wide body/narrow body is also made. The difference in aircraft size leads to a different number of service vehicles needed per handling process.

Gate numbers are assigned on even and uneven sides. At the even side of pier B there are a number of bus gates on the first level with stairs that lead to individual bus stops. A bus gate allows passengers to enter and exit the bus at a gate. There are also gate numbers at the bus stations on the ground floor of pier B, C, D, E, and G. Passengers from the bus gates and bus station gates have to travel by bus towards a separate aircraft stand.

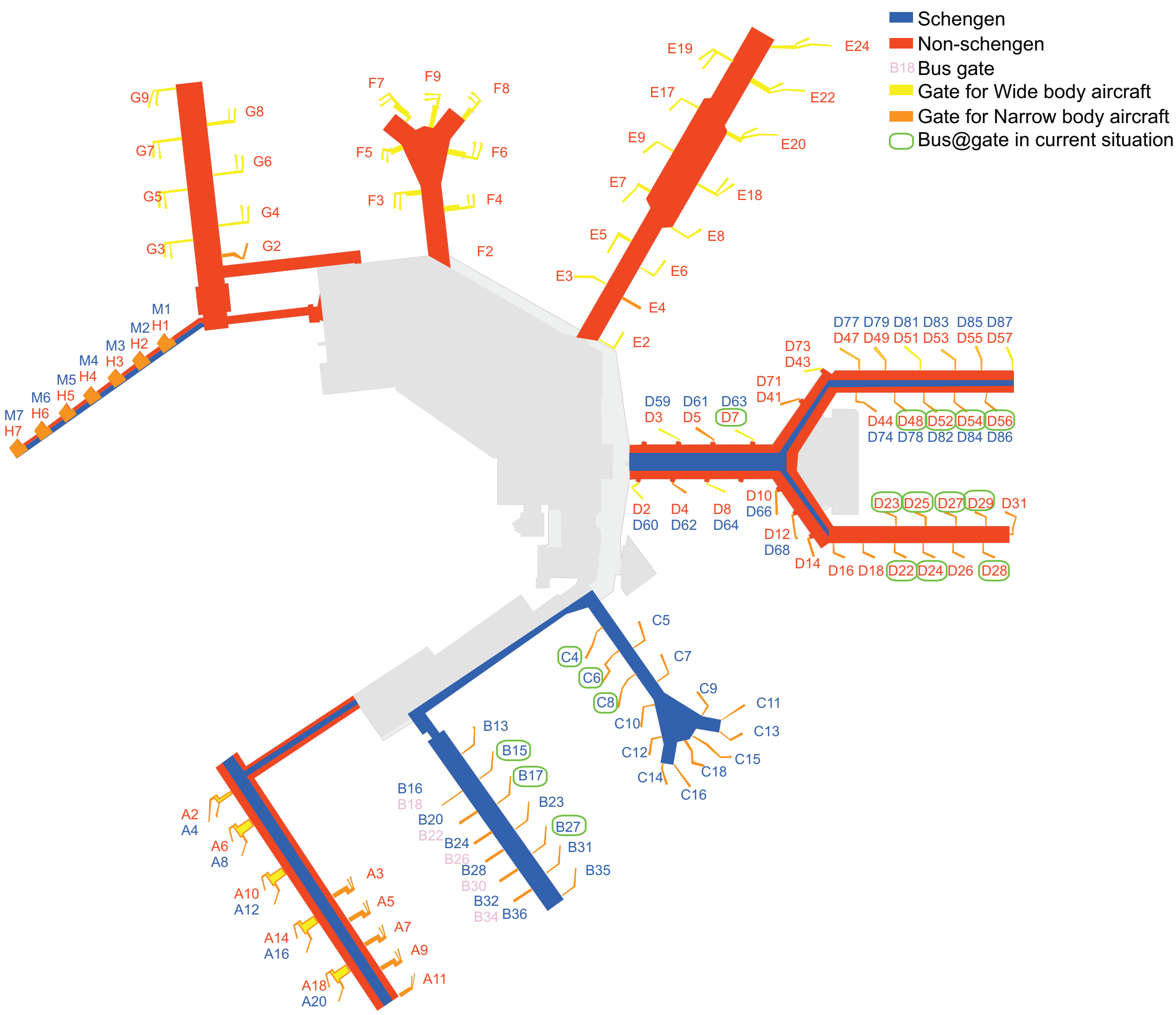


Figure 7: Aircraft stand categorisation

The concept of *bus@gate* is applied at piers B, C, and D in the current situation. The concept provides bus transport from arriving gates towards security filters at the terminal building for non-clean passengers. Passengers of the flights originating from countries that have a lower security screening level than EU legislation prescribes are considered non-clean passengers. It is expected that with the development of pier A the concept of *bus@gate* is no longer necessary, the concept is therefore not taken into account with the design of service roads.

2.3.3 BAGGAGE HALLS

The baggage halls, indicated in Figure 8, are the points of origin for the baggage and pallet trains for outgoing flights and destinations of baggage and pallet trains of incoming flights. Figure 8 is based on information provided by the department *Bagage beheer* of the Schiphol Group. The baggage halls are situated under the entire terminal building. Most entrances and exits are located at the main road, but some entrances and exits are located on the service roads. Most baggage halls are connected underground, therefore baggage and pallet trains do not have long distances to travel above ground.

The baggage halls E/F area and arrivals 2 are mostly used for sorting the luggage of arriving flights. The sorting hall South is the newest baggage hall, and is closest to the new pier. This baggage hall is extended in the future plans to accommodate the extra pier and extension of the terminal building. In the base situation the extension is complete and baggage hall South is in operation.

The entrances and exits of the baggage halls are the points on the network where vehicles enter or exit the road traffic system. The baggage halls themselves are not part of the road traffic system. The rules and regulation within the baggage halls is different from on the service roads. Because of the complexities in the underground network the entrances and exits cannot be moved and form boundaries on the road traffic system. The design of the road traffic system should take the entrances and exits of the baggage halls into account.

Figure 8: Locations of baggage halls, entrances, and exits

2.3.4 Limitations, boundaries, and potentials

Overhanging parts of the terminal building and passage roads through the pier cause height limitations for the vehicles entering the airside road traffic system of the service roads. There are a couple of overhanging parts at pier D, E, F, and G. And some passage roads through the terminal at pier A, B, C, D, and E. Other parts of the ground floor are used for offices, facilities, home bases, and bus stations.

The width of the service roads is measured by lane with maps from the drawing room of the Schiphol Group and by physical measurements on site, the results of these measurements can be seen in Figure 9. The lanes of the main service road are for the largest part 5 meters in width, with a lane for bypassing of 3 meters. The lane for bypassing are smaller in width because only the less wide vehicles have the speed and power to overtake the slower and wider vehicles. There is no bypassing lane on the main road between pier D and E. The service roads around pier B, D, E, and G are all 4.5 meters per lane. While the roads around pier A, C, and F are more broad.

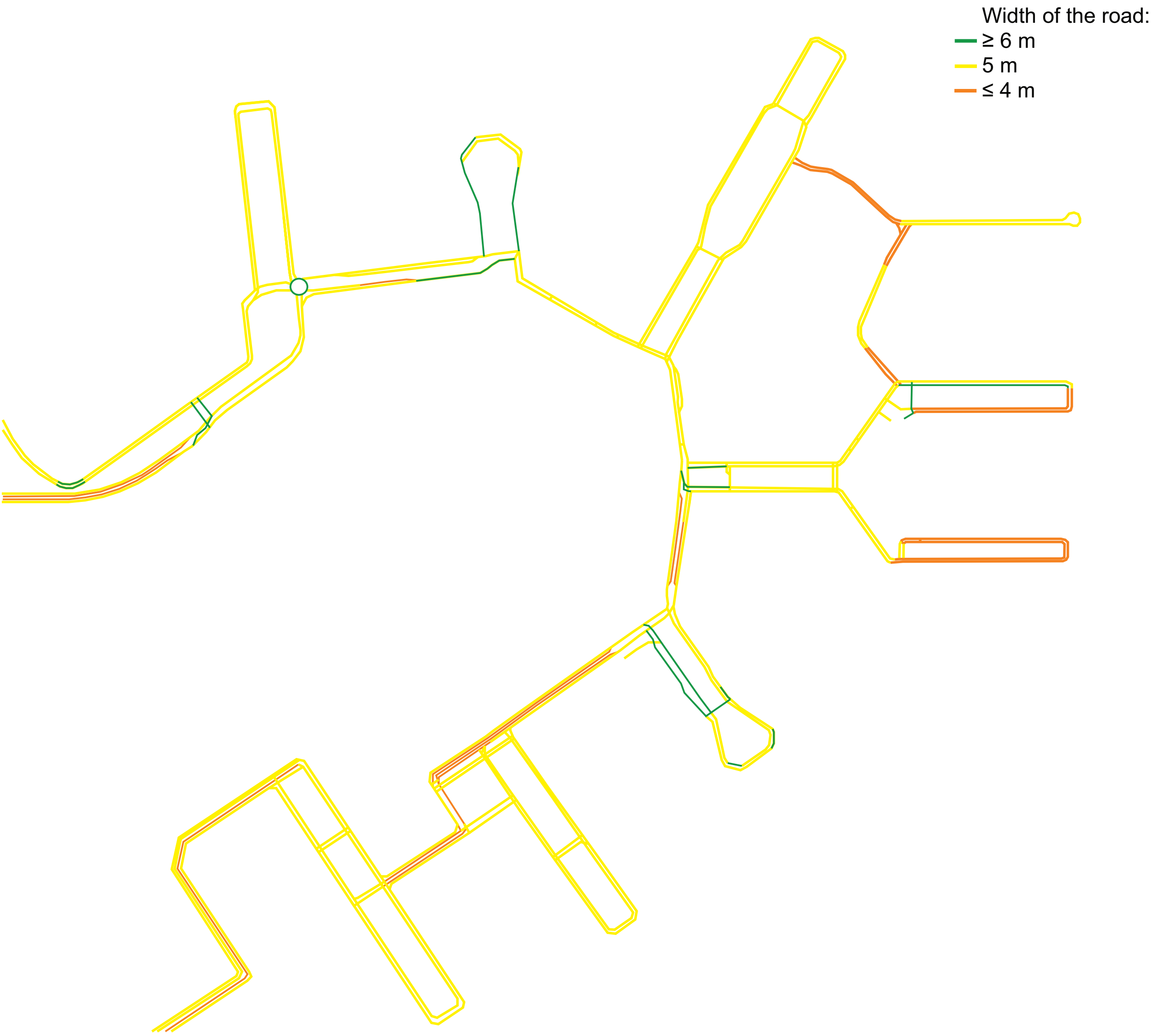


Figure 9: Categorisation of roads by width

The dimensions of the service roads in the base situation are a tight fit. A new design for the road traffic system has to take the limitations of the road width into account. A desire from the road users is that the width of a lane should not be below 5 meters, so vehicles do not have to manoeuvre out of their lane when passing a wider vehicle. Vehicles wider than 3.90 meters are not allowed to drive between pier B and E, see Figure 5. The road design of these parts of the road traffic system does not have to take vehicles wider then 3.90 meters into consideration in their dimensions.

2.4 USERS OF THE ROAD TRAFFIC SYSTEM

The users of the road traffic system can be divided into the bus company, the authority officers, the kMar, Customs, the emergency vehicles, and the handling companies. Figure 10 offers insight in where each of these users is located, the figure is based on interviews and personal observations in the field.

Bus company
Not all aircraft stands are connected to the terminal with an air bridge. For those (remote) aircraft stands there are bus stations in the terminal and parking spots for busses on the service roads, as can be seen in Figure 10. The destinations for the buses are platform B, D/E, and G. With the bus@gate concept the busses stop on the VOP to let arriving non-clean passengers in. The bus company HTM transports passengers by bus on airside from the terminal building to the aircraft stand and back.

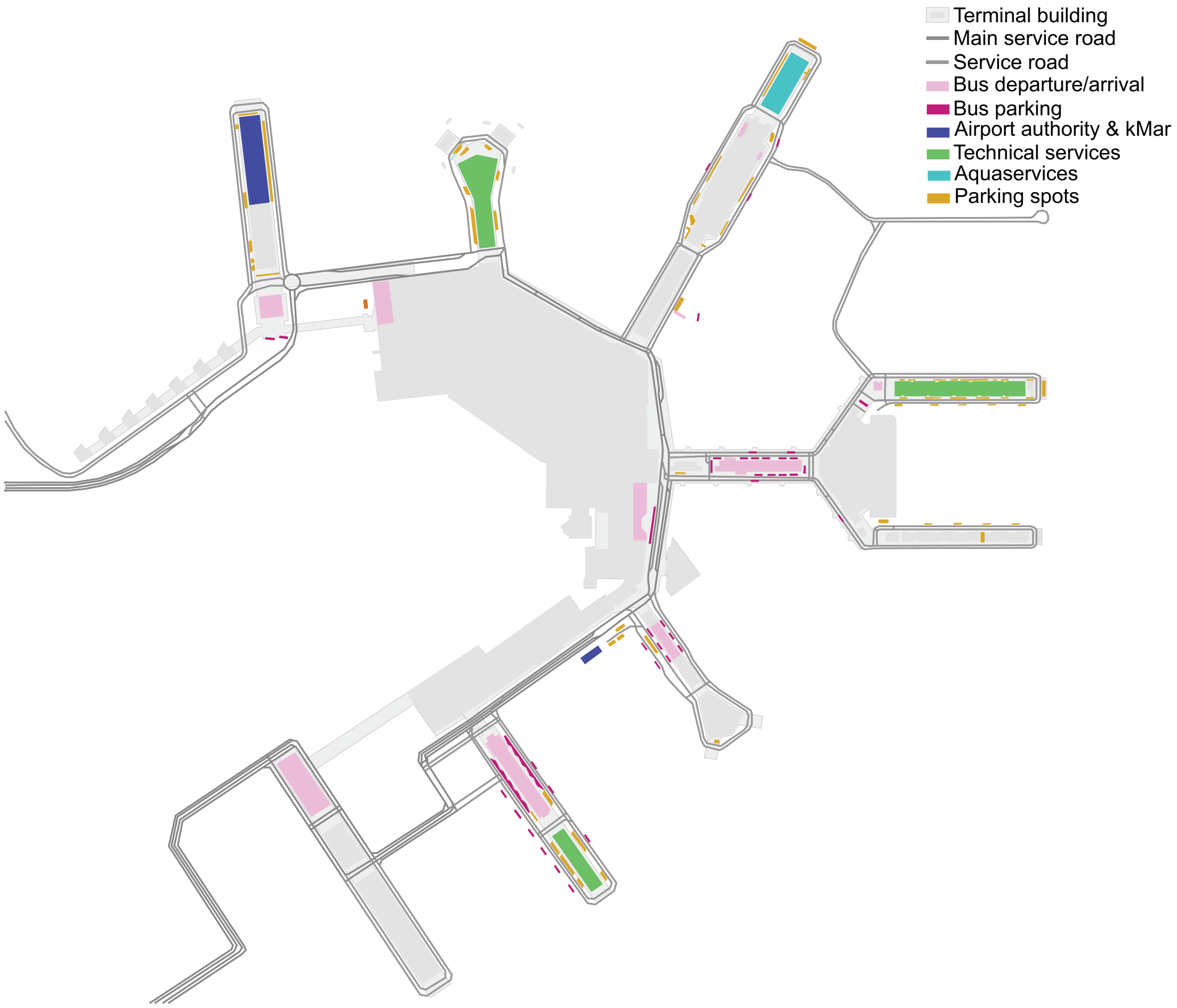


Figure 10: Locations of functionalities

Authority officers, kMar, Customs, and emergency services

The origins for both the Authority officers and the kMar are marked in blue in Figure 10. The area of interest for both is the whole airside road traffic system, the vehicles from both parties do not have a specific destination. The authority officers maintain order, investigate the state of the roads, and report to accident scenes. The kMar are responsible for the safety of the airport, the passengers, and the personnel. The emergency services located at airside report to emergencies at any part of airside.

Handling companies

The handling companies provide the handling service for the aircraft when they are located on an aircraft stand. The handling processes are very diverse, from baggage to push-back. The handling vehicles mostly used fixed routes to travel from their origin and destination. At AAS there are a number of handling companies, among others KLM, AviaPartner, Menzies.

The handling companies located in the main terminal building are marked in Figure 10, specifically technical services and aqua services. Catering services enter the service roads on the south edge of the network. Baggage trains enter and exit the road traffic system at the entrances and exits of the baggage system, as provided in Figure 8. The handling companies also have mobile offices and personnel trucks parked around the piers. The destination for all handling services are the individual aircraft stands. The type of aircraft an aircraft stand can receive determines the kind and quantity of handling service needed, as can be seen in

Table 1 and Figure 11. The mobile office truck and fuelling trucks mostly stay parked and are only used incidentally. The de-icers are only used when the weather conditions call for it, this vehicle falls outside the scope because an average day is modelled in this research.

Table 1: Quantity of airside vehicle needed per type of aircraft when handled at gate

TYPE OF VEHICLE	WIDE BODY	NARROW BODY	SMALLER AIRCRAFT
Bus	-	-	3*
Catering truck	3 - 4	2	1
Assistance vehicle	-	-	1*
Fuel dispenser	1	1	1
Personnel truck	-	-	1*
Cleaning services	1	1	1
Toilet/water service	1	1	1
Baggage trains	2 (5 dolly's)	2 (5 dolly's)	1 (5 dolly's)
Pallet trains	2 (4 dolly's)	-	-
Push-back truck	1	1	1
(Motorised) stairs	-	-	1*
Ramp snake	2	1	1
High loader	1	-	-

*) Only needed when aircraft is handled on the platform

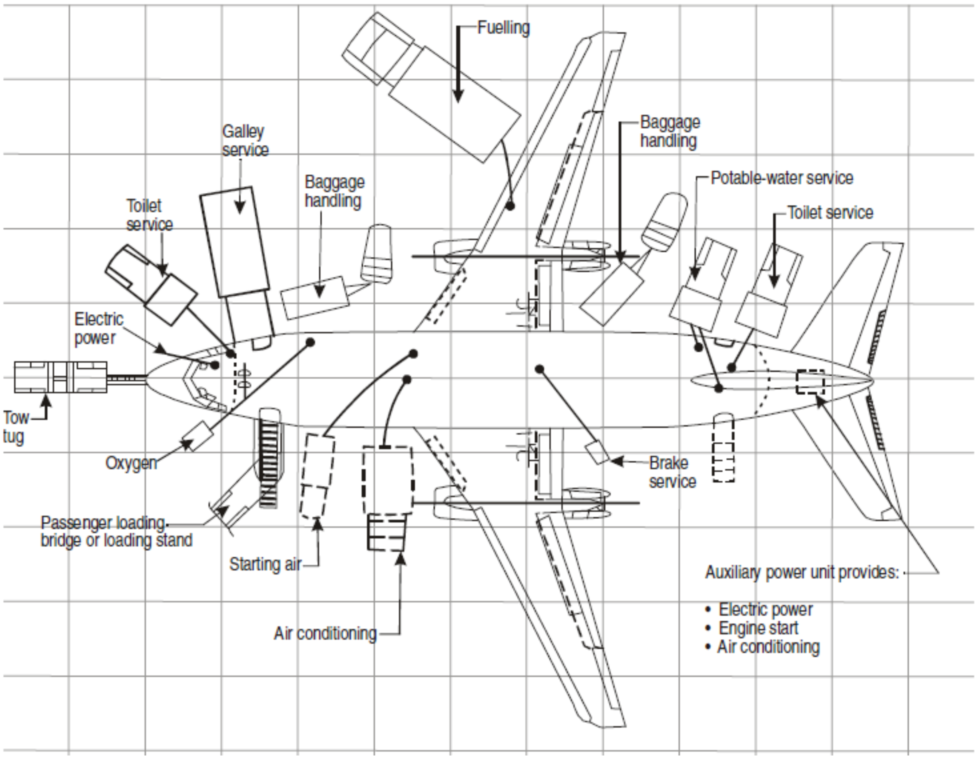


Figure 11: Standard ground equipment service layout (ICAO, 2005)

User experience

The way users experience the airside road traffic system of AAS is researched with interviews and conversations with users, and with personal observations.

The one-way situation around the F-pier is experienced as a clear traffic situation, where drivers feel calmer. There is no opposite traffic, which allows vehicles to drive in their own pace without having to worry about large vehicles coming towards them. Because some of the vehicles are so wide, opposing traffic in the two-way situation sometimes has to divert from their lane to pass. In the current situation some service roads are more broadly set up, while others have a tighter fit. This means that around some piers certain vehicles cannot pass each other.

At the moment, parking is considered an issue for the service roads. There is not enough space for handling vehicles to park on and around the aircraft stand, which now leads to unauthorised parking sometimes on the service road itself. The wrongly parked vehicles around the piers add to disruptions in driving behaviour, and make it more difficult to manoeuvre. When implementing a new design on the service road awareness and enforcement (warnings and sanctions) of the rules are considered important.

2.5 CHARACTERISTICS OF THE GROUND VEHICLES

For each ground vehicle currently present on the airside of AAS the speed, length, turning radius, and specific characteristics are given in Table 2. The pictures in Figure 12 show what the vehicles on airside look like. The transporter and ground power unit (GPU) stay at the VOP.

Table 2: Characteristics of airside vehicles

TYPE OF VEHICLE	SPEED	LENGTH	WIDTH	TURNING RADIUS	SPECIFIC CHARACTERISTICS
Bus	30 km/h	12 m	2 m	Wide	Entrances on right side of bus
Catering truck	30 km/h	10 m	2 m	Wide	
Assistance vehicle	30 km/h	10 m	2 m	Wide	
Fuel dispenser	30 km/h	10 m	2 m	Normal	
Cleaning services	30 km/h	8 m	2 m	Normal	
Toilet/water service	30 km/h	8 m	2.5 m	Normal	
Personnel truck	30 km/h	4 m	2 m	Normal	
Mobile office truck	30 km/h	4 m	2 m	Normal	
Baggage trains	15 km/h	20 m	1 m	Wide	≤ 6 dolly's; 15 km/h on ramps
Pallet trains	15 km/h	20 m	1 m	Wide	≤ 5 dolly's; 15 km/h on ramps
Fuelling trucks	15 km/h	12 m	2 m	Wide	Only a few travel to pier C
Push-back truck	15 km/h	10 m	2.5 – 4.5m	Wide	> 3.9 m: not between pier B and E
De-icer	15 km/h	10 m	3 m	Wide	Stay mostly on platform J
Motorised stairs	15 km/h	8 m	3 m	Wide	
Stairs	15 km/h	7 m	2 m	Wide	
Ramp snake	15 km/h	7 m	2 m	Wide	
Mobile GPU	15 km/h	7 m	1.5 m	Normal	Do not use service roads around piers
Mulach	15 km/h	4 m	1.5 m	Normal	
Animal transport	8 km/h	15 m	3 m	Wide	Do not use service roads around piers
High loader	8 km/h	11 m	3 – 4.5 m	Wide	Most already on aircraft stand; > 3.9 m: not between pier B and E

Bus
Catering truck
Assitance vehicle
Fuel dispenser
Personnel van
Cleaning services
Toilet/water services
Mobile office van
Baggage train
Pallet train
Fuelling truck
Push-back truck
De-icer
Motorised stairs
Stairs
Ramp snake
Mobile GPU
Mulach
Animal transport
High loader

Figure 12: Airside vehicles

HTM is the only bus company at AAS, the electrical busses are parked and charged at a bus station Southwest of platform B when they are not in use.

The handling companies all own and use their own airside vehicles, personalised with their colour and logo. Because the number of vehicles they own is determined by the busiest time of the day, a number of vehicles is just parked at empty aircraft stands or at buffers a large fraction of the time.

2.6 ACCIDENT CAUSES AND CONSEQUENCES

Several studies have already been done on incidents and accidents on the airside service roads of AAS and safety, an internal report, an internal business case, and the thesis by Borsboom (2012) were the results of these studies viewed for this research. There was an average number of 120 collisions per year between vehicles in the period 2005-2008, in the period 2009-2011 the average was already down to 80 collision per year between vehicles (Borsboom, 2012). Push-back trucks, personnel trucks, and passenger busses were most involved in the incidents.

Human error, not giving priority, and colliding with a parked vehicle were among the main causes mentioned by drivers. Lack of clear infrastructure, bad education, time pressure, and the lack of enforcement were also established as causes by a work group. The consequences of incidents and accidents on the service roads are damage to infrastructure and airside vehicles, delay or cancellations of flights, and loss of staff. The studies suggest possible solutions; mandatory single driving direction, more education and information, stricter enforcement, create more ‘turning right’ lanes, and adjusting the corners at junctions.

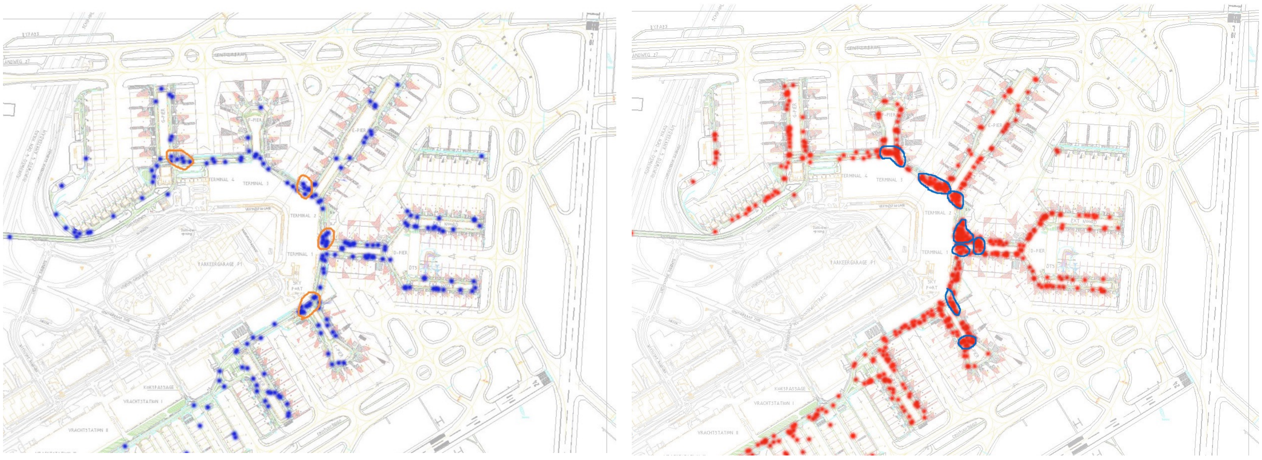


Figure 13: Results of the black spot analysis (Borsboom, 2012)

The location of unilateral collisions (in blue) and collisions between vehicles (in red) are shown in Figure 13. The marked problem areas (circles) are the conclusion to the black spot analysis by Borsboom (2012). Most collisions are identified around the entrances to the pier, where the main traffic flow has to be crossed.

2.7 STAKEHOLDERS OVERVIEW

There are multiple stakeholders involved in the decision making process at AAS. The Schiphol Group itself is key stakeholder, but the users of the road traffic system also play a role in the process. The power and interest of the stakeholders are determined with information from previous studies and observations.

2.7.1 ORGANISATIONAL STAKEHOLDERS

The airport AAS is exploited by the Schiphol Group, which has four stakeholders itself as mentioned in Chapter 1. Because the decision-making is on the possible redesign of a current road traffic system these four stakeholders are kept out of this stakeholder overview.

Several departments within the Schiphol Group play a larger role, they are therefore considered organisational stakeholders in the decision making process:

- The department Development researches possible developments of all assets of the Schiphol Group, they had a key role in the Masterplan 2020-2025.
- The department Analysis, Development, and Innovations (ADI) focuses on development of small interventions and innovations on airside.
- At the department Process Management Airside (PMA) safety advisors and road managers are responsible for the regulation on airside, the safety of the roads, and the deployment of resources. They have the domain-specific knowledge of airside roads.
- The department Construction & Maintenance Control (CMC) is consulted during the development process, oversees the implementation of the final design, and is responsible for the communication with the external stakeholders (the road users).
- The department Maintenance Operations (MO) is consulted during the development process, but is mainly responsible for the maintaining the state of the road traffic system.

The aspect safety is very important for the departments, because of the large consequences of unsafe situations and accidents. The departments PMA, ADI, and CMC find safety and robustness the most important. The department CMC finds robustness the most important aspect. And the department Development finds the amount of surface used and cost important. The departments are all not part of the traffic system, but some still have a high interest in the road traffic system. The departments PMA, ADI, and CMC have a high interest and high power in the decision of the design and the functioning of the road traffic system. The department MO also has a high interest in the decision making process, but only limited power. The department Development has a low interest, but has a high power in infrastructural interventions.

2.7.2 USERS OF THE ROAD TRAFFIC SYSTEM

The functions provided by the users of the road traffic system as well as their experience on the network is already discussed in Section 0. Here their interests are further discussed. For the bus company HTM direct and reliable routes are important. The most important handling company is KLM, as they are the home carrier of AAS. The other handling companies are AviaPartner, Menzies, and Servisair. Fast and reliable handling times are important for the companies that handle baggage, the turn-around-process of the aircrafts, and the aircraft themselves. For the authority officers, the kMar, Customs, and the emergency service it is important to have access to all part of the network at all times.

The bus company, the authority officers, and the handling companies have a high interest and high power in the decision making process. The kMar and Customs have low interest and high power on the design. And the emergency services have a high interest, but a low power in the decision making process.

2.7.3 POWER VERSUS INTEREST

Stakeholder mapping identifies the interests and power of the stakeholders. The stakeholders are positioned in a simplified Mendelow's power/interest matrix of Johnson and Scholes (1999) in Figure 14. The interests define how interested a stakeholder is to influence the decision making process, and the power indicates how large their influence is.

Keep informed

The stakeholders with high interest and low power have to be informed about any redesigns of the road traffic system. Because these stakeholders do not have high powers their opinions do not weigh as heavily as those of the key participants.

The emergency services and department MO are stakeholders that have to be kept informed.

Keep satisfied

The stakeholders with low interest and high power have to be kept satisfied. This group is sometimes referred to as a sleeping giant. At the moment their interests are still low. But when things do not go their way their interest could become larger, and they would be part of the key participants.

The kMar, Customs, and department Development are to be kept satisfied stakeholders.

Key participation is necessary
Stakeholders with high interest and high power are key participants in the decision making process. It is important to know what their interests are and how they can be satisfied. Their level of interests must be maintained during the process.

The Bus company, handling companies, Authority officers, and departments PMA, ADI, and CMC are key participants in the decision making process.

Figure 14: Stakeholder positioned in a power versus interest grid

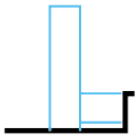
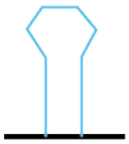
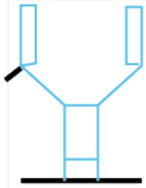
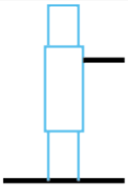
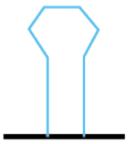
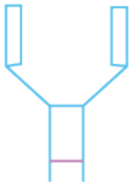
2.8 SUB CONCLUSION: CHARACTERISTICS OF THE ROAD TRAFFIC SYSTEM

In this chapter sub question 1 is answered: What are the characteristics of the airside road traffic system of the service roads around the piers in the base situation? The analysis of the base situation in this chapter provides an overview of the rules and regulation, characteristics of the service roads and immediate surroundings, users of the road traffic system, the characteristics of ground vehicles, accident causes and consequences, and the stakeholders involved in the decision-making process.

Rules and regulation are the same for the entire road system, and the signs on the road traffic system are the same as on public roads. However, it is prohibited to cycle on airside and pedestrians do not have priority. Vehicles entering the main road or a service road have to give priority to vehicles already on the road. The speed limit is 30 km/h for the roads and 15 km/h on the ramps, and vehicles wider than 3.90 meters are not allowed to drive between piers B and E.

Characteristics of the service roads and immediate surroundings are very diverse, the configuration and functionality of the pier relate to the characteristics. The road traffic system consists of a main road and independent pier road traffic subsystems. Table 3 offers an overview of the characteristics of the base situation based on the analysis of AAS in this chapter.

Table 3: Characteristics of the road traffic system per pier

	Pier A	Pier B	Pier C	Pier D	Pier E	Pier F	Pier G
Shape pier							
Road section design in base	Two-way	Two-way	Two-way	Two-way (entrance one-way)	Two-way	One-way	Two-way
Road junction design in base	Equal	Equal with turning lanes	Equal with island	Equal with turning lanes	Equal with turning lane	Equal with turning lanes	Roundabout and equal with turning lanes
Dimensions road sections	10 m	10 m	10-12 m	8-10 m	9.5-10 m	7-10 m	9-12 m
Approximate length of service road	500 m	650 m	550 m	1800 m	1200 m	500 m	550 m
Connection to network							
Passage road through the pier							
Aircraft stands	5(15) NB 5 WB	13 NB	14 NB	22(26) NB 9 WB	1 NB 13 WB	7 WB	1 NB 7 WB
Bus parking on side of building	Yes	Yes	Yes	Yes	Yes	No	No
Bus parking on side aircraft stand	No	Yes	Yes	Yes	Yes	No	No
Bus@gate parking on aircraft stand	No	Yes	Yes	Yes	No	No	No
Baggage access on service road	No	No	Yes	Yes	Yes	No	No
Existing parking spots around building	No	Yes	Yes	Yes	Yes	Yes	Yes
Fuel truck	No	No	Yes	No	No	No	No
Vehicles ≥ 3.90 meters	No	No	No	No	Yes	Yes	Yes

NB: narrow Body WB: wide body

The users of the airside road traffic system are the bus company, the authority officers, the kMar, Customs, the emergency services, and the handling companies. The bus company and the handling companies are part of the destination traffic to and from the piers. Their interests and objectives are to have short and reliable travel times. The authority officers, kMar, and emergency services use the entire road traffic system and do not have a specific destination. Their interests and objectives are to have access to all parts of the network at all times. The way users experience the service roads depends on the design and on the functionality of the pier. Clear traffic situations, awareness, and enforcement are important to the road users.

The characteristics of the vehicles show a large variety of vehicles not seen on public roads. Their diverse widths, lengths, speeds, and the entrance side of the bus influence the possible designs of the road traffic system. The service roads around the piers are mostly used by destination traffic to and from the gates or their home base.

Causes of accidents identified by the road users and a safety workgroup are human error, not giving priority, colliding with a parked vehicle, lack of clear infrastructure, bad education, time pressure, and the lack of enforcement. Most accidents happen around the main road junctions with the pier service roads, where the main traffic flow has to be crossed. The consequences of the accidents are damage to the infrastructure and airside vehicles, delay or cancellations of flights, and loss of staff.

Several departments of the Schiphol Group are considered organisational stakeholders in the decision making process. The departments PMA, ADI, and CMC find safety and robustness the most important. The department CMC finds robustness the most important aspect. And the department Development finds the amount of surface used and cost important. The other stakeholders in the process are the road users. The emergency vehicles and department MO have to be informed during the decision making process. The department Development and the kMar have to be kept satisfied. The departments PMA, ADI, and CMC, the authority officers, the bus company, and the handling companies are the key participants.

This research focuses on the development of a systematic approach to apply different infrastructural design alternatives on the service roads of the piers. In this research one pier is simulated with different designs. *Pier B* is chosen as a case study because it has the most uniform shape and length, has a bus station and a home base of technical services. The pier offers possibilities with the passage through the pier, and extra connection to the main road that makes the pier an integral part of the road traffic system.

3 INFRASTRUCTURAL DESIGN ALTERNATIVES

In this chapter sub question 2 is answered: Which infrastructural design alternatives can be applied to the airside road traffic system of the service roads around the piers? First the different designs applied to public road systems are discussed. Second, the designs of road traffic systems on airports with a similar number of flight movements are reviewed. Third, the criteria a design of an airside road traffic system has to meet are summed up and the designs are tested against the criteria. Fourth, the designs that can be applied to the airside road traffic system, their characteristics, and estimated costs are described. In the conclusion of this chapter an answer to the sub question is given.

To make a fair comparison the design alternatives are all infrastructural interventions. Changing rules and regulation of the airside road traffic system is not allowed. Traffic management and policy related design alternatives are outside of the scope.

The service roads in the base situation are categorised according to the road types of CROW (2002) for public roads. The main service road is categorised as a distributor road (*gebiedsontsluitingsweg*) with a speed of 30 km/h instead of the common 50 km/h to 70 km/h. The main function of this type of road is distribution of traffic. The service roads are categorised as an access road (*erftoegangsweg*) with a speed of 30 m/h. The main function of this type of road is direct access for destination traffic. The main difference between public roads and the airside road traffic system is that there is no speed difference between the main service road and the service roads at airside.

3.1 PUBLIC ROAD DESIGNS

As mentioned in the functional classification of Section 2.3.1, the airside road traffic system can be divided into road sections and junctions.

3.1.1 ROAD SECTION DESIGNS ON PUBLIC ROADS

The road section designs discussed in this section are based on literature about the designs of distributor roads and access roads inside residential areas. The road section designs for the public roads are two-way road, one-way road, *woonerf*, and shared space. Archetypical forms of these designs are depicted in Figure 15.

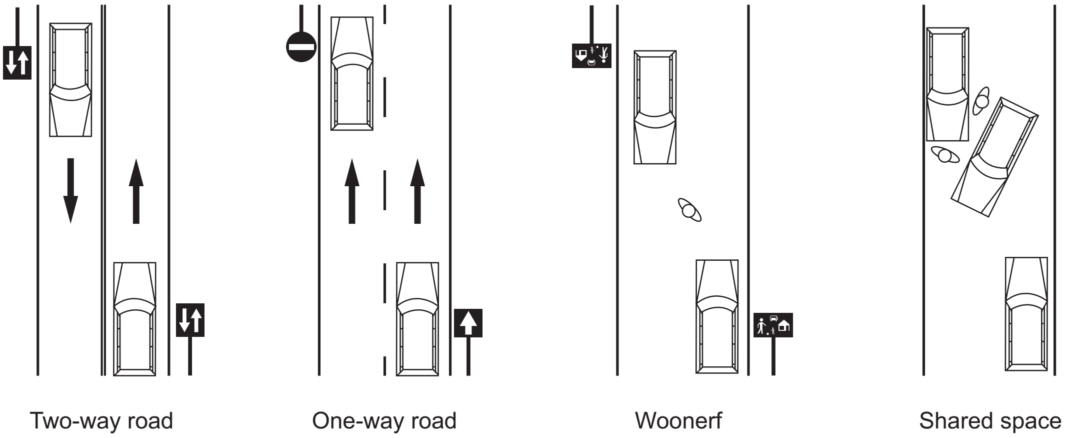


Figure 15: Road section designs on public roads

A *two-way road* is a road with 2x1 or 2x2 lanes, where traffic can travel in both directions. The roadway separation between the opposite directions can be a physical separation or double solid markings, interrupted markings form the lane separation. For cars and lorries the minimal width of a lane is the width of the vehicle with 30 to 60 centimetres course deviation (CROW, 2012). Speed reducing methods such as speed bumps can be applied to reduce the speed of the traffic, which makes it less attractive to use the road as a shortcut.

One-way roads only have one roadway with traffic in one direction, but can consist of multiple lanes. There is no roadway separation, in the case of multiple lanes interrupted markings form the lane separation. The measurements for the minimal width are the same as the two-way road. Speed reducing methods such as speed bumps can be applied to reduce the speed of the traffic.

There have been numerous studies on the advantages and disadvantages of one-way road networks compared to two-way road networks. Conversions from two-way streets to one-way streets means that there is more room for turning lanes and for parking along the curb. There are less conflict points at crossings resulting in 22% less accidents, 66% less stops, and a 50% decrease in intersection delays as found out with data analysis of streets in New York city by Wiley in 1959 and Karagheuzoff in 1972 (Stemley, 1998). The downside of one-way roads is the additional travel time and distance due to out-of-direction travel, and confusion experienced by incidental users and public transit users (Stemley, 1998). Because drivers have to make less stops and experience less delays at crossings there is an more steady overall speed, which also leads to less travel time. One-way streets experience higher speeds (Walker, Kulash, & McHugh, 2000), causing the accidents to be more severe. One-way streets can also lead to accidents due to driver inattention and disregarding traffic signals because of wanting to stay in the “platoon” of the traffic flow (Tindale & Hsu, 2005). One-way streets force drivers to take circuitous trips, resulting in longer trip lengths, which is especially problematic for emergency vehicles (Gayah & Daganzo, 2012).

Only some aspects of the upsides and downsides of one-way roads compared to two-way roads are applicable to the airside. There are less conflict points, out-of-direction travel, and some driver inattention. But there are no incidental users or public transit users, the speeds are of a different calibre, the road network is one main axis with independent subsystems instead of an integral road traffic system, and the composition and material of the vehicles is incomparable. The results of the studies of Wiley and Karagheuzoff are dated and therefore not directly applicable as hypothetical results of this research.

A *woonerf* (or *shared street*) is mostly found in residential areas with a lot of children (Veilig Verkeer Nederland, 2015). In this type the whole street can be used by everyone, from driver to playing children. Motorised vehicles and cyclists are seen as guests on this type of street, pedestrians are the hosts. The guests are not allowed to jeopardise the safety of the hosts. There is a speed limit of 15 km/h (Veilig Verkeer Nederland, 2015). A lack of clear separation between driving directions and the different modes of traffic are characteristic of the *woonerf*.

Shared space is a traffic concept introduced by the Dutch traffic engineer Hans Monderman (Provincie Friesland, 2005), and is considered a new application of the *woonerf*. In the concept the interests and responsibility of all users are essential in the design of the public space as a space for people, not as a space for traffic. Shared space strives towards a design and layout of public spaces with a balance in traffic, human exchange, and other spatial functions. Public space is designed as a people place and invites social interaction. The concept of shared space only works when the different people places are interconnected with a overlying coarse network of traffic roads. There is no signage, domination, or explicit priority rules. All users are equal and respect the other users.

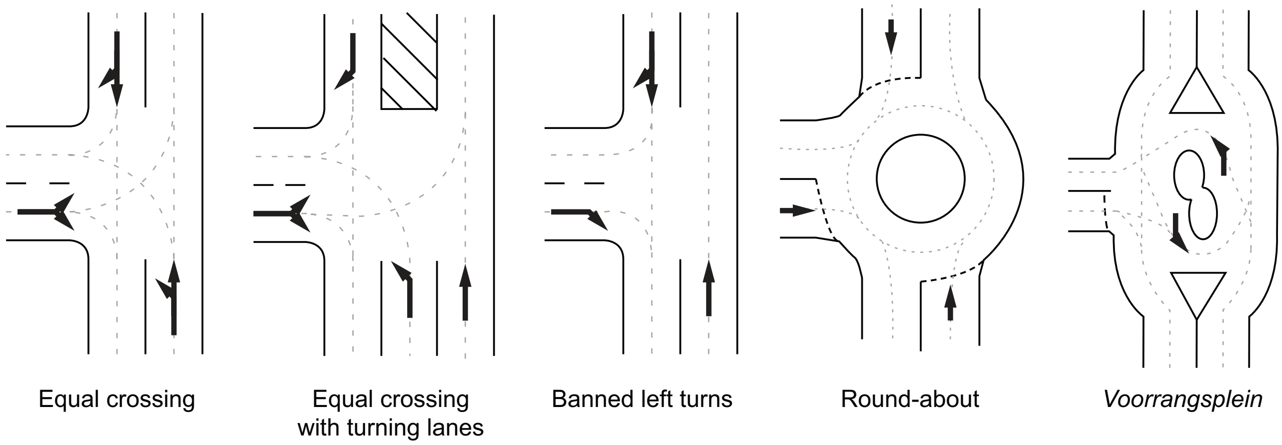
The design of the *woonerf*, or shared street, is the foundation of the design of shared space, which makes the two designs very similar. The design of the *woonerf* is applied in residential areas, whereas the concept of shared space is applied in urban areas, and not exclusively in residential areas. This research is focused on the design of airport road infrastructure, therefore only the design of shared space are used as a base for the design alternatives.

3.1.2 JUNCTION DESIGNS ON PUBLIC ROADS

The junction designs discussed in this section are based on literature about the designs of distributor roads outside and inside residential areas, and access roads inside residential areas. The junction designs on public roads are the equal crossing (with and without turning lanes), banned left turns, the roundabout, and the *voorrangsplein*. Archetypical forms of these designs are depicted in Figure 16. The junction designs principles of junctions are all designed as T-crossings, which is what most junctions on the airside road traffic system look like in the base situation.

A cross-shaped or T-shaped meeting of roadways on the same level where traffic may turn is considered an *equal crossing* (CROW, 2001). An equal crossing with turning lanes has separate lanes for traffic going left. On three-armed junctions, applying turning lanes for going left on the main road compared to main roads that have no separate turning lanes reduces the number of accidents by 60 percent according to the research of CROW (2002). On cross-shaped junctions an accident reduction of 40 percent is perceived. Speed reducing methods such as speed bumps or slightly raised crossings can be applied to equal crossings to reduce the speed of the traffic.

Banned left turns on junctions only allow going straight ahead, it is prohibited for traffic to turn left. The design of this junction allows larger throughput and less disturbances because the traffic does not have to cross the other roadway. The strategy for banning left turns reduces the number of conflict points at crossings just as a one-way network. But this measure is not as restrictive to emergency or transit vehicles as using one-way streets because the turning restrictions can be lifted for these types of vehicles (Gayah & Daganzo, 2012).


Equal crossing

Equal crossing with turning lanes

Banned left turns

Round-about

Voorrangsplein

Figure 16: Junction designs on public roads

A *roundabout* is a traffic square where the traffic on the square has priority, and the roads connect radially (CROW, 2001). Recognisability is very important for a roundabout, this is achieved by lighting and placing a vertical element in the centre. The capacity of a roundabout is determined by the number of lanes on the roundabout and the number of lanes to enter and exit the roundabout. For a single-lane roundabout with single-lane entrances and exits the capacity is 20,000 to 25,000 vehicles/day that can enter the roundabout. The radius of a single-lane roundabout is 12.50 to 20 metres (CROW, 2012).

The *Voorrangsplein* is a junction with elements of a priority crossing and a roundabout (CROW, 2012). It was introduced in 2007 as part of the "*Langzamer rijden gaat sneller*"-idea, this idea assumes that travelling at a lower overall speed is better than travelling at high speeds on the road sections and stopping at the junctions. The turning lanes of this type of junction makes vehicles cross behind the opposite traffic. Figure 17 is a photo of a *voorrangsplein* in the municipality of Hilversum, one of the first built in the Netherlands.

Figure 17: *Voorrangsplein* in the municipality of Hilversum (Gemeente Hilversum, 2012)

3.2 Design currently found in airside road traffic systems

At AAS, the service roads around pier A, B, C, D, E, and G are designed as a two-way road with one lane per direction. The service road on the south side of pier H also is designed as a two-way road with one lane per direction, this pier is mentioned separately because the service road is not around the entire pier.

The service road around pier F and the beginning of pier D is designed as a one-way road, only around the head of the pier are two lanes.

3.2.1 SERVICE ROADS OF SIMILAR AIRPORTS

Similar airports in terms of aircraft movements are the airports London Heathrow, Frankfurt/Main, Paris-Charles de Gaulle, Istanbul Atatürk, New York JFK, Munich, Madrid-Barajas, and Singapore. The airports of Copenhagen and Brisbane are also part of this small research because of similarities in the design and the partnership the Schiphol Group has with Brisbane Airport. The designs of the airside road traffic systems of these airports is analysed with aerial photos (Google, 2015) and available maps of the airports. The airport Istanbul Ataturk had low-quality imaging, and is not discussed further. A more detailed description of this research can be found in Appendix A.

The airside road traffic system of London Heathrow consists mainly of throughput roads, there is no pier concept as AAS. Large parts are designed as *one-way roads*, the roads connecting the west to the east are mainly designed as two-way roads. The orange roads in Figure 18 are one-way roads, the two-way roads are marked dark-grey.

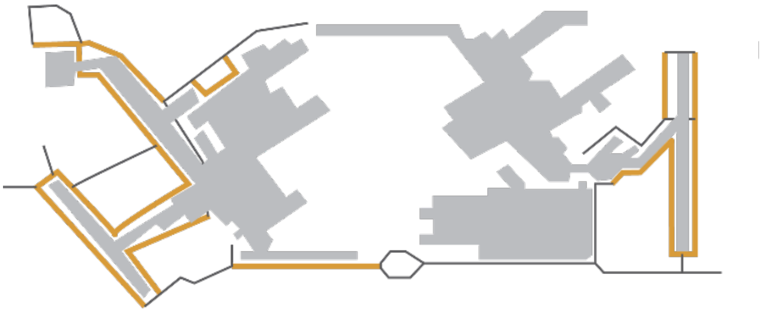


Figure 18: The service roads and terminal buildings 1 to 3 of London Heathrow

The airports Charles de Gaulle and Copenhagen have some roads that are designed as one-way, but the largest part of the system is two-way. The remaining airports all have *two-way* designs in their airside road traffic system.

Brisbane Airport has implemented *shared zones*, areas shared by pedestrians and vehicles (Pond, 2014). The airport consists of two terminals, a linear terminal and a terminal with a piers, separated from each other with a road in between. The shared zones are implemented with signage (seen in Figure 19) on the airside road in front of the domestic terminal and international terminal, the general aviation apron and the logistics apron. The maximum speed in these areas is 20 km/h, the road between the two terminals has a speed limit of 40 km/h. At Brisbane airport the drivers drive on the left side and must give way to pedestrians at all times.

Figure 19: Sign for shared zone in front of the domestic terminal (Pond, 2014)

3.2.2 EUROPEAN AIRPORT DESIGN GUIDELINES

The European aviation safety agency (EASA) provides European guidelines regarding airport design in their directive (EASA, 2014), the guidelines regarding service roads on airside are:

- The service roads should be planned so that they do not cross runways and taxiways;
- The planning of the service road network should take the use by emergency vehicles into account;
- An aircraft stand should provide a minimum clearances of 7.5 meters between an aircraft using the stand and any adjacent building, aircraft on another stand and other objects;
- An aircraft stand equipped with a visual docking guidance system should provide the minimum clearance of 4.5 meters between an aircraft using the stand and any adjacent building, aircraft on another stand or other objects;
- Apron safety lines should include such elements as wing tip clearance lines and service road boundary lines as required by the parking configurations and ground facilities

The location of the service roads and the access for emergency vehicles are already implied in the dimensions of the base design as non-removable objects.

3.2.3 SCHIPHOL RULES AND REGULATION

For the design of the airside roads the Schiphol group uses the design guidelines for roads in residential areas (*ASVV*) of CROW as leading.

The speed limit for vehicles on all roads on airside is 30 km/h. Roundabouts on airside have to be accessible for airside vehicles, the dimensions of a roundabout are therefore 19.80 meters for the outer radius, and 9.20 meters for the inner radius (Schiphol Group, 2015).

The width of the service roads depends on the width of the vehicle with the largest accepted width. This is 3.90 meters for vehicles between pier B and E, and 4.80 meters for other parts of the road traffic system. On airside the course deviation is 60 centimetres, so the minimal width of a lane is 4.50 meters between pier B and E, and 5.40 meters for the other road sections.

The width and length of parking spots for non-handling vehicles is 3.50 by 5.00 meters. The spots can only be applied at the terminal side of the service road, it is prohibited to apply parking spots at the platform side.

3.3 TESTING THE DESIGNS ON CRITERIA

To determine which infrastructural design alternatives can be applied to the service roads of AAS the alternatives have to meet set criteria. The meaning of these criteria is first specified, after which all road section designs and junction designs are tested on these criteria.

3.3.1 CRITERIA

The design has to take into account the non-removable elements and airside users, and comply with the to the rules and regulation.

Take into account non-removable elements and the airside users

The entrances and exits of the (underground) baggage halls, the bus stops, and columns supporting the overhanging building are elements around the service roads that are set. The design of service roads has to be adjusted to these elements

The airside vehicles using the service roads around the piers have a broad range in dimensions, and some have specific characteristics that must be taken into account in the design. Pier A, B, C, D, and E have bus stations and bus parking spots and thus have to take the characteristics of the busses into account, pier F and G do not have to take the characteristics of busses into account. Gate C4 is not connected to the underground fuel system, the fuelling truck needed for handling cannot take a sharp left at the north junction towards the main road.

Comply with the official design rules for airports of the Dutch government and EASA, and the rules and regulations of AAS

The airside of AAS and its road traffic system is bound by rules set up by the Schiphol Group (Section 3.2.3). These traffic rules are an application of the official design and traffic rules of the Dutch government and the design guidelines as specified in Section 3.2.2.

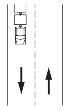
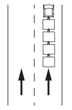
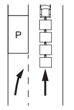
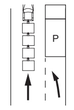
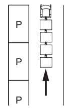
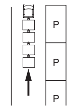
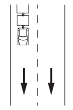
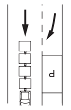
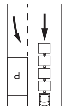
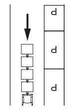
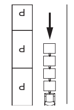
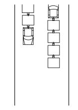
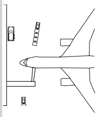
3.3.2 ROAD SECTION AND JUNCTION DESIGNS

Different design variations on the basic road section and junction designs are presented and checked with the criteria. The generation of road section design and junction design already took the limited width of the road system into account.

Road section designs

The generation of road section designs already took the limited width of the road system into account. The principle of one-way is translated into clockwise designs and counter clockwise designs. All road section designs are presented and scored in Table 4.

Table 4: Generated road section designs checked for criteria

	Two-way design	One-way design										Shared space design	
Criterion	 Base situation	 Counterclock-wise	 Counterclock-wise with left parking bays	 Counterclock-wise with right parking bays	 Counterclock-wise and left parking	 Counterclock-wise and right parking	 Clockwise 2 lanes	 Clockwise with left parking bays	 Clockwise with right parking bays	 Clockwise and left parking	 Clockwise and right parking	 On service road	 On apron
Non-removable elements and users	X						X*	X*	X*	X*	X*	X	X
Rules and regulation	X	X	X	X**			X	X**	X			X	
	PASSED	🟥	🟥	🟥	🟥	🟥	PASSED	PASSED	PASSED	🟥	🟥	PASSED	🟥

*) After bus@gate is no longer applied **) When part of the aircraft stand

X	MEETS CRITERIA
PASSED	Meets all criteria
🟥	Not applicable

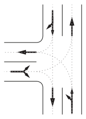
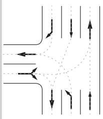
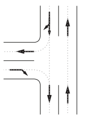
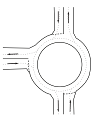
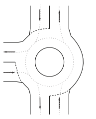
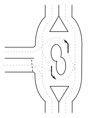
The clockwise design takes the characteristics of the busses into account, which have doors on the right side of the vehicle. Therefore all alternatives which are designed counter clockwise do not pass the first criterion, as the users of the airside are not taken into account. The bus@gate concept means that the busses need to (un)board passengers on the platform side as well, a one way system can therefore only be applied if the bus@gate concept is no longer applied or if different busses are introduced.

Using one lane exclusively for parking does not pass the second criterion because then the system cannot be used at all times. Parking spots on the platform side are prohibited according to the Schiphol rules, therefore the alternatives counter clockwise with right parking and clockwise with left parking do not pass the second criterion. For the parking bays parking on the platform side is an option if the parking is made part of the aircraft stand.

Junction designs

The junction designs are designed for the junctions of the main road with the service roads around the piers.

Table 5: Generated junction designs checked for criteria

	Equal crossing design			Special crossing design		
Criterion	 Equal crossing	 Equal crossing with pre-sorting	 Equal crossing with banned left	 Roundabout 19.8 m diameter	 Roundabout 12 m diameter	 *Voorrangsplein*
Non-removable elements and users	X	X*	X		X	X
Rules and regulation	X	X		X		X
	PASSED	PASSED	🟥	🟥	🟥	PASSED

X	MEETS CRITERIA
PASSED	Meets all criteria
🟥	Not applicable

*) Not for pier A

The banned left turns make the piers inaccessible for users coming from the north. The roundabout has to large dimensions to fit within the airside road system. With smaller dimensions, it does not comply to the design rules regarding the diameter needed for the large vehicles. The *voorrangsplein* does fit within the dimensions of the road traffic system, but is only applied with two-way roads.

3.4 INFRASTRUCTURAL DESIGN ALTERNATIVES

The combination of road section designs of Table 4 and junction designs of Table 5 that passed the criteria form the design alternatives as presented in Figure 20.

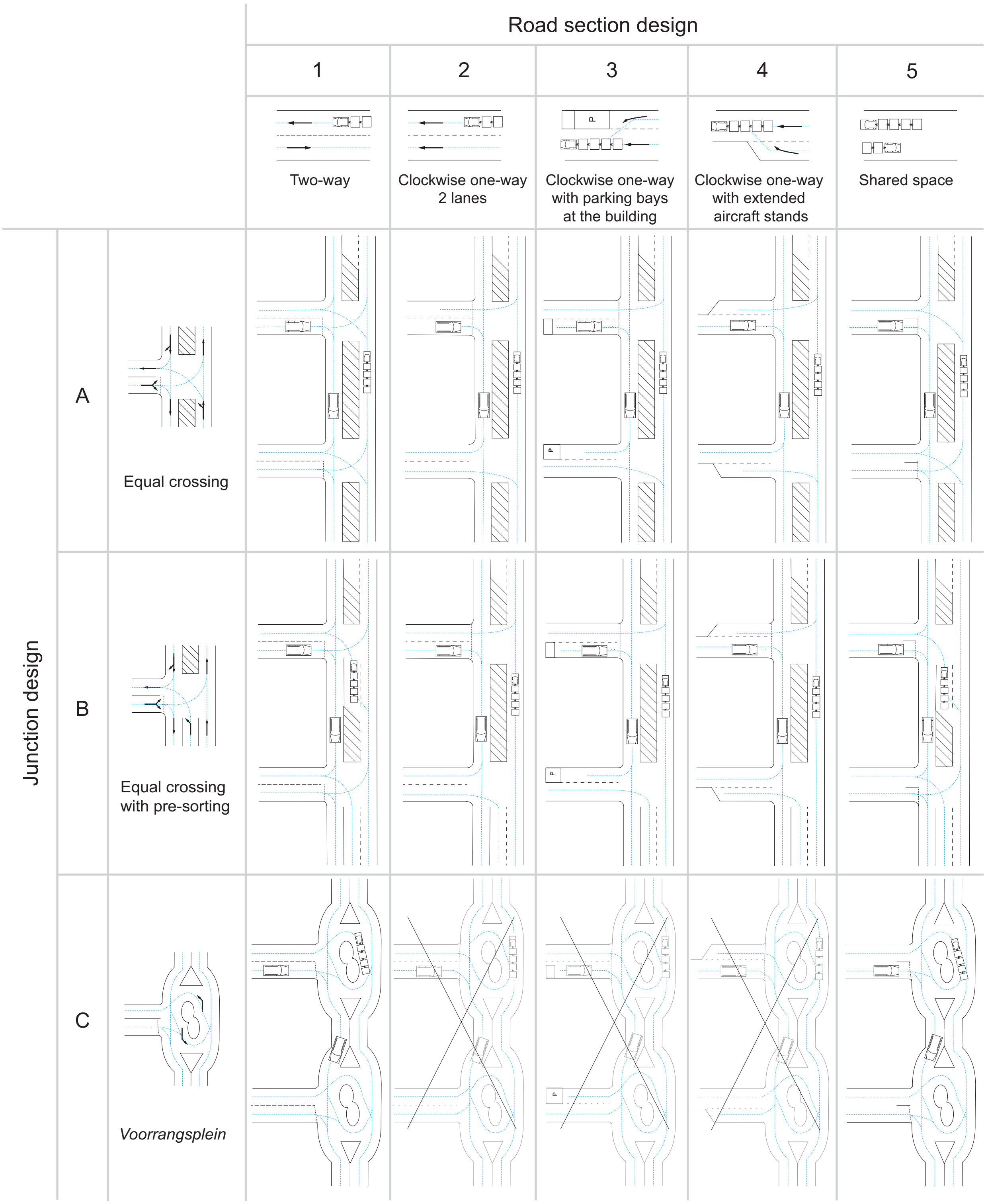


Figure 20: Matrix of design alternatives

Horizontally the road section designs are listed: Two-way, one-way, one-way with parking bays, one-way with extended aircraft stands, and shared space. Vertically the junction designs are listed: equal crossing, equal crossing with turning lanes, and the *voorrangsplein*.

Not all possible combinations are sensible combinations. The *voorrangsplein* is designed to safely allow the turning of vehicles from the main road to the secondary road. When the secondary road is one-directional the *voorrangsplein* at the side of the entrance to the pier is used according to the design. On the exit side of the pier the *voorrangsplein* only provides the option of a U-turn, as vehicles cannot enter the secondary road from this crossing. The implementation of the *voorrangsplein* may cause confusion for the drivers on this crossing, who assume that they can enter the secondary road on this crossing as well. The combinations 2C, 3C, and 4C are therefore labelled incompatible, and are excluded from further research.

3.4.1 SPECIFICATIONS OF THE DESIGN ALTERNATIVES

Changing the design of the road traffic system does not alter the rules & regulation. The yield lines and priority rules are still applied in all alternatives at the exits of the service roads. The direction of traffic is indicated with the appropriate signs and road markings as on the public road designated by the design alternative. The *voorrangsplein* has roundabout signs at the exits of the pier to avoid wrong-way driving. On the public roads there are no specific signs available for the *voorrangsplein*. The one-way alternatives 1A, 1B, 2A, 2B, 3A, and 3B are all clockwise, which is the opposite direction of the one-way situation of pier F. When one of these design alternatives is chosen to be applied to the road traffic system of a pier the situation at pier F should be clockwise as well to avoid confusion.

The equal crossing has a wide raised border that separates the opposing traffic flows, while the equal crossing with turning lanes only has a small raised border between the opposing traffic and the left-turning lane. The voorrangsplein has a traffic island, where the middle of the island is slightly raised.

Parking

Design alternatives with the road section designs two-way, one-way with two lanes, and shared space do not have designated parking spaces as part of their design.

Users in the shared space alternatives have temporary parking possibilities that are not assigned to a specific section of the road. It is the responsibility of the user to take the other users into account in the shared space, parking on the road is not prohibited if is does not hinder the other users.

In the one-way design with parking bays 40 parking spaces that already existed in the base situation are extended with 3 meters. And 5 parking spaces are added to the road traffic system. In the one-way design with extended aircraft stands the extra space dedicated to the aircraft stand is used for parking handling vehicles. A total surface of 200 m^2 is divided among eight different aircraft stand. All other existing parking spaces are maintained.

Surface used

The borders and traffic islands of all junction designs are included in the road surface, which means that the road surface of all three junctions is the same. Therefore size of the road surface is only dependant on the road section design.

The two-way and one-way with two lanes alternatives do not have extra parking facilities. In the concept of shared space the surface does not have a designated function, to compare the alternatives better the whole shared space surface is considered road surface. The total road surface used for the two-way, one-way with two lanes, and shared space alternatives is 10,650 m^2.

The extended parking spaces in the one-way alternative with parking bays at the building add 250 m^2 to the total square meters of parking spaces. The remaining 10,400 m^2 is road surface. The one-way alternative with extended aircraft stand adds 200 m^2 to the aircraft stands, and has a total road surface of 10,450 m^2.

Costs

The expected costs for the implementation of a design alternative depend on the specifications of a design, the state of the existing infrastructure, and the soil conditions of the pier. For this research only the specifications of the design in the base situation and the design specifications of the design alternatives is taken into account for the construction costs. Research costs, investment costs, costs that arise due to construction nuisance, and maintenance costs are not taken into account. Research and investment costs are hard to estimate. Construction takes place outside of peak hours, so construction nuisance is kept to a minimal. And maintenance costs are the same for the design alternatives.

The key figures of construction costs are estimates provided by a manager of Asset Management of the Schiphol group. The estimates are based on previous experience of Asset Management with construction works on the infrastructure of the service roads.

Alternative 1B is the design of the base situation, and therefore does not have construction costs. The construction costs for a new road section design on the pier subsystem are small, only new road markings and traffic signs have to be taken care of. The construction costs for a new road section design are estimated at €5000 for the service roads around the entire pier. The construction costs of a junction other than the equal crossing with turning lanes (the junction in the base situation) are estimated at €100 per square meter of extra asphalt. The raised borders and traffic islands are counted as extra asphalt.

The raised borders of two equal crossings are extended 146m^2 beyond the existing borders of the two junctions of the base situation. The raised borders and traffic islands of the two *voorrangspleinen* are 240m^2 of new constructed asphalt.

Table 6: Construction costs of the design alternatives

	Two-way	One-way with 2 lanes	One-way with parking bays	One-way with extended aircraft stands	Shared space
Equal crossing	€ 14,600 (1A)	€ 19,600 (2A)	€ 19,600 (3A)	€ 19,600 (4A)	€ 19,600 (5A)
Equal crossing with turning lanes	€ 0 (1B)	€ 5,000 (2B)	€ 5,000 (3B)	€ 5,000 (4B)	€ 5,000 (5B)
Voorrangsplein	€ 24,000 (1C)	-	-	-	€ 29,000 (5C)

The estimated costs are calculated with the key figures and presented for all design alternatives in Table 6.

3.5 Effect framework

In this research the effects of a design of an airside road traffic system is measured on six aspects: travel time, travel distance, robustness, safety, surface used, and costs. These aspects are measured in the design specifications and the simulation program.

3.5.1 Definitions

The definitions for these six aspects and how the aspects are taken into account is shortly discussed to prevent misconceptions.

The definition of *travel time* is a period of time spent travelling. In this research the travel time is the period of time all vehicles on the airside road traffic system take to travel from their origin to destination in the assigned time period. This aspect is measured in the simulation model as total travel time.

The definition of *travel distance* is the distance a user has travelled over a period of time. In this research the travel distance is the distance all vehicles on the airside road traffic system have travelled in the assigned time period. This aspect is measured in the simulation model as total travel distance.

This research uses the definition of Snelder et al. (2004), where *robustness* is “the ability to fulfil the function for which the network is designed, even in non-regular situations which differ strongly from regular user conditions”. In transport systems redundancy (reserve capacity), compartmentalisation, and adaptability are important aspects to robustness. An incident scenario in the simulation model tests the airside road traffic system of the infrastructural design alternative on robustness. Robustness is tested by comparing the travel times of the normal scenario and the incident scenario. This aspect is measured by the percentage of extra travel time in the accident scenario compared to the normal scenario.

In this research the *safety* of a design of an airside road traffic system is approached as traffic safety, which is defined as follows: “the methods and measures for reducing the risk of a person using the road network being killed or seriously injured” (International Transport Forum, 2008). Conflicts are unexpected and undesirable event, incidents where a vehicle gets into contact with infrastructural elements or other vehicles within the road network are called collisions. From the definitions of safety, conflicts, and collisions it can be deduced that to improve the safety of an airside road traffic system the number of conflicts have to be reduced. The number of conflicts is determined with a surrogate safety measures application that analyses the trajectory data from the simulation runs, categorised by crossing, rear end, and lane change conflicts. This aspect is measured by the total number of conflicts.

In this research, the definition for *surface used* is the size of the surface the design has assigned to the function road.

The *costs* of a design are split into investment costs, construction costs, costs that arise due to construction nuisance, and maintenance costs. The costs of the design of the airside road traffic system in this research only uses the key figures for construction costs.

3.5.2 ASSESSMENT FRAMEWORK

The assessment of the design alternatives depends on how the stakeholders appreciate the aspects travel time, travel distance, robustness, safety, surface used, and costs. In this research the organisational stakeholders and the road users are involved with the choice for a design of the airside road traffic system. The organisational stakeholders are several departments of the Schiphol Group, and the users of the system are the bus companies, authority officers, kMar, Customs, emergency services, and handling companies.

The effects on travel time, travel distance, robustness, safety, surface used, and costs are compared with each other based on equal weights and with weight sets based on the desires and interests of the stakeholders.

3.6 SUB CONCLUSION: DESIGN ALTERNATIVES AND ASSESSMENT FRAMEWORK

In this chapter sub question 2 is answered: Which infrastructural design alternatives can be applied to the airside road traffic system of the service roads around the piers? Several public road designs are currently found on the airside of AAS and other similar airports. The two-way road, one-way road, shared zones, equal crossing, equal crossing with turning lanes, and roundabout are already applied at the airsides of the airports AAS, London Heathrow, Frankfurt/Main, Paris-Charles de Gaulle, New York JFK, Madrid-Barajas, Copenhagen, and Brisbane.

These designs and other public road designs of road sections and junctions that take non-removable elements and airside users into account, and comply with the rules and regulations can be applied to the airside road traffic system of AAS. The two-way, one-way with two lanes, one-way with parking bays, one-way with extended aircraft stands, shared space concepts, equal crossings, equal crossings with turning lanes, and the *voorrangsplein* all meet the criteria. The designs of road sections and junction that meet all criteria are matched with each other to form the design alternatives. The design of the *voorrangsplein* causes confusion for the users when applied in combination with the one-way designs. Therefore three designs are eliminated due to lack of sensibility, which leaves 12 designs.

The effect of a design of an airside road traffic system is measured on six aspects: travel time, travel distance, robustness, safety, surface used, and costs. Travel time, travel distance, robustness and safety show the performance of the airside road traffic system. Surface used and costs are included in the design specifications of the design alternatives.

The two-way, one-way with two lanes, and shared space alternatives all have the same total surface used, 10,650 m^2. The one-way alternative with parking bays at the building has a road surface of 10,400 m^2, the remaining 250 m^2 are dedicated to parking. The one-way alternative with extended aircraft stand adds 200 m^2 to the aircraft stands, and has a total road surface of 10,450 m^2. The costs are construction costs estimated with key figures. The base situation of two-way and equal crossings with turning lanes has zero construction costs. Another road section design has €5000 on construction costs to adjust road markings and traffic signs. Another junction design costs €100 per square meter of extra borders and traffic islands, any alternative -A has €14,600 of junction construction costs and any alternative -C has €24,000 of junction construction costs.

4 MODEL

In this chapter sub question 3 is answered: What type of model can be used for simulating the airside road traffic system? The model is used to simulate the twelve design alternatives set up in chapter 3 for travel time, travel distance, robustness, and safety. First the different types of existing modelling programs are reviewed. Second, the implementation of the design alternatives in the modelling program is discussed. And third, the verification and face validity of the simulation model and safety analysis is discussed. In the conclusion of this chapter an answer to the sub question is given.

4.1 MODELS AVAILABLE

A literature study on models provides an overview of the models available. When searching for a model a number of angles can be used, as can be seen in Figure 21. This research uses a simulation model to measure the effectiveness. In a simulation model the traffic moves through a network, the time and route a vehicle takes depend on the (dynamic) circumstances of the network (CROW, 2012). Assignment of the position of vehicles is constantly recalculated and adjusted according to the vehicle behaviour. A benefit of using a simulation model is that it also shows a visual representation of the results, which makes it easier to interpret and present results.

4.1.1 NATURE OF THE STUDY

The first step in narrowing down the number of models to choose from is based on the nature of the study; the problem definition, the area of interest, if a static or dynamic model is needed, and what the vehicle differentiation is.

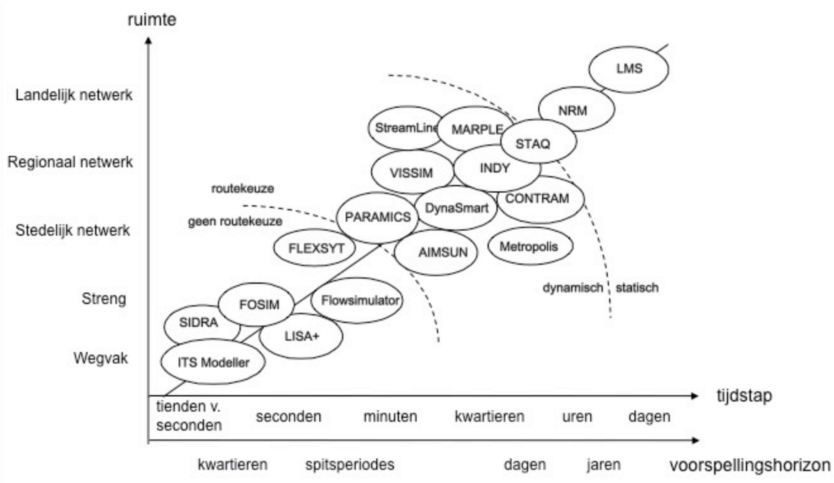


Figure 21: Available models according to Grontmij (2002)

The problem definition of a study determines what kind of model is necessary. If a study is about finding the general solution to a problem without using detailed designs an *exploratory study* is more suitable. For a study with detailed design alternatives a *detailed study* is more appropriate.

The size of the area of interest is important when choosing a model, the distinction is made between local level, strand level, and network level. A study on the *local level* focuses on the effects a measure has on a road section or junction. Studies on *strand level* are zoomed out to the connected sections and junctions. The *network level* has the lowest level of detail, and focuses on a network of sections and junctions on a large scale.

Static models are characterised by large (regional, national) networks, only static traffic measures can be applied (CROW, 2012). Traffic flows are modelled as average traffic flows in rush hour. The results of this type of model offer broad outlines for a long time horizon of 10 to 15 years, and are expressed relative to each other. This type of model is mostly used to compare model variants. *Dynamic models* are characterised by smaller networks, like junctions, series of road sections, and local networks (CROW, 2012). Traffic is modelled on a longer time period with different intensities. The focus is on the flow of individual vehicles, less on the traffic flow. Dynamic traffic (management) measures, road designs, and traffic light schemes can be applied alone or in combinations. Model indicators as travel time and waiting time are expressed in absolute terms for each model variant. The results of this type of model offer detailed results for a short time horizon of 2 to 5 years.

Vehicle differentiation in a model determines the level of detail. *Macroscopic models* take average values for all road users, averagely distributed over the time period. This type of model is used for modelling on a larger scale where the behaviour of individual vehicles is not part of the results needed. *Mesoscopic models* have vehicle groups, where each group has different aspects (speed, density). *Microscopic models* have users with variable characteristics in driving behaviour, the individual driving behaviour of a user influences the speed and capacity of the network. Microscopic models are used for small sections of a network, such as junctions.

Table 7: Available models and their characteristics according to Grontmij (2002)

	EXPLORATORY STUDY	DETAILED STUDY	LOCAL LEVEL	STRAND LEVEL	NETWORK LEVEL	STATIC	DYNAMIC	MACROSCOPIC MODEL	MESOSCOPIC MODEL	MICROSCOPIC MODEL
COCON	X		X			X				**X**
aaSIDRA	X		X			X		X		
FLEXSYT-II-		**X**	X	**X**			**X**			**X**
MIXIC		**X**	X				**X**			**X**
FOSIM		**X**	X	**X**			**X**			**X**
AIMSUN		**X**	X	**X**	X		**X**		X	**X**
Paramics		**X**	X	**X**	X		**X**			**X**
VISSIM		**X**	X	**X**	X		**X**		X	**X**
FREQ	X			**X**			**X**	X		
METNET/MaDAM	X			**X**	X		**X**	X		
TRANSYT		**X**		**X**			**X**	X		
INTEGRATION		**X**		**X**	X		**X**			**X**
FlowSimulator		**X**		**X**			**X**	X		
QBLOK	X				X	X		X		
TRIPS (dynamic)	X				X		**X**	X		
CONTRAM		**X**			X		**X**		X	
SATURN		**X**			X		**X**		X	

X Desired characteristic

The first step in narrowing down the number of models to choose from is based on the nature of the study, the area of interest, if a static or dynamic model is needed, and what the vehicle differentiation is. How the models compare to each other is shown in Table 7.

The study done in this research is a detailed study, so all models meant for exploratory study are eliminated from the list of models. The area of interest for this study is the service road around a pier and the connection to the main service road, which is considered strand level. The vehicle movements are based on origin destination, the simulation model should support dynamic assignment. The diversity of the airside vehicles needs to be modelled with individual vehicles, so a microscopic model is the most appropriate. This first step in narrowing down the number of takes it down to FELXSYT-II-, FOSIM, AIMSUN, Paramics, VISSIM, and INTEGRATION.

4.1.2 INPUT AND OUTPUT

From the problem definition formed in the introduction the following goal for a model is formed: To provide information on the change of the design of the service roads around the piers to optimise the road system. To implement a design in the model, the model should allow for certain design parameters.

The designs contain information about the number of lanes per road section, speed limits, the shape of a junction, and the number of lanes per direction on a junction. The design alternatives do not have no traffic light installations. The circumstances of the airside are the same for each design alternative. There are 13 types of vehicles that drive on the road system, each with their own speed limitation, behaviour, and other characteristics.

Table 8: Input parameters of the remaining models according to Grontmij (2002)

	FLEXSYT-II-	FOSIM	AIMSUN	PARAMICS	VISSIM	INTEGRATION
Number of lanes	X	X	X	X	X	X
Speed limits	X	X	X	X	X	X
Shape of junction			X	X	X	X
Number of lanes/direction of junction	X		X	X	X	X
13 types of vehicles	X		X	X	X	
Vehicle length	X	X	X	X	X	X
Driving behaviour	X	X	X	X	X	X

The remaining models are compared on the input parameters. The needed input parameters are related to the problem definition and characteristics of the design alternatives. How the models compare to each other is shown in Table 8. In FLEXSYT-II- the shape of the junction cannot be specified. In the FOSIM model the shape and number of lanes per direction in a junction cannot be specified. Since the junction design is important for this research, FLEXSYT-II- and FOSIM are not appropriate to use. The FOSIM model and INTEGRATION model are not suited to represent the number of vehicle types.

The limited number of vehicle types in FOSIM and INTEGRATION, and the fact that junctions cannot be specified in FLEXSYT-II- and FOSSIM eliminates the three models. Narrowing down the model types to AIMSUN, Paramics, and VISSIM.

4.1.3 TIME HORIZON

Because of the small scale and the nature of the processes on airside the results have to be accurate. It is therefore important that the model works in the smallest time step, in seconds. Table 9 provides an overview of the time horizons based on the comparison study of Gettman & Head (2003).

Table 9: Time horizons of the remaining models according to Gettman & Head (2003)

	AIMSUN	PARAMICS	VISSIM
VARIABLE TIME STEPS	Yes	Yes	Yes
TIME STEPS < 1 SECOND	Yes	Yes	Yes

All three models have variable time steps, and offer results in time steps smaller than 1 second. The models AIMSUN, Paramics, and VISSIM are therefore all applicable in this study. The Schiphol Group does not have licenses for any of the three simulation programs, nor does it have experience with using the simulation programs themselves. At the TU Delft only the simulation program VISSIM is available for students. Therefore the program *VISSIM* is chosen.

4.2 IMPLEMENTATION OF THE DESIGN ALTERNATIVES IN VISSIM

The simulated network in VISSIM is a representation of the actual network around pier B of AAS on an average day for a certain time period. The network is implemented according to the specifications of the alternatives presented in chapter 3 using the tools available in VISSIM. For the simulation a number of assumptions and abstractions are made concerning the design of the network, the vehicles on airside, the origins and destinations, and the handling times.

4.2.1 Design of the network

The design of the airside road traffic system of AAS is simulated as a network consisting of links and nodes in the computer program VISSIM. Junctions and the origins and destinations of the network are modelled as nodes; the nodes represent path choices, starts and endings. The links connect the nodes to each other to form the abstract network.

In VISSIM the links are drawn according to the specification of a design in the infrastructure of the base situation, see Figure 22. A background image of the current situation is used as a template. The width of a link is adjusted by assigning the number of lanes to a link and specifying the lane width per lane, the assigned width is based on the dimensions of available space and the design specifications. For most lanes the width is 4 meters. There are no restrictions for vehicles types to enter a lane.

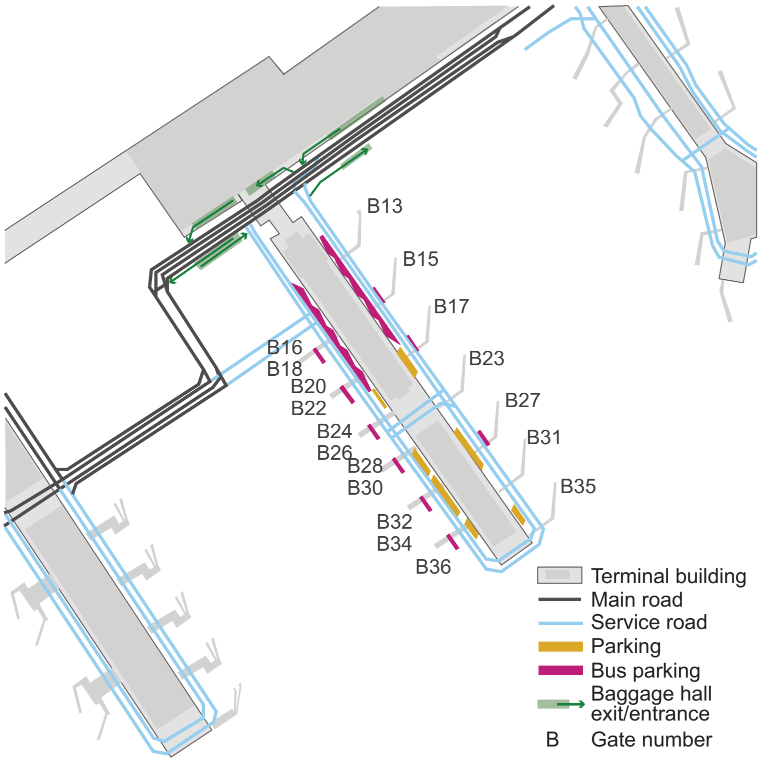


Figure 22: Infrastructure of pier B in the base situation

The entrances and exits to the baggage halls in proximity to pier B are also part of the network as ends and beginnings of the network. The bus gates at the side of the aircraft stands and its corresponding parking spaces on the side of the road are also considered nodes in the network.

Links are connected with each other with connectors at points where the number of lanes change and on junctions where users have a choice in path, see Figure 23. The design of shared space is implemented in VISSIM with overtaking zones of overlapping links, as can be seen in Appendix B. Nodes are drawn around a grouping of connectors to represent junctions, which creates a more abstract network necessary for the dynamic assignment.

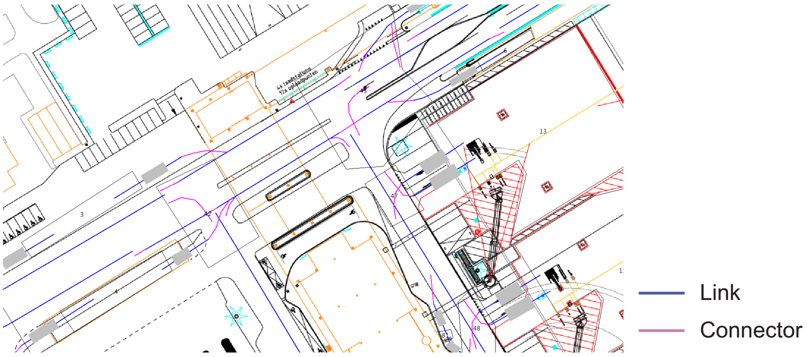


Figure 23: The base situation as drawn in VISSIM with links and connectors

Parking lots are network elements assigned to zones where vehicles appear or disappear from the road network. The zones in the network correspond to the zones in the origin destination matrix (OD matrix). A parking lot is only one-way, so there has to be at least one origin and one destination parking lot for each zone. Trips originating from this zone starts at a parking lot assigned to that zone. While another parking lots assigned to the same zone has trips ending in this zone.

Figure 24: Priority rules as applied on two junctions

Priority rules are used to simulate the priority rules of the actual network. The main road (RH road) always has priority, and vehicles already on the road have priority over vehicles coming from an aircraft stand. The priority rules contain stop lines (in red) and conflict lines (in green) that allows vehicles to cross or not, see Figure 24. Applying slow areas on the connectors mimic the real life conditions on junctions, where vehicles have to slow down to take the corner.

Figure 25: Nodes and zone numbers in VISSIM

The network contains 27 zones (Table 10) represented as nodes in the model (Figure 25). The junction nodes also have a number, but are not considered zones for origin and destination.

Table 10: Zone number and corresponding zone names

ZONE NUMBER	ZONE NAME
1	Pier A and beyond
2	Pier C and beyond
3,4,5,6	Entrances and exits to baggage hall South
13,15,17,23,27,31,35	Uneven gates B13, B15, B17, B23, B27, B31, and B35 on the Northeast side
16,20,24,28,32,36	Even gates B16, B20, B24, B28, B32, and B36 on the Southwest side
81,83,85,87	Uneven bus gates B1, B3, B5, and B7 on the Northeast side
82,84,86,88	Even bus gates B2, B4, B6, and B8 on the Southwest side

4.2.2 VEHICLES

The 9 vehicles used for the handling process are divided into 6 vehicle types; bus, personnel vehicles, handling services, baggage, push back, and baggage handlings. The length, width, design, and speed profiles of the different vehicles are put into VISSIM. There are two vehicle compositions, one for the bus gates (Table 11), and one for the normal gates (Table 12).

Figure 26: Vehicles traveling on the road network

There are three speed profiles: airside 8 km/h, airside 15 km/h, and airside 30 km/h. The speed profile of 8 km/h has a speed distribution of 5 km/h to 8 km/h. The speed profile of 15 km/h has a speed distribution of 12 km/h to 18 km/h. The speed profile of 30 km/h has a speed distribution of 25 km/h to 33 km/h.

The relative flow in the vehicle composition is based on the number of vehicles needed for each handling process, the number of gates, and the number of bus gates. In the vehicle composition for bus gates there are 3 buses for every personnel truck that travels from origin to destination according to the relative flow. And the vehicle composition of normal gates says that 22.2% of the traffic in the OD matrix of normal gates is catering trucks.

Table 11: Vehicle composition bus gates

VEHICLE	VEHICLE TYPE	LENGTH	WIDTH	DESIGN	SPEED PROFILE	RELATIVE FLOW
Bus	Bus	12 m	2 m	1 element	30 km/h	3
Personnel truck	Personnel vehicle	4 m	2 m	1 element	30 km/h	1

Table 12: Vehicle composition normal gates

VEHICLE	VEHICLE TYPE	LENGTH	WIDTH	DESIGN	SPEED PROFILE	RELATIVE FLOW
Catering truck	Handling services	8 - 10 m	2 m	1 element	30 km/h	26
Fuel dispenser	Handling services	8 - 10 m	2 m	1 element	30 km/h	13
Cleaning services	Handling services	8 - 10 m	2 m	1 element	30 km/h	13
Toilet/water services	Handling services	8 - 10 m	2.5 m	1 element	30 km/h	13
Baggage train	Baggage	11 - 21 m	1 m	3-7 elements	15 km/h	26
Push back	Push back	10 m	4 m	1 element	15 km/h	13
Ramp snake	Baggage handling	7 - 11 m	2 m	1 element	8 km/h	13

The default values for acceleration, deceleration, weight, and force for the different vehicles are not changed. The distributions of acceleration and deceleration are based on the Wiedemann principle, and can be applied to the airside road network. The distribution of weight and force of a vehicle is not changed because it is used for emissions calculations and environmental effects, which is outside the scope of this research.

4.2.3 TIME PERIOD AND DYNAMIC ASSIGNMENT

As a representation for the vehicle flows of the airside road traffic system an average day with an average number of flight movements is simulated, the average number of flights per day was 2000 flight movements per day in 2015. Thursday November 19 2015 is a day with approximately 2000 flight movements and is therefore simulated in VISSIM. A period of 3 hours and 40 minutes containing 2 peak moments is modelled, from 7.00 till 10.40.

The vehicle movements are based on dynamic assignment, an origin destination (OD) matrix supplies the data for the model. There is an OD matrix for every 20 minutes, with an evaluation time of 10 minutes. The last OD matrix is made entirely out of zeros to cool down the road network. The flows in the OD matrix are based on the gate planning of AAS for that particular day, static handling times, the vehicles needed for the handling process, and a traffic count. There is a matrix factor of 1.2 to account for the difference in the amount of vehicles between 2015 and 2025 with an average growth of 2% per year.

Table 13: Fragment of the gate planning November 19 2015

ARRIVAL TIME	DEPARTURE TIME	GATE NUMBER	AIRCRAFT TYPE
7:09:04	7:49:00	B36	EMJ
7:09:05	7:55:30	B28	F70
7:19:00	8:12:17	B24	EMJ

There is one large baggage hall under pier B, therefore baggage to and from the aircraft is assumed to come from and go to the nearest entrance or exit of this baggage hall. Baggage trains and push-back trucks are assumed to travel between gates after finishing the handling process on an aircraft, and do not return to their home base. Static handling times and a gate planning from an average day are used, in reality this process is more dynamic. It is assumed aircraft do not change gates between arriving and departing.

Through traffic is modelled with the same vehicle compositions. The number of through vehicles is based on traffic counts of the traffic coming and going from the direction of platform B and pier C. The traffic counts of Table 14 were carried out on March 10 2016 between 16:35 and 17:15. The assumption is made that the amount of through traffic does not change because of the new pier, only taking the average growth factor into account. Vehicles that entered the main road from the service roads of pier B and vehicles leaving the main road towards pier B were not counted. Only the through traffic was counted.

Table 14: Traffic count on March 10 2016 at pier B

TIME	PLATFORM B TO PIER C	PIER C TO PLATFORM B
16:35 – 16:55	33	40
16:55 – 17:15	33	42

4.2.4 DESIGN OF THE SIMULATION RUNS IN VISSIM

For each infrastructural design alternative two road traffic models were built in VISSIM, a model that simulates vehicles in the normal scenario and a model that simulates vehicles in an accident scenario. Both models are run for 15 simulations of 13200 seconds each. These simulations represent a morning period of 7.20 till 10.40 on an average day for pier B in 2025. There were approximately 1475 vehicles in each simulation run for each alternative in both the normal scenario and the accident scenario. The number of vehicles in the road traffic system is different for each run, each run increasing the number of vehicles by 0.3%. This successive increase of traffic demand in the dynamic assignment is applied to monitor the effect an increase of the traffic demand has on the results. The lowest number of vehicles represents the scenario where the number of vehicles and demand is lower than in the current situation. The highest number of vehicles represents the scenario where the amount of vehicles and demand increases over time. The final results for each alternative are determined the means of the produced output of all runs.

The traffic model in the accident scenario was the normal road traffic system with a road closure on the northwest side of the pier near the connection with the main road, as shown in Figure 27. The road closure was on all two lanes, the detour made by the vehicles normally using this entry and/or exit point causes a higher total travel time. The percentage of extra travel time compared to the normal scenario determines the level of robustness.

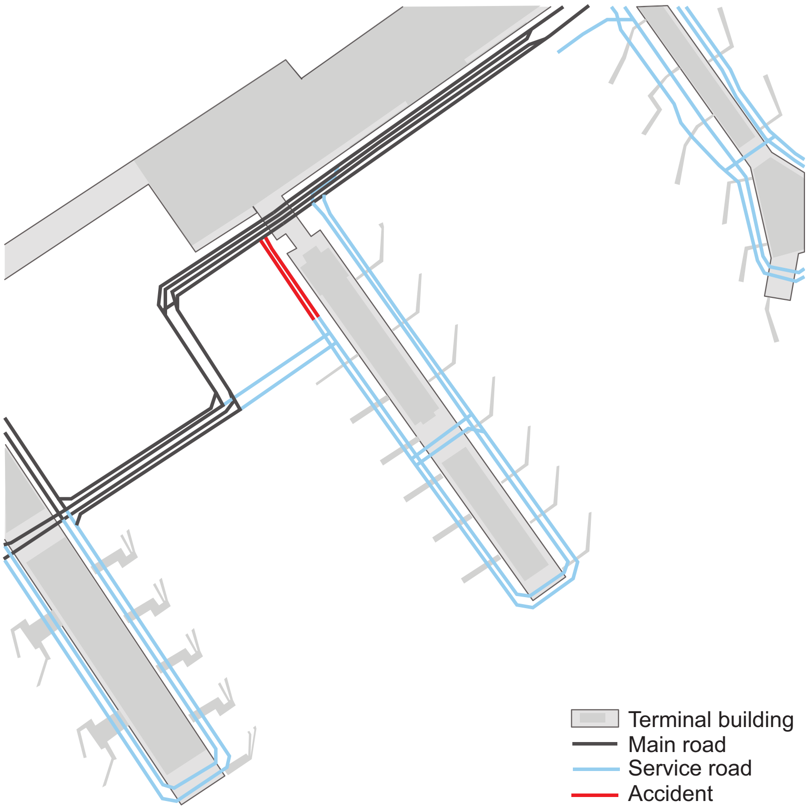


Figure 27: Location of accident in accident scenario

The output of the VISSIM model for this research consisted of trajectory output files for the surrogate safety measures analysis, the network performance, node evaluation, and link evaluation. The network performance included the number of vehicles in each run, as well as the total travel time and travel distance. The node evaluation showed the number of vehicles traveling in each direction for the seven junctions, which gives an indication on the routes vehicles travelled through the airside road traffic system. The link evaluation shows the number of vehicles per hour using the extra connection road to the main road and the passage road through the pier.

4.2.5 ANALYSIS OF SURROGATE SAFETY MEASURES

The analysing application SSAM by the Federal highway administration of the United States (FHWA) provides a tool to perform comparative safety analysis based on the output of a variety of traffic simulation models (Gettman & Head, 2003). The application identifies traffic conflicts from the vehicle trajectories of the vehicles in VISSIM. A conflict is an observable situation in which two road users approach each other in such a way that there is a risk of collision if their movements remain unchanged (Amundsen & Hyden, 1977).

The file containing trajectories of the simulated vehicles in VISSIM is analysed to define time-to-collisions (TCT), post-encroachment times (PET), and the conflict angle between the first and second vehicle. TTC is defined as the difference between the encroachment time end time of the turning vehicle and the projected arrival time of the right-of-way vehicle if the vehicle continues at the same speed (Gettman & Head, 2003). PET is defined as the time between the departure of the encroaching vehicle from the conflict point and the arrival of the vehicle with the right-of-way at the conflict point (Gettman & Head, 2003).

There are three conflict threshold parameters, maximum TCT, maximum PET, and conflict angle. These threshold parameters can be adjusted to define what is counted as a certain type of conflict. The threshold parameter of TTC is set at 1.3 seconds for an entering speed of 30 km/h according to the research of Hyden (1987). The PET value is difficult to apply when vehicle trajectories do not cross at a right angle (Laureshyn, Svensson, & Hyden, 2010), therefore this parameter is only used as a supporting parameter and not an identifying parameter in this research. The threshold parameter of PET is set to the default setting of 5.0 seconds.

According to Caliendo and Guida (2012) conflicts in which the TTC and PET is zero should be excluded from the analysis, the values of TTC and PET are only zero when the hypothetical crash does not occur or the leader vehicle is not decelerating. Both scenarios are not part of a surrogate safety analysis. A negative deceleration rate suggests that the following vehicle is not decelerating but accelerating, and is therefore also considered a false positive (Ariza, 2011).

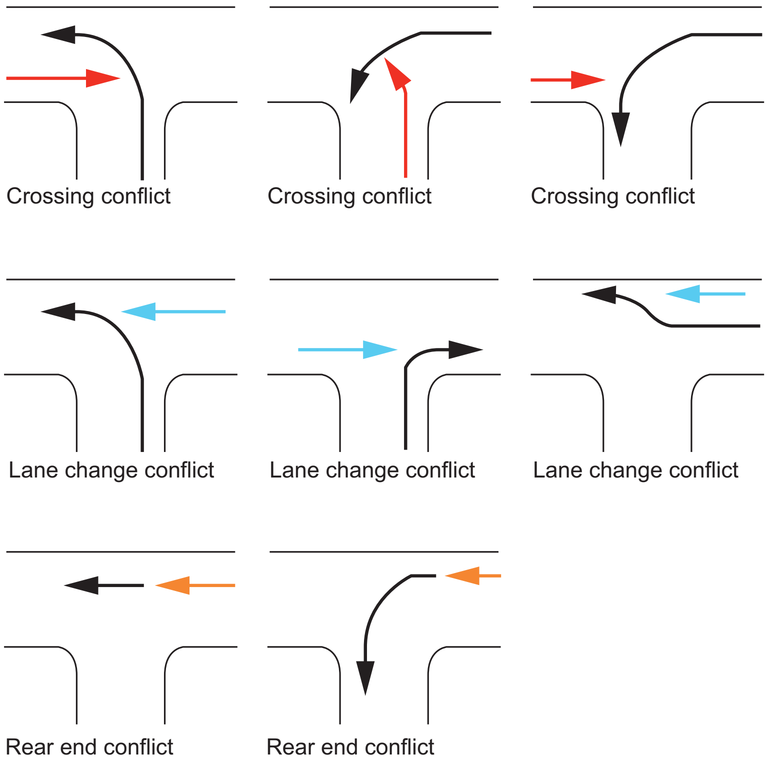

Crossing conflict
Crossing conflict
Crossing conflict
Lane change conflict
Lane change conflict
Lane change conflict
Rear end conflict
Rear end conflict

Figure 28: Conflict classification of conflicts based on conflict angle

A conflict is a possible crash, the relation between conflicts and crashes can be determined by comparing the conflicts to historical crashes on a junction or road section. The traffic flow in a junction or road section should also be taken into account when relating conflicts to crashes. Several researches have already been done on urban intersections, relating the measured number of crashes with the amount of conflicts measured by video. But there is no present formula relating the number of conflicts and the traffic flow to the number of expected crashes for the situation on airside. Therefore the potential number of crashes is not part of this research.

4.3 Verification and face validity of the simulation model and safety analysis

Verification of the road traffic systems in VISSIM and the parameters of SSAM ensure that the programming and implementation is correct. Face validity checks if the model application in VISSIM and SSAM generates results that are in the line of expectation. The step of verification and face validation is important in a research, because it determines if the results of the model and analysis tool are an accurate representation of expected results in real life. The model should represent an average day on airside around pier B, and the analysis tool should only take normally occurring conflicts into account.

4.3.1 Verification of the simulation model

The verification of the road traffic model in VISSIM verifies if the design of the model is correctly translated into VISSIM, and if the traffic flow of road users behaves in a similar way compared to the real life expected behaviour. Where the design is not correctly translated and/or the traffic flow behaves in a non-realistic way changes are made to the model to solve these issues.

Before starting with a simulation run VISSIM verifies if all essential aspects (nodes, links, parking lots, OD matrices) are correct. If not all aspects are correct VISSIM shows an error and aborts the simulation run.

When something is wrong in the model VISSIM shows a warning, but continues the simulation. Verifying the conceptual model is done by face value, before running the simulation the links and connectors are verified with the drawn conceptual design of the model. It is also verified if the links and connectors are drawn according to the guidelines of VISSIM. The OD matrices of the dynamic assignment are based on a historical flight planning: the data of the model is verified.

In the simulation the road users behave as expected, they stop at the stop lines to give priority to the main road, accelerate when there is no preceding vehicle, and slow down when turning.

4.3.2 FACE VALIDITY OF THE SIMULATION MODEL

There is no data available on the driving behaviour and expected results of the implementation of these infrastructural changes on the airside road traffic system. Therefore validation is based on face validity. The behaviour of the traffic flow and the layout of the road traffic system are compared with visual information on the real life situation.

The dimensions of the design alternative models are based on the AutoCAD drawings of the card room of the Schiphol Group in combination with the specification of the design alternatives of Section 3.4. The dimensions of the designs include the length of the road sections, the number of lanes, the width of the lanes, and the turning movements. The priority rules set in the model correspond to the priority rules present on airside. Priority rules on airside are applied in the same way as on 'normal roads' and can therefore directly be applied. There is a distinction made between vehicle types. There are 6 vehicle types with different lengths, widths, design, and speed profiles. The speed profiles correspond to the speed limitations and measurements on airside. The road users in the model travel the shortest path to their destination, with the extra connection between the pier and the main road there are 2 shortest paths for the throughput traffic going from zone "pier C" to zone "pier A". It cannot be validated if road users would travel this route in real life, as this part of the road traffic system is only implemented with the construction of the new pier. It is assumed that a small part of the road users uses this bypass, but further research is needed on this topic. The amount of vehicles in the output of the model corresponds to the counting of throughput traffic.

For a simulation to be valid the modelled time period has to be long enough to represent an average day, and must be repeated a number of times for more accurate results. The model represents the situation of the design alternative between 7.00 and 10.20 and a cooling down period of 20 minutes. This period has two peak moments in it. Each design alternative model has 15 simulation runs with an increasing number of road users, going from 85% to 100%.

4.3.3 SENSITIVITY OF THE SSAM PARAMETERS

In the analysis application SSAM the parameters maximum TTC, maximum PET, and conflict angle can be adjusted before the application analyses the trajectory files from the VISSIM simulation. The sensitivity of these parameters is tested on the trajectory outputs of 15 simulation runs of the base situation (alternative 1B).

The file containing trajectories of the simulated vehicles in VISSIM is analysed to define TCT, PET, and the conflict angle between the first and second vehicle. The values used in this research for maximum TTC and maximum PET are 1.3 seconds and 5 seconds respectively. The conflict angle does not change the number of identified conflicts, but changes the categorisation of the conflicts.

Table 15: Sensitivity of the SSAM parameters

PARAMETER	BASE SITUATION	0 < TTC ≤ 1.2 S	0 < PET ≤ 4.5 S
Number of crossing conflicts	5.5	5.0	5.5
Percentage of change		-8.5%	0.0%
Number of rear end conflicts	7.9	7.3	7.5
Percentage of change		-7.2%	-4.6%
Number of lane change conflicts	5.1	4.5	5.1
Percentage of change		-12.4%	-0.7%

The values of TTC and PET indicate the probability of the conflict. Where a lower value indicates a higher probability of collision. It is expected that the number of conflicts with a higher probability is higher than the number of total conflicts. A lower TTC has a larger effect on the number of conflicts, indicating that probability is more dependent on TTC-values. Which is also the result of earlier research on surrogate safety measures analysis. However, the values for the base situation and after the TTC adjustments have a large overlap. Only the number of lane change conflicts changes significantly. A lower PET value has no significant effect on the number of conflicts, consistent with the definition of PET.

4.3.4 FACE VALIDITY OF THE SSAM ANALYSIS

Face validity checks if the model in VISSIM generates results in SSAM corresponding with expectations. Applying a number of measures in the VISSIM model tests the validation of the SSAM analysis. These measures are: Adjusting the decision parameters by increasing the acceptable headway and gap time, and placing the stop line further away from the junction. These measures are implemented in VISSIM and run for 15 simulations, the same way as a normal alternative.

Table 16: VISSIM parameter sensitivity of SSAM

PARAMETER	BASE SITUATION	DECREASING ACCEPTABLE HEADWAY AND GAP TIME	MOVING BRAKE LINE CLOSER TO JUNCTION
Number of crossing conflicts	5.5	6.9	3.6
Percentage of change		25.0%	-34.4%
Number of rear end conflicts	7.9	9.9	6.2
Percentage of change		25.3%	-21.3%
Number of lane change conflicts	5.1	6.0	4.2
Percentage of change		18.2%	-18.2%

The acceptable headway and gap time are adjusted from 12 meter to 5 meter and 5 seconds to 3 seconds. Which indicates that the vehicles when crossing a through flow accept a smaller gap in the vehicles to make their manoeuvre. By accepting a smaller gap in the vehicles the number of conflicts increases, because critical values for TTC and PET occur more often. The highest increase in conflicts is on crossing conflicts and rear end conflicts.

The brake line is moved from 2 meters before the junction to the edge of the junction. Moving the brake line results in less crossing, rear end, and lane change conflicts. These results show that the start point of a crossing vehicle closer to the through traffic causes far less crossing conflicts. The longer turning lanes for vehicles are the main cause of a lower number of rear end and lane change conflicts from the main road to the service road.

Changing the parameters in VISSIM has a larger effect on the number of conflicts than changing the parameters in SSAM, as can be seen in Table 15 and Table 16. Because the parameters are adjusted in VISSIM a new set of trajectories is analysed in SSAM. The routes of the normal alternative and the adjusted parameter-alternatives are mostly the same, so the changes in the number of conflicts are a direct result of the measure.

4.4 SUB CONCLUSION: VISSIM MODEL

In this chapter sub question 3 is answered: What type of model can be used for simulating the airside road traffic system? This research on effects of the design of the service roads around the piers of AAS requires the use of a simulation model to test the design alternatives. The choice of a model depends on the nature of the study, the area of interest, the nature of the traffic measures, the vehicle differentiation, the needed input and output of the model, and time horizon.

The simulation model needed offers a detailed study on a local level and strand level that can model individual vehicles. There were six dynamic microscopic models that met these specifications, namely FLEXSYT-II-, FOSIM, AIMSUN, Paramics, VISSIM, and INTEGRATION. VISSIM is chosen because it has the parameters needed to simulate the design alternatives, provides the needed output to measure the effects on travel time, travel distance, and robustness, results are in a time step of 1 second, and it is available to use at the TU Delft. The model simulated in VISSIM does not have a direct safety output. Therefore the analysing application SSAM by the Federal highway administration is used as a tool to perform a surrogate safety analysis based on the trajectory output of VISSIM.

For this research an average day with an average number of flight movements, Thursday November 19 2015, is simulated in VISSIM. The design of the airside road traffic system of AAS is simulated as a network consisting of links and nodes. The links are drawn according to the specification of the design in the existing infrastructure. The network contains 27 zones represented as nodes in the model. Priority rules are used to simulate the priority rules of the actual network. The length, width, design, and speed profiles of the six vehicle types are an abstraction of the actual vehicles driving on the airside road traffic system. The vehicle movements are based on dynamic assignment with an origin destination matrix that supplies the data for the model. The data in the OD matrix is based on the gate planning of AAS for that particular day, static handling times, the vehicles needed for the handling process, and a traffic count of through traffic.

To test if the model and analysis tool provide the expected results and coincide with the airside traffic and road conditions verification, face validity, and sensitivity studies were performed. The verification and face validity study were on a VISSIM model of the base situation, and showed expected behaviour and layout of the road traffic system. The sensitivity and face validity study of SSAM focused on the parameters of SSAM, the results of the analysis correspond with the expectations.

5 EFFECTS OF THE INFRASTRUCTURAL DESIGN ALTERNATIVES

In this chapter sub question 4 is answered: What are the effects of the infrastructural design alternatives on travel time, travel distance, robustness, and safety? First, the results of the simulation runs of the alternatives in VISSIM are discussed in groupings by road section design. Second, the alternatives are compared with each other on the aspects travel time, travel distance, robustness, and safety. Third, the sensitivity of the results to changes in input and parameters is analysed. In the conclusion of this chapter an answer to the sub question is given.

The design specifications surface used and costs are not part of the discussion and comparison of results in this chapter. The design specifications where already discussed in Section 3.4. In the assessment of Chapter 7 all aspects of the design alternatives are assessed.

5.1 RESULTS OF THE SIMULATION AND SAFETY ANALYSIS

In this section the results of the VISSIM simulation and the surrogate safety measures analysis in SSAM of the 12 infrastructural design alternatives are discussed. The infrastructural design alternatives include the design of the road traffic system in the base situation. The results presented in this section are the mean results and the range of results of 15 simulation runs. The execution of these runs is described in Section 4.2. The conflicts identified by SSAM of all 15 runs are indicated on maps of pier B with the design of the infrastructural design alternative. The location and density of the conflict dots identify the location where most conflicts occur.

The effects of the infrastructural design alternatives are mostly dependant on the type of road section design of the service roads. Therefore the results of the simulation and safety analysis are grouped by road section design. The results of the parameters total travel time, total travel distance, percentage of extra travel time compared to normal scenario, and total number of conflicts are the values representing the aspects travel time, travel distance, robustness, and safety. The averages of travel time and travel distance per vehicle, the extra travel time, and the number of conflicts per classification are also given to better compare the results to each other on a smaller scale.

5.1.1 RESULTS OF THE TWO-WAY ALTERNATIVES

The design of the road traffic system around the piers is two-directional for design alternatives 1A, 1B, and 1C. The junction designs for the two main points connecting the service road to the main road are equal crossings with road barriers for 1A, equal crossings with turning lanes for 1B, and *voorrangspleinen* for 1C. The third connection to the main road is an equal crossing for all three design alternatives, corresponding to the design in the base situation. The road traffic system of design alternative 1B corresponds to the base situation.

Table 17: Performance of the road traffic systems of design alternative 1A, 1B, and 1C

ASPECT	PARAMETER	ALTERNATIVE 1A		ALTERNATIVE 1B		ALTERNATIVE 1C	
		MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
Travel time	**Total travel time**	**48.0 h**	**45.6 h 50.3 h**	**44.8 h**	**42.5 h 46.5 h**	**47.4 h**	**44.6 h 49.1 h**
	Average travel time per vehicle	116.9 s	113. 6 s 120.2 s	109.1 s	106.0 s 111.3 s	115.4 s	111.1 s 118.4 s
Travel distance	**Total travel distance**	**545.7 km**	**531.5 km 556.9 km**	**545.1 km**	**530.9 km 555.8 km**	**551.2 km**	**536.6 km 559.0 km**
	Average travel distance per vehicle	369.2 m	368.9 m 369.6 m	368.8 m	368.6 m 369.2	372.7 m	372.5 m 373.3 m
Robustness	**Percentage of extra travel time compared to normal scenario**	**5.3 %**	**2.6 % 8.5 %**	**6.0 %**	**4.6 % 9.4 %**	**2.7 %**	**-1.9 % 6.7 %**
	Extra Travel Time in accident scenario	2.5 h	1.3 h 4.0 h	2.7 h	2.1 h 4.0 h	1.3 h	-0.9 h 3.2 h
Safety	**Total number of conflicts**	**15.3**	**10 23**	**18.3**	**9 28**	**15.4**	**8 22**
	Number of crossing conflicts	5.3	3 9	5.5	2 10	4.7	1 10
	Number of rear end conflicts	4.9	0 8	7.9	1 13	4.6	1 7
	Number of lane change conflicts	5.2	2 10	5.1	2 11	6.1	2 12

The total travel time of alternative 1B is the lowest with 44.8 h, which translates into an average travel time of 109.1 seconds per vehicle in the road traffic system. In alternative 1A the average travel time is 116.9 seconds, and in alternative 1C 115.4 seconds. Comparing the average travel times, the differences in travel time are not large, only a few seconds. The travel distance of alternative 1A and 1B is virtually the same; the average travel distance per car differs only 0.4 meters. For alternative 1C the total distance travelled is higher by 4 meters on average per vehicle. In alternative 1B and 1A a third of the throughput traffic takes the shorter route along the pier to the extra connection to the main road, while in alternative 1C more users take the main road route. In the accident scenario this is no longer possible. Resulting in higher extra travel times in comparison to alternative 1C, where staying on the main road is more attractive for the drivers.

Figure 29: Conflict analysis of alternative 1A

The total number of conflicts of alternative 1A is the lowest of the three alternatives, alternative 1C scores about the same. Alternative 1B has the highest total number of conflicts. The slightly lower number of crossing conflicts for the equal crossing with road barriers and the voorrangsplein is caused by a smaller percentage of through vehicles turning left on the main road. Figure 29 is a visual representation of the conflicts identified by SSAM in alternative 1A, the conflict analysis of alternatives 1B and 1C are in Appendix C. The number of rear end conflicts is also higher in alternative 1B, most conflicts are the result of traffic on the main road passing the turning traffic entering the turning lane. Passing the traffic on the turning lanes usually results in a rear end conflict due to limitations in VISSIM. These rear end conflicts should be taken out of the results, and lead to better safety results of 1B. The higher amount of lane change conflicts is the result of the curved design of the voorrangsplein, which means that the conflicts on the junction are categorised crossing conflicts as well as lane change conflicts. The curved shape does lead to smoother braking when turning left, which lowers the amount of rear end conflicts compared to alternative 1B.

5.1.2 RESULTS OF THE ONE-WAY ALTERNATIVES WITH TWO LANES

The design of the road traffic system around the piers of design alternatives 2A and 2B is one-directional with two lanes. The junction designs for the two main points connecting the service road to the main road are equal crossings with road barriers for 2A and equal crossings with turning lanes for 2B. The third connection to the main road is an equal crossing for both design alternatives, corresponding to the base situation.

Table 18: Performance of the road traffic systems of design alternative 2A and 2B

Aspect	Parameter	Alternative 2A Mean	 Range	Alternative 2B Mean	 Range
Travel time	**Total travel time**	**52.4 h**	**49.3 h 54.1 h**	**51.4 h**	**49.9 h 52.8 h**
	Average travel time per vehicle	128.4 s	124.2 s 127.5 s	126.0 s	124.2 s 127.5 s
Travel distance	**Total travel distance**	**614.0 km**	**595.7 km 628.1 km**	**610.7 km**	**600.0 km 623.5 km**
	Average travel distance per vehicle	418.0 m	414.6 m 420.0 m	415.7 m	414.1 m 420.4 m
Robustness	**Percentage of extra travel time compared to normal scenario**	**6.9 %**	**4.2 % 10.7 %**	**7.2 %**	**5.8 % 8.4 %**
	Extra Travel Time in accident scenario	3.6 h	2.3 h 5.5 h	3.7 h	2.9 h 4.4 h
Safety	**Total number of conflicts**	**15.3**	**10 20**	**14.5**	**10 19**
	Number of crossing conflicts	3.3	1 7	3.2	1 6
	Number of rear end conflicts	6.4	4 9	6.6	3 10
	Number of lane change conflicts	5.6	1 9	4.7	3 7

The total travel time of the two alternatives show a slight difference, the turning lanes added to the equal crossing shorten the total travel time by 1 hour. Which saves the vehicles 2.4 seconds on average for this part of the airside road traffic system. The total travel distance is higher for alternative 2A because in this alternative more vehicles travel a route around the pier to avoid the slow vehicles on the main road. The amount of extra travel time for both alternatives in the accident scenario is approximately the same. Because of the lower original travel time of alternative 2B, this alternative has a higher percentage of extra travel time.

Figure 30: Conflict analysis of alternative 2B

Alternative 2B has the lowest total number of conflicts. The difference between the number of crossing conflicts is only slight. The number of rear end conflicts is also virtually the same, mainly concentrated at the junctions with the main road. The rear end conflicts at the turning lanes are the results of limitations in VISSIM, when they are taken out of the results alternative 2B scores even better. The difference between the two alternatives becomes more apparent in the number of lane change conflicts. Figure 30 is a visual representation of the conflicts identified by SSAM in the trajectories of the vehicles in alternative 2B, the conflict analysis of alternative 2A is in Appendix C. In alternative 2A there are a large amount of lane change conflicts on the junctions as well. There is a higher percentage of through traffic taking a route around the pier to avoid slow vehicles in alternative 2A, which results in more lane change conflicts at the junctions and on the service roads around the piers.

The road traffic system of the pier in a one-way design has one entrance for the entire pier (Northest), one entrance to only reach two bus stops (Southwest), and two exits (Northwest and Southwest). The crossing conflicts in the one-way alternatives are mostly focused at the junction where road users enter the pier road traffic system at the Northeast side of the main road and at the exit junction on the Southwest side of the main road. These two junctions have the highest number of left-turning road users per hour, so the larger number of conflicts is expected.

5.1.3 RESULTS OF THE ONE-WAY ALTERNATIVES WITH PARKING BAYS AT THE BUILDING

The design of the road traffic system around the piers of design alternatives 3A and 3B is one-directional with parking bays on the side of the building. Vehicles mostly used the left lanes, and can pass each other on the right side. The junction designs in 3A for the two main points connecting the service road to the main road are equal crossings with road barriers. In 3B the junctions are designed as equal crossings with turning lanes for 3B. The third connection to the main road is an equal crossing for both design alternatives, corresponding to the base situation.

Table 19: Performance of the road traffic systems of design alternative 3A and 3B

ASPECT	PARAMETER	ALTERNATIVE 3A		ALTERNATIVE 3B	
		MEAN	RANGE	MEAN	RANGE
Travel time	**Total travel time**	**53.3 h**	**50.6 h** **54.8 h**	**51.5 h**	**49.0 h** **53.4 h**
	Average travel time per vehicle	130.6 s	127.5 s 133.1 s	126.2 s	123.4 s 129.1 s
Travel distance	**Total travel distance**	**619.0 km**	**604.3 km** **634.0 km**	**618.1 km**	**599. 7 km** **633.6 km**
	Average travel distance per vehicle	421.4 m	419.9 m 423.1 m	420.8 m	419.0 m 422.8 m
Robustness	**Percentage of extra travel time compared to normal scenario**	**7.0 %**	**5.2 %** **9.8 %**	**6.5 %**	**5.4 %** **8.0 %**
	Extra Travel Time in accident scenario	3.8 h	2.7 h 5.1 h	3.3 h	2.8 h 4.1 h
Safety	**Total number of conflicts**	**18.5**	**10** **24**	**18.6**	**18** **31**
	Number of crossing conflicts	3.2	1 5	3.0	1 5
	Number of rear end conflicts	8.1	4 10	8.3	5 11
	Number of lane change conflicts	7.2	3 12	7.3	3 11

The total travel time of alternative 3A and 3B is 53.3h and 51.5h respectively. Just as in the other alternative pairs of -A and -B, -B has a lower total travel time. The total travel distance is only slightly shorter for alternative 3B. The percentage of extra travel time in the accident scenario is lower for alternative 3B.

Alternative 3A has the lowest total number of conflicts. Alternative 3B has less crossing conflicts but there is only a small difference. There are more rear end and lane change conflicts in alternative 3B. The rear end conflicts at the beginning of the turning lanes are detected due to limitations in VISSIM and the length of the vehicles. When these rear end conflicts are not taken into account the equal crossing with turning lanes (3B) gives the best result. The conflict analysis of alternatives 3A and 3B are in Appendix C.

5.1.4 Results of one-way alternatives with extended aircraft stands

The design of the road traffic system around the piers of design alternatives 4A and 4B is one-directional with extended aircraft stands. The main lane is on the right, while vehicles can overtake on overtake bays on the left. The junction designs in 3A for the two main points connecting the service road to the main road are equal crossings with road barriers. In 3B the junctions are designed as equal crossings with turning lanes for 4B. The third connection to the main road is an equal crossing for both design alternatives, corresponding to the base situation.

There is a relatively high difference in the travel times of the two alternatives, which is explained by the larger number of cars taking the route around the pier to avoid the slow vehicles on the main road in alternative 4A. Which also explains the difference in the number of kilometres. The percentage of extra travel time between is higher in alternative 4B. The differences between the set 3A and 3B and the set 4A and 4B suggest that overtaking areas when more focused on a single area instead of spread out over the entire pier yields better results.

Table 20: Performance of the road traffic systems of design alternative 4A and 4B

Aspect	Parameter	Alternative 4A		Alternative 4B	
		Mean	Range	Mean	Range
Travel time	**Total travel time**	**53.6 h**	**51.7 h** **55.2 h**	**50.4 h**	**47.3 h** **52.0 h**
	Average travel time per vehicle	138.7 s	129.3 s 133.6 s	123.5 s	119.1 s 126.0 s
Travel distance	**Total travel distance**	**624.1 km**	**611.3 km** **634.5 km**	**609.1 km**	**589.5 km** **623.3 km**
	Average travel distance per vehicle	424.8 m	422.9 m 429.1 m	416.6 m	412.5 m 417.0 m
Robustness	**Percentage of extra travel time compared to normal scenario**	**8.6 %**	**5.7 %** **12.3 %**	**8.1 %**	**7.0 %** **10.0 %**
	Extra Travel Time in accident scenario	4.6 h	3.0 h 6.5 h	4.1 h	3.6 h 5.0 h
Safety	**Total number of conflicts**	**19.2**	**12** **30**	**19.3**	**11** **28**
	Number of crossing conflicts	3.4	2 7	3.7	2 7
	Number of rear end conflicts	7.7	4 12	8.8	4 12
	Number of lane change conflicts	8.1	2 13	6.8	2 13

Alternative 4A has the lowest total number of conflicts, but the difference between the two alternatives is very small. The number of crossing and rear end conflicts is higher for alternative 4B. Most conflicts occur on the northeast junction with the main road. The rear end conflicts at the turning lanes are the results of limitations of VISSIM, and therefore should not be taken into account. The number of lane change conflicts is lower for the B-alternative. When the rear end conflicts at the turning lanes are not taken into account 4B has better safety results. The conflict analysis of alternatives 4A and 4B are in Appendix C.

5.1.5 Results of the shared space alternatives

The road traffic system around the piers is designed as shared space for design alternatives 5A, 5B, and 5C. The junction designs for the two main points connecting the service road to the main road are equal crossings with road barriers for 5A, equal crossings with turning lanes for 5B, and *voorrangspleinen* for 5C. The third connection to the main road is an equal crossing for all three design alternatives, corresponding to the design in the base situation. The implementation of shared space in the model consists of a couple of overlapping road sections where vehicles can overtake while taking opposing traffic into account.

The total travel time and the total travel distance of alternative 5B is the lowest of the three alternatives, while alternative 5C has the highest total travel time and travel distance. The higher average number of vehicles can partly explain the high results of alternative 5C in the road traffic system during the simulations, but in the average results per vehicle the difference is still notable. The percentage of extra travel time is the lowest for alternative 5C, and the highest for alternative 5B.

Table 21: Performance of the road traffic systems of design alternative 5A, 5B, and 5C

Aspect	Parameter	Alternative 5A		Alternative 5B		Alternative 5C	
		Mean	Range	Mean	Range	Mean	Range
Travel time	**Total travel time**	**45.4 h**	**42.4 h** **47.2 h**	**44.6 h**	**41.8 h** **46.3 h**	**48.2 h**	**45.7 h** **49.6 h**
	Average travel time per vehicle	110.6 s	105.7 s 113.7 s	108.6 s	104.1 s 111.2 s	116.1 s	114.3 s 118.7 s
Travel distance	**Total travel distance**	**546.2 km**	**531.8 km** **557.3 km**	**546.0 km**	**531.7 km** **557.2 km**	**555.9 km**	**535.3 km** **563.1 km**
	Average travel distance per vehicle	369.6 m	369.4 m 370.0 m	369.4 m	369.2 m 269.9 m	372.1 m	371.8 m 372.4 m
Robustness	**Percentage of extra travel time compared to normal scenario**	**4.5 %**	**3.5 %** **6.4 %**	**5.2 %**	**3.9 %** **7.7%**	**2.9 %**	**-1.9 %** **6.6 %**
	Extra Travel Time in accident scenario	2.1 h	1.6 h 2.7 h	2.3 h	1.7 h 3.3 h	1.4 h	-0.9 h 3.2 h
Safety	**Total number of conflicts**	**17.7**	**11** **21**	**18.9**	**13** **26**	**17.7**	**12** **24**
	Number of crossing conflicts	6.2	2 10	6.1	4 8	4.5	2 7
	Number of rear end conflicts	5.5	2 9	6.5	3 9	6.4	3 11
	Number of lane change conflicts	6.0	3 12	6.3	3 14	6.8	3 15

The total number of conflicts of alternative 5A is the lowest of the three alternatives, alternative 5C scores about the same. Alternative 5B has the highest total number of conflicts. Alternatives 5A and 5C have less rear end conflicts compared to alternative 5B. However, it should be noted that the rear end conflicts at the beginning of the turning lanes occur because of limitations in VISSIM. The amount of lane change conflicts in alternative 5C is higher than the other two because of the curved design of the *voorrangsplein*, which causes other conflict angles.

Figure 31: Conflict analysis of alternative 5C

Figure 31 is a visual representation of the conflicts identified by SSAM in alternative 5C, the conflict analysis of alternatives 5A and 5B are in Appendix C. All three alternatives have lane change, rear end, and crossing conflicts on the service roads where vehicles where shared spaces where implemented. The conflicts on the north side of the service road are the most apparent, suggesting that the implementation of shared space at the beginning of the pier caused more conflicts. When the rear end conflicts at the beginning of the turning lanes are not taken into account the equal crossing with tuning lanes (-B) gives the best safety result.

5.2 COMPARISON OF THE INFRASTRUCTURAL DESIGN ALTERNATIVES

In this section the results of all alternatives are compared with each other. Because the absolute results for a best alternative are determined by the goal of a stakeholder, only the best alternative per aspect is determined. These aspects are travel time, travel distance, robustness, and safety. Alternatives with lower results of total travel time, total travel distance, percentage of extra travel time, and number of conflicts are considered better alternatives. A sample T-test using the statistical program SPSS and the calculation of effect sizes are used to assess if there is a statistical and substantive significant difference between the results of an alternative and the base situation.

5.2.1 BEST DESIGNS PER ASPECT

The results of the VISSIM simulation and the surrogate safety measures analysis in SSAM are discussed in grouping of junction design and road section designs to determine the best road section design and junction design.

Best road section design
The results of total travel time, total travel distance, percentage of extra travel time in accident scenario compared to normal scenario, and the total number of conflicts per design alternative are compared per junction design grouping in Table 24. The one-way alternatives (2, 3, and 4) had higher total travel times and travel distances compared to two-way and shared space. The one-way alternatives have higher percentages of extra travel time compared to the two-way and shared space alternatives. The results show that there are more conflicts in shared space alternatives (5) and in more complicated road section designs with overtake bays (3 and 4).

The shared space designs (5-) have the two lowest total travel times. For travel distance the two-way designs (1-) gives the best result for all junction design combinations. The percentage of extra travel time is the lowest for two shared space designs (5-). The most safe road section design according to the results is the one-way design (2-).

Table 22: Best alternative for each aspect per junction design

	A EQUAL CROSSING	B EQUAL CROSSING WITH TURNING LANES	C *VOORRANGSPLEIN*	BEST ROAD SECTION
Travel time	5A (45.4 h)	5B (44.6 h)	1C (47.4 h)	5
Travel distance	1A (545.7 km)	1B (545.1 km)	1C (551.2 km)	1
Robustness	5A (4.5 %)	5B (5.2 %)	1C (2.7 %)	5
Safety	2A (15.3 conflicts)	2B (14.3 conflicts)	1C (15.4 conflicts)	2

Best junction design
The results of total travel time, total travel distance, percentage of extra travel time in accident scenario compared to normal scenario, and the total number of conflicts per design alternative are compared per road section design grouping, and put into Table 24. For all road section designs groupings the equal crossing with turning lanes (-B alternatives) scored the best on the aspects travel time and travel distance. On the aspect robustness both –B alternatives and –C alternatives have the best result in 2 road section groupings. But overall the *voorrangsplein* alternatives (-C) have a lower percentage of extra travel time. The least amount of total conflicts occur in the equal crossing design (–A alternatives).

Table 23: Adapted safety results

	1A	1B	1C	2A	2B	3A	3B	4A	4B	5A	5B	5C
Total conflicts	15.3	18.3	15.4	15.3	14.3	18.5	18.6	19.2	19.3	17.7	18.9	17.7
Adapted total conflicts	15.3	15.3	15.4	15.3	14.1	18.5	18.4	19.2	18.2	17.7	17.9	17.7

However, it should be noted that the rear end conflicts at the beginning of the turning lanes occur because of limitations in VISSIM. When these rear end conflicts are not taken into account in awarding the best junction design (Table 23), the equal crossing with tuning lanes (-B) gives the best result.

Table 24: Best alternative for each aspect per road section design

	1 Two-way	2 One-way with two lanes	3 One-way with parking bays	4 One-way with extended aircraft stands	5 Shared space	Best junction
Travel time	1B (44.8 h)	2B (51.4 h)	3B (51.5 h)	4B (53.6 h)	5B (44.6 h)	B
Travel distance	1B (545.1 km)	2B (610.7 km)	3B (618.1 km)	4B (609.1 km)	5B (546.0 km)	B
Robustness	1C (2.7 %)	2A (6.9 %)	3B (6.5 %)	4B (8.1 %)	5C (2.9 %)	C
Safety	1B * (15.3 conflicts*)	2B * (14.1 conflicts*)	3B * (18.4 conflicts*)	4B * (18.2 conflicts*)	5A (17.7 conflicts*)	B*

*) when rear end conflicts at the turning lanes are not taken into account

Combining best road section and best junction design

The shared space (5–) alternatives were the best in the aspect travel time, two-way (1–) alternatives scored the best in the aspects travel distance and robustness, and one-way (2–) alternatives scored the best in safety. The equal crossing with turning lanes (–B) alternatives were the best alternatives for the aspects travel time and travel distance. The *voorrangsplein* (-C) alternatives had the lowest extra travel time in the accident scenario. And equal crossing with turning lanes (–B) alternatives have the lowest amount of conflicts. When the best road section designs and the best junction designs are combined the best alternative on the aspect travel time is shared space in combination with equal crossings with turning lanes. On the aspect travel distance the combination two-way and equal crossings with turning lanes has the best results. Two-way in combination with the *voorrangsplein* is the most robust. And one-way combined with equal crossings with turning lanes result in the least amount of conflict.

Table 25: Best alternative for each aspect

	Best road section design	Best junction design	Best alternative	Result
Travel time	5	B	5B	44.6 h
Travel distance	1	B	1B	545.1 km
Robustness	5	C	1C	2.7 %
Safety	2	B	2B	14.5 conflicts

The combinations of best road section and best junction design are similar to the best overall results, as seen in Table 25. The results of best road section and junction design on the aspect robustness do not match with the best alternatives. Alternative 1C has only slightly better results compared to alternative 5C.

5.2.2 Comparison with the base situation

The comparisons of mean results of the infrastructure design alternatives with the base situation are visually represented in Figure 32. The mean results of the base situation, alternative 1B, are at zero percent. The bars represent the difference in percentages between alternative 1B and any other alternative. Alternatives with aspects in negative percentages are considered better alternatives, in that aspect or those aspects, compared to alternative 1B.

The ranges represent the results between the 15th and 85th percentiles for each alternative compared with the mean results of alternative 1B. These percentile values approximately represent the results within one standard deviation of the mean result. The 15th and 85th percentile are commonly used in speed-related studies (Hou, Sun, & Edara, 2011). The position of the ranges in relation to the mean results bars also indicates if there were more higher or lower results in proportion with the mean result. Smaller percentile ranges indicate smaller differences between the results of the 15 simulation runs of a design alternative, which makes the mean results more reliable.

The result ranges for the aspect travel time are small for almost all alternatives, with the exception of alternative 1C. The result ranges for the aspect travel distance are small for all alternatives. The result ranges of the aspects robustness and safety are much larger. For alternatives 1C and 5C the results of only 1 out of 3 simulation runs could be used. The alternative was run 45 times to make up for the small number of results, which caused the travel time and robustness results of the working 15 runs to spread further apart than with the other alternatives. The results for travel time and travel distance can therefore be considered reliable for all alternatives except 1C. The mean results of robustness and safety are less reliable. But because the ranges are of even size for almost all alternatives this should not affect the outcomes of best alternative.

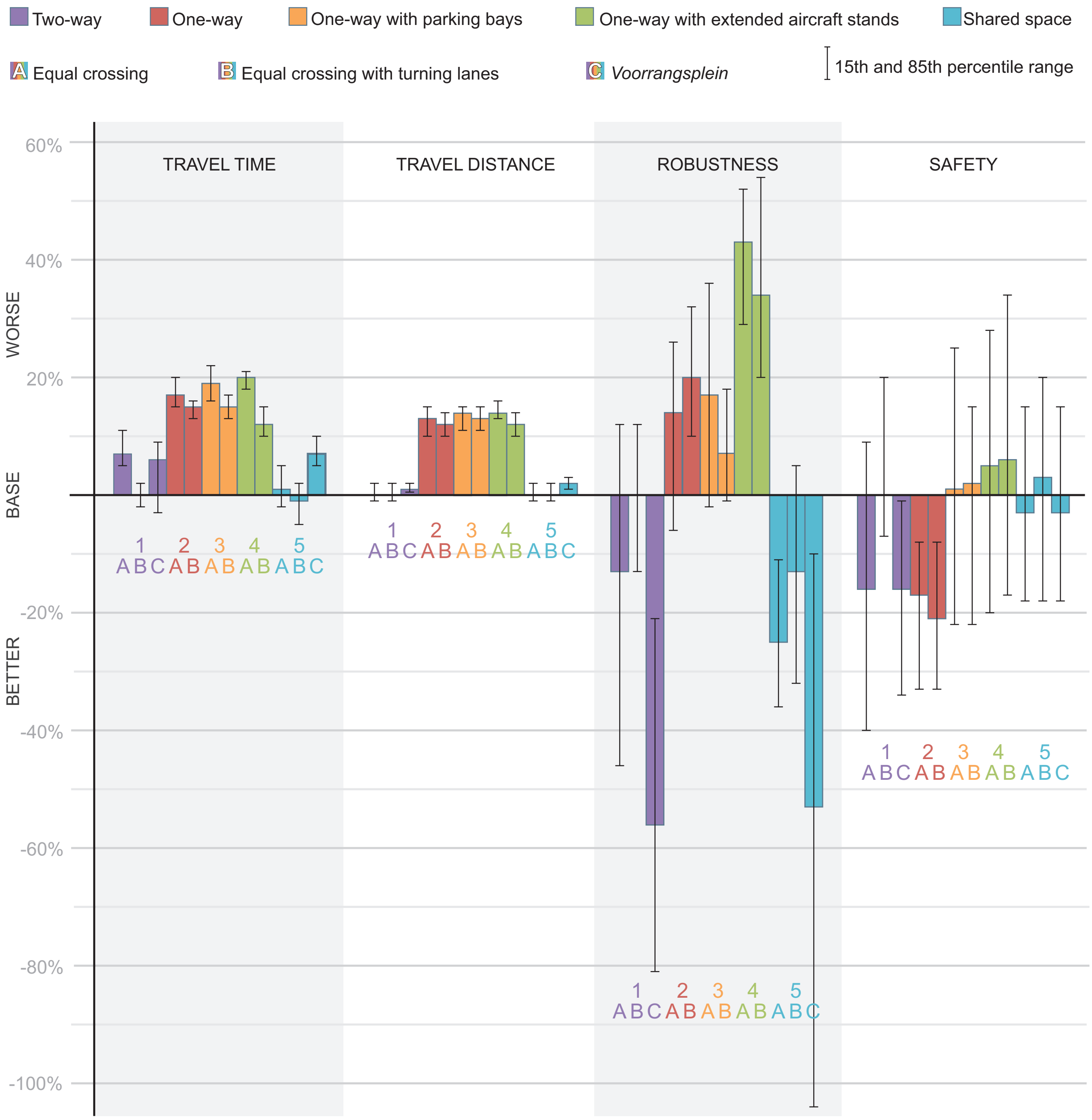


Figure 32: Mean results of the alternatives compared in percentages to the base situation

None of design alternatives has only bars on the better side in the graph of Figure 32. There is no design alternative that has a better performance on all aspects than alternative 1B. Only alternative 5B has a lower total travel time, and none of the alternatives has a lower total travel distance. The alternatives 1A, 1C, 5A, 5B, and 5C have a lower percentage of extra travel time, and therefore a better robustness. And last, the total number of conflicts is lower than that of alternative 1B in alternatives 1A, 1C, 2A, 2B, 5A, and 5C.

5.2.3 SIGNIFICANT DIFFERENCE IN RESULTS

To determine if there is a significant difference between the numerical results of the infrastructural design alternatives an independent sample T-test is executed. The significance level of 95% is used for comparing alternative 1B with the other design alternatives. When the probability value (p-value) ≤ 0.05 the null hypothesis is rejected. The null hypothesis is that there is no difference between the performance for all vehicles in the base situation (alternative 1B) and the performance of a design alternative. Other results of the independent sample T-test can be found in Appendix D. The safety results of the simulation are used for the significance test.

Table 26: P-values of the alternatives compared to alternative 1B

	1A	1C	2A	2B	3A	3B	4A	4B	5A	5B	5C
Travel time	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.61	0.00
Travel distance	0.85	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.76	0.00
Robustness	0.15	0.00	0.12	0.03	0.03	0.22	0.00	0.00	0.00	0.07	0.00
Safety	0.07	0.07	0.03	0.01	0.90	0.82	0.53	0.56	0.67	0.70	0.71

Statistical significant difference between alternative and the base situation (p-value ≤ 0.05)

The p-values state if there is a statistical significant difference in the results of an alternative compared to alternative 1B. Statistical significance does not state how large the difference between the results is. Therefore a substantive significance is also calculated for the comparison with alternative 1B. The substantive significance is calculated as the effect size (d-value) of Cohen (1988) with equation 1.

$$d = \frac{M_x - M_{alternative\,1B}}{\sigma_{pooled}} \qquad \sigma_{pooled} = \sqrt{\frac{{\sigma_x}^2 + {\sigma_{alternative\,1B}}^2}{2}} \qquad (1)$$

d	*Effect size*
M_x	*Mean of other alternative*
$M_{alternative\,1B}$	*Mean of alternative 1B*
σ_{pooled}	*Pooled standard deviation*
σ_x	*Standard deviation of other alternative*
$\sigma_{alternative\,1B}$	*Standard deviation of alternative 1B*

A negative d-value means that the mean results for an aspect of the other alternative is smaller than that of alternative 1B. The effect sizes of Table 27 indicate the distance in combined standard deviation between the means of alternative 1B and the means of another alternative. Disregarding positive and negative values of d, an absolute value lower than or equal to 0.80 means that the results of both alternatives overlap 52.6%, these results are not significant.

Table 27: Difference in standard deviations between an alternative and alternative 1B

	1A	1C	2A	2B	3A	3B	4A	4B	5A	5B	5C
Travel time	2.47	2.07	6.18	6.47	7.31	5.83	8.44	4.54	0.43	-0.19	2.85
Travel distance	0.07	0.85	7.22	7.98	8.42	7.87	9.92	6.64	0.14	0.11	1.34
Robustness	-0.55	-1.89	0.59	1.19	0.85	0.45	1.92	1.91	-1.44	-0.70	-1.61
Safety	-0.70	-0.70	-0.82	-1.01	0.08	0.05	0.23	0.21	-0.16	0.14	-0.14

Significant difference, better result compared to alternative 1B

The results of Table 26 show that there is one alternative with p-values lower than 0.05 for all 4 aspects; the one-way and equal crossing with turning lanes design (alternative 2B) has significantly different results compared to the design of the base situation. The results of alternative 1C and 2A are significantly different from the results of the base design on all aspects except one, safety and robustness respectively. The results of the shared space design in combination with equal crossings with turning lanes (alternative 5B) are not significantly different on any aspect from the results of the base situation. Which suggests that the implementation of shared space does not significantly improve or worsen the performance of the road traffic system. It should however be noted that the simulation program VISSIM could not accurately implement all concepts of shared space onto the modelled road traffic system.

On the aspect travel time there is significant difference between the results of alternative 1B and alternatives 1A, 1C, 2A, 2B, 3A, 3B, 4A, 4B, and 5C. All these significant differences were for means larger than alternative 1B. On this aspect the effect sizes of the one-way designs (alternative 2A to 4B) are very large, with their means more than 4.5 times the standard deviation removed from the mean of alternative 1B. For alternatives 5A and 5B the p-value > 0.05, so there is not enough evidence to reject the null hypothesis for these alternatives. The mean travel time result of alternative 1A, where only the junction design was different from the base situation, is more removed from the mean result of the base situation than the travel time results of 5A, where the road section design and the junction design were changed.

The p-values for the aspect travel distance indicate that there are significant differences between the travel distances of alternative 1B and those of alternatives 1C, 2A, 2B, 3A, 3B, 4A, 4B, and 5C. All travel time results had positive standard deviation results, and where therefore worse results then the base situation. The travel distances of alternatives 1A, 5A, and 5B are statistically too close to the results of alternative 1B, which is also apparent in Figure 32. The results of the one-way alternatives 2A till 4B show large differences with the mean result of alternative 1B.

Alternative 1B is significantly different from alternative 1C, 2B, 3A, 4A, 4B, 5A, and 5C on the aspect robustness. The effect sizes of all alternatives are smaller than of the aspects travel time and travel distance, caused by the larger standard deviations on the aspect robustness.

The aspect safety has very few alternatives that have a significant difference compared to alternative 1B. Only the p-values of alternatives 2A and 2B are lower than or equal to 0.05. The number of conflicts of the other alternatives was not significantly different from the base situation is most cases (9 out of 11). This can be explained by the large spread of results, which caused larger standard deviations. The significance study shows that a change in a number of conflicts is not easily measured and/or influenced with a simulation study as performed in this research. While the other aspects are more easily measured and/or influenced by the design of infrastructure.

5.3 SENSITIVITY OF THE RESULTS

The simulated road system in VISSIM is a representation of the actual road traffic system around pier B of AAS and possible infrastructural design alternatives to the road system. The implementation of this actual road traffic system in VISSIM required several assumptions in input and parameters. In this section the sensitivity of the generated results of the road traffic system in VISSIM and the analysis in SSAM is analysed on these assumptions.

5.3.1 SENSITIVITY OF THE INPUT FOR THE MODEL

The origin-destination matrix is based on the flight planning of an average day in 2015, Thursday November 19 and static handling times. In reality, this process of route planning and gate assignment is more dynamic. The number of delayed aircraft and aircraft arriving earlier or at other gates in reality balances each other out. Therefore this assumption does not have a large influence on the results.

The vehicle composition of the road traffic system is assumed to be the same as needed for handling an aircraft. In reality, the vehicle composition is more complex. The impact of changing the vehicle composition is very low. The routing stays the same, only the amount of slow vehicles changes. The amount of through traffic is based on a traffic count, carried out in March 2016. During that time the new pier A was not yet build. It was assumed that the amount of handling vehicles would not change with the implementation of the new pier. If the amount of through traffic does change this could have an effect on the results. The amount of traffic takes the 2% average growth of the number of vehicles between 2016 and 2015 into account. The amount of vehicles could in reality shrink of grow exponentially in ten years due to technological advances or a growing flight market. A much higher amount of vehicles has a large negative effect on the road traffic system due to blockages. A smaller amount of vehicles has a smaller impact on the results.

There is one large baggage hall under pier B, therefore baggage to and from the aircraft is assumed to come from and go to the nearest entrance or exit of this baggage hall. In the daily operations some baggage carts go to Arrivals 2, which is outside this part of the simulated road system. Which changes the routes of the vehicles. Empty baggage trains and returning push-back trucks are assumed to travel to the nearest aircraft stand where a new aircraft arrives. All other vehicles return to their home base. During field observations, a couple of vehicles parked on an empty aircraft stand, instead of returning to their home base. The assumption that most vehicles return to their home base can lead to an overestimation of the number of vehicles on the road system.

It is assumed that aircraft do not change gates between arriving and departing. In reality, a small number of aircraft is moved to another aircraft stand. This could lead to a small under- or overestimation of the number of handling vehicles on the road.

The assumptions made in this research have an impact on the results of this research, but most likely affects all alternatives in the same manner. Therefore the current implementation is sufficient for this research.

5.3.2 Sensitivity of the parameters in VISSIM

The VISSIM software allows its user to adjust a high number of parameters to model the expected human behaviour more accurately. The parameters in VISSIM are all set up at default values that represent urban traffic driving behaviour. For the simulation of an airside road traffic system most parameters are kept at their default value. But further research is done on the sensitivity of these parameters. In the sensitivity analysis the effect the parameters have on the results of VISSIM and SSAM are analysed.

Following behaviour

The car-following behaviour of users consists of the parameters look ahead and look back distance, reaction to the number of observed vehicles, temporary lack of attention, standstill distance, and safety distance.

The sensitivity of the parameters look ahead and look back distance, and reaction to the number of observed vehicles is displayed in Table 28.

Table 28: Validation of parameters of vehicle following behaviour

Aspect	Parameter	Base situation		Decreasing look back and look ahead distances		Decreasing number of preceding vehicles that can be observed	
Travel time	**Total travel time**	**44.8 h**	**42.5 h 46.5 h**	**44.6 h**	**42.3 h 46.0 h**	**44.7 h**	**42.3 h 46.2 h**
	Percentage of change			-0.5%		-0.3%	
Travel distance	**Total travel distance**	**545.1 km**	**530.9 km 555.8 km**	**536.2 km**	**528.8 km 553.6 km**	**542.8 km**	**528.7 km 553.6 km**
	Percentage of change			-1.6%		-0.4%	
Safety	**Total number of conflicts**	**18.3**	**9 28**	**16.3**	**13 22**	**16.5**	**9 30**
	Percentage of change			-11.9%		-10.8%	

The default value for the look ahead and look back distance are between 0 and 250 meters and between 0 and 150 meters respectively. Pier B is approximately 300 meters long, so a smaller look ahead and look back distance would be more appropriate. A quantitative analysis (Table 28) reveals the effects of decreasing this value on travel time, travel distance, and safety. For the sensitivity analysis of the model and SSAM a robustness analysis is not necessary, the effect on the travel time in an accident scenario is the same as the effect on total travel time. Decreasing the look ahead and look back distance to between 0 and 150 meters and between 0 and 90 meters respectively causes only a small change in the travel time, travel distance, and number of rear end conflicts. But the number of crossing and lane change conflicts decrease by a significant amount. A reason why the number of crossing and lane change conflicts decrease could be that vehicles move through the road traffic system with more caution when decreasing their look back and look ahead distances.

The default value for the number of vehicles a road user can observe is 4. Because of the long width and various heights of the airside vehicles a lower number of observed vehicles is expected. A quantitative analysis reveals the difference between setting the number of vehicles a road user can observe to 4 or 3, see Table 28. For the sensitivity analysis of the model and SSAM a robustness analysis is not necessary, the effect on the travel time in an accident scenario is the same as the effect on total travel time. In the results of travel time and travel distance only small changes are noticed. The number of crossing, rear end, and lane change conflict decrease, most notably the number of crossing conflicts. The changes in the number of conflicts do not coincide with the results of decreasing the look back and look ahead distances. An explanation could be that by decreasing the number of preceding vehicles that can be observed more attention is paid to vehicles directly in front, which decreases the number of crossing and rear end conflicts.

Changing the default values of the look back and look ahead distances and the number of preceding vehicles that can be observed has an effect on the results. With a T-test the results of the different models are compared to calculate the significance of the results. The substantive significance is calculated with the effect size of Cohen (1988), as applied in section 0. The results are statistically not significant when the p-value is higher than 0.05. An absolute d-value lower than or equal to 0.80 means that the results of both alternatives overlap 52.6%, these results are not significant. The p-values and effect sizes (d-value) of the two quantitative analyses are presented in Table 29.

Table 29: Statistical and substantive significance

	Decreasing look back and look ahead distances		Decreasing number of preceding vehicles that can be observed	
	p-value	d-value	p-value	d-value
Travel time	0.58	-0.20	0.72	-0.13
Travel distance	0.25	-0.43	0.44	-0.29
Safety	0.14	-0.55	0.31	-0.38

The p-values of all aspects are above 0.05, which means that there is no statistical significant difference between the results of the both quantitative analyses and the results of the base situation. The highest absolute value of the two analyses is 0.55, which means an overlap of 64.4% of the results of the model with decreased look back and look ahead distances and the results of base situation. The effect sizes are all negative because the total travel time, total travel distance, and the number of conflicts all go down in the quantitative analyses. Changing the default values changes the mean values but the outer results stay the same. This large overlap of results means that statistically there is no significant difference. Changing the default parameters by taking smaller values does not have a significant effect on the results. It can therefore be concluded that the driving behaviour parameters look back/look ahead distance and observed preceding vehicles are not sensitive.

The driving behaviour can also depend on the type of vehicle. The range of vehicles on airside is so diverse, the size, but also the location of the driver (at the back or in the front) should change the way road users react to each other. This idea can be implemented in VISSIM when there is research done in the behaviour of the different types of road users. At the moment it is not known how the driving behaviour is affected.

Temporary lack of attention, standstill distance, safety distance, and lane change behaviour should be based on measurements, but no research has been done on this topic. For this research the default parameters coincide with rough observations on airside.

Gap acceptance

The influence of gap acceptance is already discussed in Section 4.3.4 with the acceptable headway and gap time. The lower acceptable headway and gap time result in a lower total travel time because gaps are more easily accepted. The total travel time changes with -3.5%, but the percentage of change of the number of conflicts ranges from 18.2% to 25.3%. It is expected that the total travel distance is hardly influenced by the gap acceptance, and this expectation is met with only -0.3% difference between the two scenarios.

Some parameters used in the simulation runs would represent the real life conditions on airside better after calibration. Because of the large impact on the number of conflicts it is necessary to research these parameters in more detail for further research.

5.4 Sub conclusion: effects on travel time, travel distance, robustness, and safety

In this chapter sub question 4 is answered: What are the effects of the infrastructural design alternatives on travel time, travel distance, robustness, and safety? There is no direct relation between the aspects travel time, travel distance, robustness, and safety. Total travel time, total travel distance, percentage of extra travel time in the accident scenario, and the number of conflicts are affected in a positive or negative way depending on the specifications of a design.

On the aspect travel time, travel distance, and robustness, two-way and shared space designs score better than the one-way alternatives. While on the aspect of safety, the one-way design performs better. More complicated road section designs with overtake bays and shared space lead to a higher amount of conflicts. Equal crossings with turning lanes give the best results on the aspects travel time, travel distance, and safety. On the aspect robustness the *voorrangsplein* is best in combination with the available road section designs. For the one-way alternatives, which are not combined with the *voorrangsplein*, the combination with equal crossings with turning lanes has the best robustness results.

The two-way and equal crossings with turning lanes design alternative is the base situation. When another design alternative is applied the effects on travel time, travel distance, robustness, and safety are not all positive. There is no design alternative that has a better performance on all aspects. Only the shared space alternative with equal crossings with turning lanes has a lower total travel time. None of the alternatives has a lower total travel distance. The other two-way alternatives and all three shared space alternatives have a lower percentage of extra travel time, and are therefore more robust. The base situation does have a high amount of conflicts, so improvements to the safety of the road traffic system around the pier can be achieved by choosing the other two-way alternatives, the two one-way alternatives with two lanes, or shared space in combination with equal crossings or *voorrangspleinen*.

The one-way and equal crossing with turning lanes design (2B) has significantly different results compared to the design of the base situation. The results of two-way with *voorrangsplein* (1C) and the one-way with equal crossings design (2A) are significantly different from the results of the base design on all aspects but one. The results of the shared space and equal crossings with turning lanes design (5B) are not significantly different from the results of the base situation on any aspect.

The assumptions made about the input for the model have an impact on the results of this research, but most likely affect all alternatives in the same manner. The parameters of driving behaviour in VISSIM are all set up at default values for urban traffic driving behaviour. The effects on the aspects are not sensitive to the researched changes of the two driving behaviour parameters.

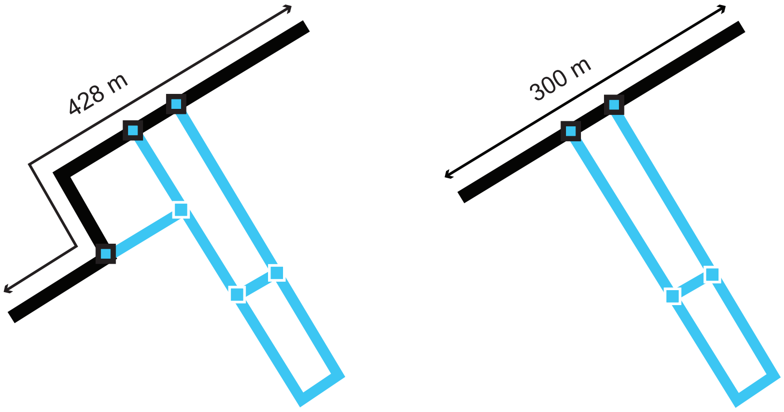
6 GENERAL APPLICATION

In this chapter sub question 5 is answered: How do the characteristic elements of a pier relate to the most effective infrastructural design alternative of the airside road traffic system? First, the performance of the alternatives in a pier configuration with two main road junctions is discussed, and compared with the results of pier B. Second, the performance of the alternatives in a pier configuration without a passage road through the pier is discussed and compared with the results of the pier configuration with two main road junctions. Third, the effect functionalities have on the results is discussed. In the conclusion of this chapter an answer to the sub question is given.

The pier that was modelled in this research possesses a couple of distinctive characteristic elements; the third connection to the main road, the passage road through the pier, the bus parking, and the narrow body-only aircraft stands. To apply the results of this research in a more general way, the effects of these distinctive elements on the network performance has to be determined. For the third connection with the main road and the passage road through the pier several simulations are run and analysed to determine the results. For the other two characteristic elements the effects are only theoretically discussed.

6.1 PIER CONFIGURATION WITH TWO MAIN ROAD JUNCTIONS

In the configuration of pier B, with three main road junctions, the use of the extra connection to the main road is measured in vehicles per hour. The results of use can be found in Appendix E. The results show that 13% (2B) to 24% (1A) of the road users take the route along the pier to avoid the slow vehicles on the main road. The majority of the road users in the simulation model (57.3%) is through traffic travelling past the pier towards destinations of pier A and the platforms or pier C till H. The pier configuration tested in the simulation runs has a shorter distance between the two edges representing pier A and pier C, reducing the shortest path from 428 m to 300 m. The total number of junctions is reduced from 6 to 4 junctions with this configuration, as can be seen in Figure 33. This large difference in network layout means that the results of the alternative can only be compared within the same pier configuration, and not with alternatives in other pier configurations.



Pier B configuration

Pier configuration with two main road junctions

Figure 33: Pier configurations of pier B and with two main road junctions

Surface used and costs
The size of the road surface is only dependant on the road section design. The two-way, one-way with two lanes, and shared space alternatives do not have extra designated parking facilities. Therefore, the total road surface used for all alternatives is 8,165 m^2.

The airside road traffic subsystems around the piers A, B, C, D, and E are designed with two-way road sections. The base situation for the general configuration is therefore the same as on pier B, alternative 1B. The construction costs for the implementation of the design alternatives for this pier configuration are the same as for pier B. For design alternative 1A the costs are €14,600, there are no construction costs for the design of the base situation, and the costs for the construction of the *voorrangsplein* are €24,000. The construction costs for a new road section design are estimated at €5000 for the service roads around the entire pier. The costs for design alternative 2B and 5B are both €5000.

6.1.1 PERFORMANCE OF ROAD SECTION DESIGNS

The effects on the performance were first tested on the three main road section designs, namely two-way, one-way with two lanes, and shared space. For a better comparison one junction design, equal crossings with turning lanes, was implemented in combination with these road section designs. In alternative 2B, when one of the main road junctions is closed off because of an accident, no traffic can get out of the pier road system and into the main road. The results are that the travel time in the accident scenario are more than double the total travel time in the normal scenario, therefore the robustness scenario is not simulated for this alternative and robustness is set at 100% extra travel time.

Table 30: Performance of the road traffic systems of design alternative 1B, 2B, and 5B

ASPECT	PARAMETER	ALTERNATIVE 1B		ALTERNATIVE 2B		ALTERNATIVE 5B	
		MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
Travel time	**Total travel time**	**30.7 h**	**28.8 h 31.7 h**	**33.4 h**	**32.2 h 34.2 h**	**30.3 h**	**28.4 h 31.4 h**
	Average travel time per vehicle	74.4 s	72.1 s 76.2 h	81.6 s	80.3 s 82.6 s	73.9 s	70.9 s 75.5 s
Travel distance	**Total travel distance**	**406.4 km**	**399.4 km 413.4 km**	**449.2 km**	**437.1 km 451.1 km**	**407.3 km**	**400.3 km 414.3 km**
	Average travel distance per vehicle	275.0 m	273.8 m 277.7 m	304.8 m	300.1 m 304.4 m	275.6 m	274.4 m 278.4 m
Robustness	**Percentage of extra travel time compared to normal scenario**	**11.0 %**	**10.1 % 12.0 %**	**100%***	**-**	**10.3 %**	**8.7 % 11.4 %**
	Extra Travel Time in accident scenario	3.4 h	2.9 h 3.8 h	-	-	3.1 h	2.7 h 3.5 h
Safety	**Total number of conflicts**	**4.6**	**3 8**	**4.1**	**2 6**	**7.7**	**4 11**
	Number of crossing conflicts	1.1	0 3	0.4	0 2	1.9	1 4
	Number of rear end conflicts	2.6	1 6	2.0	1 3	3.3	2 5
	Number of lane change conflicts	0.9	0 2	1.7	0 3	2.5	0 4

*) assumed value

The total travel times and travel distances of alternatives 1B and 5B are close together, and are the lowest results. The shared space alternative has the lowest total travel time, and is therefore considered the best. The lowest total travel distance is found in the two-way alternative, making it the best alternative for this pier configuration.

Figure 34: Conflict analysis of alternatives 1B and 2B

On the aspect robustness the one-way alternatives score 100% extra travel time because no traffic can get out of the road system until the traffic accident is resolved. The shared space alternative had the least amount of extra travel time compared to the normal scenario, and is therefore considered the best for this pier configuration.

The one-way alternative has the least amount of conflicts, while the shared space alternative has a lot of conflicts. Figure 34 is a visual representation of the conflicts identified by SSAM in the trajectories of the vehicles in alternative 1B and 2B. The number of crossing conflicts and rear end conflicts are the lowest for alternative 2B. But the two-way alternative (1B) has a lower amount of lane change conflicts compared to the one-way and shared space alternative. The one-way alternatives are considered the best alternatives concerning safety.

6.1.2 PERFORMANCE OF JUNCTION DESIGNS

The effects on the performance were then tested on the different junction designs. For a better comparison one road section design, the two-way design, was implemented in combination with these junction designs.

The total travel time of alternative 1B is the lowest, the total travel times of alternatives 1A and 1C are close together but higher. The best alternative is therefore the equal crossing with turning lanes on the aspect travel time. The total travel distances of the three alternatives are far apart, but vehicles in alternative 1A travel the shortest distance. The equal crossing alternative is therefore the best alternative on the aspect travel distance. The extra connection with the main road provided an additional route along the pier for the vehicles in the road traffic system, but the users of this route actually travel more kilometres in the end. More vehicles used this route in alternative 1A, compared to alternative 1B. Therefore alternative 1B had the best results in the pier B configuration. Alternative 1B has the lowest percentage of extra travel time, but only with a slight advantage over alternative 1C. The best alternative in terms of robustness is therefore the equal crossings with turning lanes alternative.

Table 31: Performance of the road traffic systems of design alternative 1A, 1B, and 1C

ASPECT	PARAMETER	ALTERNATIVE 1A		ALTERNATIVE 1B		ALTERNATIVE 1C	
		MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
Travel time	**Total travel time**	**34.0 h**	**31.7 h** **35.9 h**	**30.7 h**	**28.8 h** **31.7 h**	**34.8 h**	**33.1 h** **36.0 h**
	Average travel time per vehicle	82.9 s	79.0 s 86.0 s	74.4 s	72.1 s 76.2 h	84.8 s	82.5 s 86.2 s
Travel distance	**Total travel distance**	**405.8 km**	**379.7 km** **415.4 km**	**406.4 km**	**399.4 km** **413.4 km**	**429.3 km**	**419.5 km** **438.3 km**
	Average travel distance per vehicle	274.6 m	262.8 m 275.5 m	275.0 m	273.8 m 277.7 m	290.5 m	290.3 m 290.7 m
Robustness	**Percentage of extra travel time compared to normal scenario**	**15.1%**	**9.8 %** **21.0%**	**11.0 %**	**10.1 %** **12.0 %**	**11.0 %**	**7.3 %** **14.4 %**
	Extra Travel Time in accident scenario	5.2 h	3.3 h 7.5 h	3.4 h	2.9 h 3.8 h	3.8 h	2.5 h 5.1 h
Safety	**Total number of conflicts**	**4.2**	**2** **7**	**4.6**	**3** **8**	**4.5**	**2** **7**
	Number of crossing conflicts	1.3	0 3	1.1	0 3	0.8	0 2
	Number of rear end conflicts	2.3	0 5	2.6	1 6	2.4	1 5
	Number of lane change conflicts	0.6	0 2	0.9	0 2	1.3	0 3

The equal crossing alternative has the lowest total amount of conflicts, but the results of all three alternatives are close together. The least amount of crossing conflicts occur within the voorrangsplein alternative. The least amount of rear end and lane change conflicts occur within the equal crossing alternative. For safety, the best alternative is an equal crossings alternative. When the rear end conflicts that occur due to limitations in VISSIM are not counted in the total number of conflicts, the equal crossing is only just the safest junction design.

6.1.3 PERFORMANCE COMPARISON WITH THE PIER B CONFIGURATION

The results of the alternatives in the two road traffic systems cannot be compared with each other because of the network differences. Only the outcomes of best alternative per aspect are compared with each other.

In the pier configuration with two main road junctions shared space is the best road section design for the aspects travel time and robustness. For travel distance the two-way design is the best, and for the aspect safety one-way design gives the best results. For pier B the same results for best road section design per aspect apply, which means that the added junction with the main road does not affect the outcome on the best road section design per aspect.

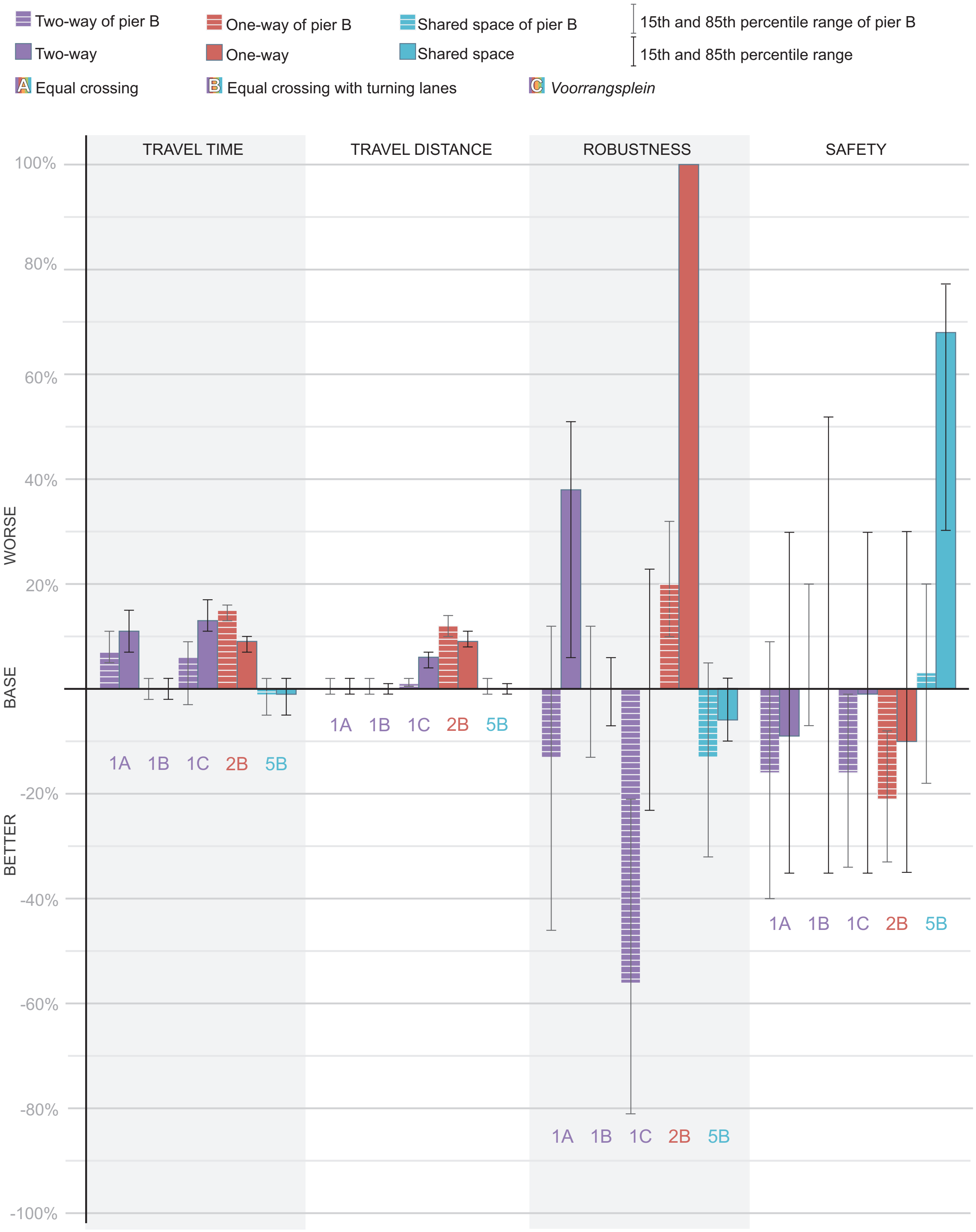


Figure 35: Comparison of mean results of the alternatives with alternative 1B

In the pier configuration with two main road junctions equal crossing with turning lanes is the best junction design for the aspects travel time and robustness. For the aspects travel distance and safety the equal crossing gives the best results. The results of the configuration with two main road junctions and the results of pier B match each other for the best junction design on the aspect travel time and safety. But do not match on the aspects travel distance and robustness. In the latter case only just, because the difference was 0.06 percent between the alternatives equal crossing and voorrangsplein. It means that the extra junction with the main road changes the outcome on the best junction design per aspect.

In Figure 35 the mean results of the alternatives are compared to the mean results of the alternatives in the pier B configuration. The values in the figure are in percentages, and compare the alternatives with the base situation (alternative 1B) in both configurations. With the exception of the robustness in the one-way alternatives and the aspect safety for the shared space alternatives, the values for all alternatives are more close to the results of the base situation compared to the results in the pier B configuration. The result margins, the 15th and 85th percentile ranges, are smaller compared to the pier B configuration, with the exception of the aspect safety.

The results of 1A, 1C, and 2B on the aspect travel time were significantly different from 1B for the pier configuration of pier B and with two main road junctions. Significance in both configurations was also found on the aspect travel distance for alternatives 1C and 2B, on for alternative 2B on the aspect robustness. Only for the pier B configuration the result of 1C on the aspect robustness was also significant, and the safety result of 2B was also significantly different. Not in the pier B configuration, but in the two main road junction configuration the 1A and 5B robustness results, and the 5B safety results are significantly different.

6.1.4 SIGNIFICANT DIFFERENCE IN RESULTS

To determine if there is a statistical significant difference between the numerical results of the infrastructural design alternatives an independent sample T-test is executed. The significance level of 95% is used for comparing alternative 1B with the other design alternatives, a p-value ≤ 0.05 means that the null hypothesis is rejected. The null hypothesis is that there is no difference between the performance for all vehicles in the base situation (alternative 1B) and the performance of a design alternative. A p-value of ≤ 0.05 thus means that there is a significant difference in the results of the two alternatives, choosing for one or the other has a meaningful impact on the results. Substantive significance is also calculated for the comparison with alternative 1B, state how large the difference between the results is. The substantive significance is calculated as the effect size of Cohen (1988) with equation 1 of Section 0. A negative d-value means that the mean results for an aspect of the other alternative is smaller than that of alternative 1B. An absolute value lower than or equal to 0.80 means that the results of both alternatives overlap 52.6%, these results are not significant. The effect size (d-value) indicates the distance in combined standard deviation between the two means for all alternatives in Table 32.

Table 32: Statistical and substantive significance

	1A		1C		2B		5B	
	P-VALUE	EFFECT SIZE	P-VALUE	EFFECT SIZE	P-VALUE	EFFECT SIZE	P-VALUE	EFFECT SIZE
Travel time	0.00	3.08	0.00	4.79	0.00	3.96	0.29	-0.40
Travel distance	0.81	0.28	0.00	4.27	0.00	8.44	0.58	0.02
Robustness	0.00	1.90	0.95	0.02	0.00	197.92	0.01	-0.99
Safety	0.47	-0.27	0.90	-0.05	0.38	-0.32	0.00	1.82

Statistically significant difference, better result compared to alternative 1B

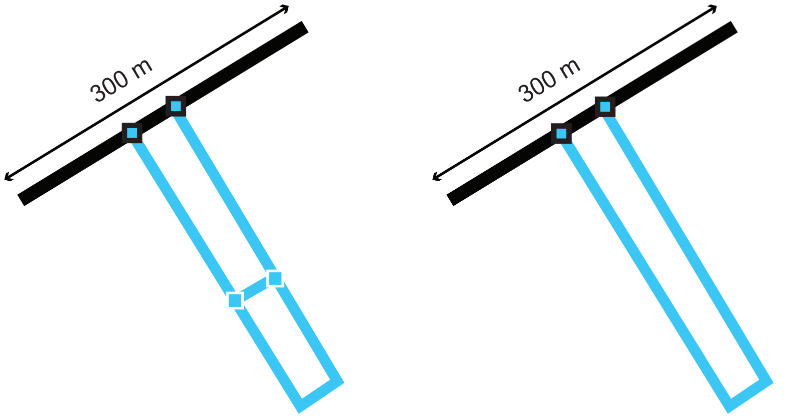
The p-values for the aspect travel distance indicate that there are significant differences between the travel times of alternative 1B and those of alternatives 1A, 1C, and 2B. The travel time results of alternatives 5B are statistically too close to the results of alternative 1B. On the aspect travel distance there is a significant difference between the results of alternative 1B and alternatives 1C and 2B. For alternatives 1A and 5B the p-value > 0.05, so there is not enough evidence to reject the null hypothesis for these alternatives. There is no significant difference between the robustness results of 1B and 1C, as the difference between the two is a matter of decimals. The robustness results for the other three alternatives differ significantly from alternative 1B. Only alternative 5B is significantly different from 1B on the aspect safety, all other alternatives have higher p-values. This can be explained by the small amount of total conflicts on this small scale.

Only the robustness of alternative 5B is statistically and substantively better than alternative 1B. All other better results are not statistically and substantively different from alternative 1B.

6.2 PIER CONFIGURATION WITHOUT PASSAGE ROAD THROUGH THE PIER

Around 6% of the users in the road traffic system has an origin and destination on the pier. For these users the passage road through the pier is used as a route from one side of the pier to the other. The removal of the passage road has the most effect on the performance of one-way alternatives in terms of travel time and travel distance. In the configuration of pier B, with three main road junctions, the use of the extra connection to the main road is measured in vehicles per hour. The results of use can be found in Appendix E. The results show that 9% (1A) to 14% (2B) of the road users take the passage road through the pier. In the configuration with two main road junctions, the vehicles in the two-way and shared space alternatives use both ways of the passage road (8% of road users). While vehicles in the one-way alternatives only use one direction of the passage road, but have the same amount of vehicles per hour (7% of road users) as using both ways in the two-way and shared space alternatives.

The pier configuration without the passage road through the pier has the same shortest path for through traffic as the pier configuration with two main road junctions. By removing the passage road, there are no more routes through the pier and the number of junctions goes down to two in the road traffic system. This difference in network layout means that the results of the alternative can only be compared within the same pier configuration, and not with alternatives in other pier configurations. A visual representation of the road traffic system in this pier configuration is found in Figure 36.



Pier configuration with two main road junctions

Pier configuration without passage road through pier

Figure 36: Pier configurations with and without the passage road through the pier

Surface used and costs

The size of the road surface is only dependant on the road section design. The two-way, one-way with two lanes, and shared space alternatives do not have extra designated parking facilities. Therefore, the total road surface used for all alternatives is 7,845 m^2.

The airside road traffic subsystems around the piers A, B, C, D, and E are designed with two-way road sections. The base situation for the general configuration is therefore the same as on pier B, alternative 1B. The construction costs for the implementation of the design alternatives for this pier configuration are the same as for the pier configuration with passage roads. For design alternative 1A the costs are €14,600, there are no construction costs for the design of the base situation, and the costs for the construction of the *voorrangsplein* are €24,000. The construction costs for the new road section designs of 2B and 5B are estimated at €5000 for the service roads around the entire pier.

6.2.1 PERFORMANCE OF ROAD SECTION DESIGNS

The effects on the performance were tested on the two-way, one-way with two lanes, and shared space road section designs. All in combination with equal crossings with turning lanes.

In alternative 2B, when one of the main road junctions is closed off because of an accident, no traffic can get out of the pier road system and into the main road. The results are that the travel time in the accident scenario are more than double the total travel time in the normal scenario, therefore the robustness scenario is not simulated for this alternative and robustness is set at 100% extra travel time.

Table 33: Performance of the road traffic systems of design alternative 1B, 2B, and 5B

Aspect	Parameter	Alternative 1B		Alternative 2B		Alternative 5B	
		Mean	Range	Mean	Range	Mean	Range
Travel time	**Total travel time**	**31.6 h**	**29.6 h 32.6 h**	**34.5 h**	**32.9 h 35.5 h**	**31.0 h**	**29.1 h 32.1 h**
	Average travel time per vehicle	76.9 s	74.0 s 78.1 s	84.4 s	82.5 s 86.0 s	75.6 s	72.4 s 77.4 s
Travel distance	**Total travel distance**	**420.0 km**	**408.4 km 428.6 km**	**475.1 km**	**461.9 km 484.5 km**	**421.0 km**	**409.3 km 429.6 km**
	Average travel distance per vehicle	284.2 m	284.0 m 284.4 m	322.4 m	321.5 m 322.7 m	284.9 m	284.7 m 285.0 m
Robustness	**Percentage of extra travel time compared to normal scenario**	**15.4 %**	**13.6 % 18.9 %**	**100%***	**-**	**15.3 %**	**14.2 % 16.7 %**
	Extra Travel Time in accident scenario	4.9 h	4.3 h 6.0 h	-	-	4.7 h	4.4 h 5.3 h
Safety	**Total number of conflicts**	**4.5**	**3 9**	**4.1**	**2 7**	**7.3**	**3 12**
	Number of crossing conflicts	1.1	0 3	0.4	0 1	1.8	0 4
	Number of rear end conflicts	2.3	1 5	2.4	0 4	3.9	2 7
	Number of lane change conflicts	1.1	0 2	1.3	0 3	1.7	0 4

*) assumed value

The total travel times, travel distances, and percentages of extra travel time of alternatives 1B and 5B are close together. With only an average 1.3 seconds difference for each vehicle in the favour of alternative 5B, a 0.7 m difference in favour of alternative 1B, and a 0.1 percentile difference in favour of 5B. The best alternative in the aspect travel time and robustness is therefore the shared space alternative. The best alternative in the aspect travel distance is the two-way alternative. For the total amount of conflicts the results of alternative 1B and 2B are more similar. Alternative 1B has slightly less rear end conflicts and lane change conflicts, but 2B has less crossing conflicts, making it the best alternative. On the aspect safety the one-way alternative is the best alternative.

6.2.2 PERFORMANCE OF JUNCTION DESIGNS

The effects on the performance were then tested on all junction designs. For a better comparison one-way section design, the two-way design, was implemented in combination with these junction designs.

Table 34: Performance of the road traffic systems of design alternative 1A, 1B, and 1C

Aspect	Parameter	Alternative 1A		Alternative 1B		Alternative 1C	
		Mean	Range	Mean	Range	Mean	Range
Travel time	**Total travel time**	**34.9 h**	**32.6 h 37.0 h**	**31.6 h**	**29.6 h 32.6 h**	**35.0 h**	**32.8 h 36.0 h**
	Average travel time per vehicle	85.0 s	81.2 s 88.5 s	76.9 s	74.0 s 78.1 s	85.0 s	81.6 s 87.0 s
Travel distance	**Total travel distance**	**416.1 km**	**404.6 km 424.6 km**	**420.0 km**	**408.4 km 428.6 km**	**425.6 km**	**414.5 km 430.4 km**
	Average travel distance per vehicle	281.6 m	281.4 m 281.7 m	284.2 m	284.0 m 284.4 m	287.1 m	286.9 s 287.2 s
Robustness	**Percentage of extra travel time compared to normal scenario**	**18.5 %**	**15.7 % 25.2 %**	**15.4 %**	**13.6 % 18.9 %**	**18.6 %**	**11.0 % 22.2 %**
	Extra Travel Time in accident scenario	6.5 h	5.1 h 8.8 h	4.9 h	4.3 h 6.0 h	6.5 h	3.9 h 7.9 h
Safety	**Total number of conflicts**	**4.2**	**1 8**	**4.5**	**3 9**	**4.4**	**4 5**
	Number of crossing conflicts	1.3	0 4	1.1	0 3	1.0	0 2
	Number of rear end conflicts	1.9	0 4	2.3	1 5	1.2	0 2
	Number of lane change conflicts	1.0	0 2	1.1	0 2	2.2	1 3

The total travel times of alternative 1A and 1C are only 0.1 h apart, and have the exact same average travel time per vehicle. But the total travel time of alternative 1B is the lowest, and therefore the equal crossing with turning lanes is the best alternative in travel time. The travel distances are not close together, the best alternative is the equal crossings alternative (1A). The alternatives 1A and 1C had the same amount of extra travel time that translated into the same higher percentage of extra travel time compared to alternative 1B. The best alternative on the aspect robustness is therefore the equal crossing with turning lanes. The safest alternative is the equal crossing. When the rear end conflicts that occur due to limitations in VISSIM are not counted in the total number of conflicts, the equal crossing with turning lanes is the safest junction design.

6.2.3 Performance comparison with the two main road junction configuration

The results of the alternatives in the two road traffic systems cannot be compared with each other because of the network differences. Only the outcomes of best alternative per aspect are compared with each other.

The removal of the passage road through the pier has no effect on the outcome of best road section and junction design. In both pier configurations shared space is the best road section design and equal crossings with turning lanes is the best junction design on the aspects travel time and robustness. On the aspect travel distance the two-way road section design and the equal crossing have the best results. The one-way road section design and the equal crossing junction design have the lowest amount of conflicts in total.

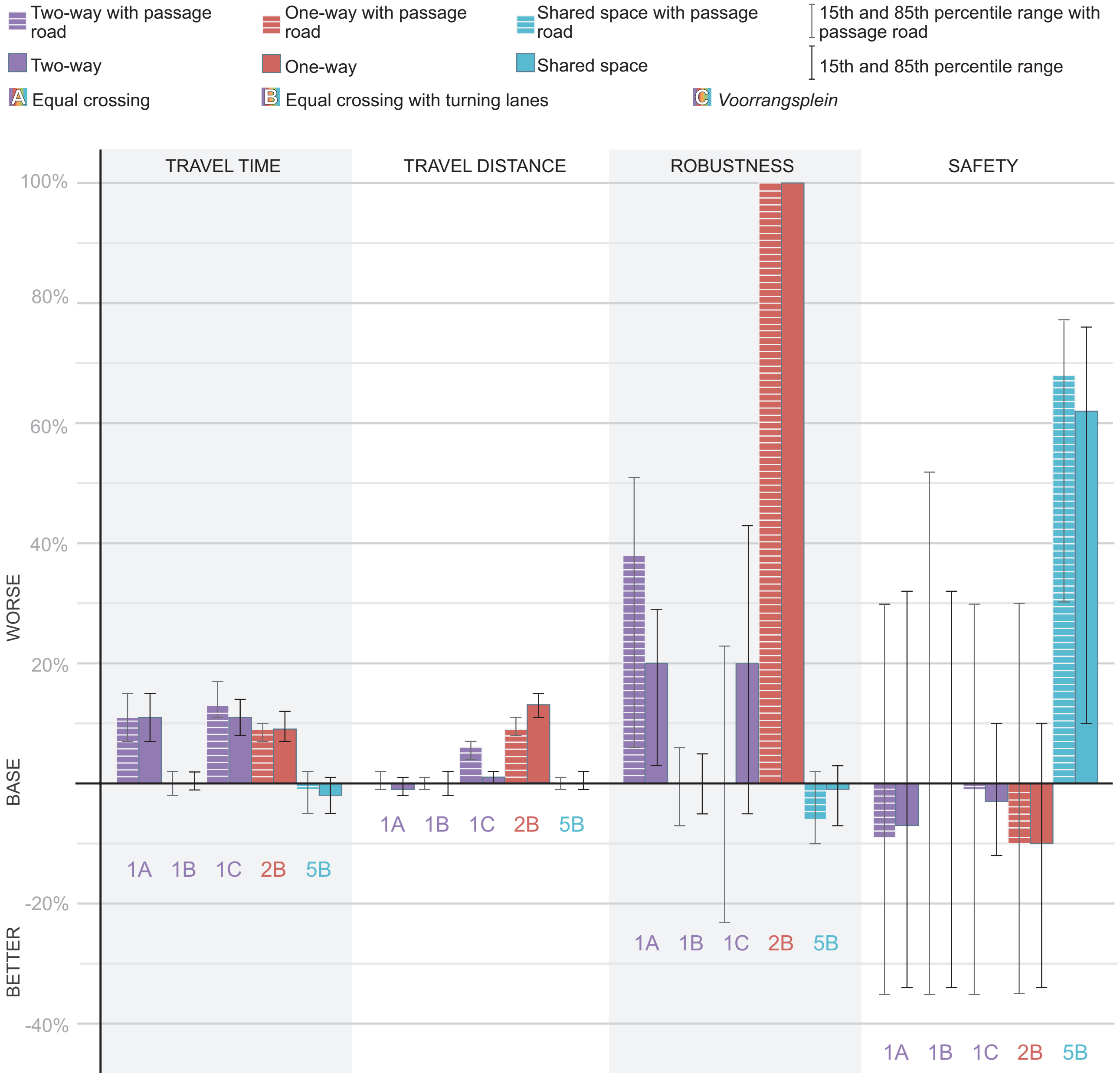


Figure 37: Comparison of mean results of the alternatives with alternative 1B

In the two main road junctions configuration there was no statistical significant difference on the aspect robustness of alternative 1C and 1B, in this pier configuration there is a statistical difference and a large substantive difference. In this pier configuration there is no statistical difference with alternative 5B on the aspect robustness, while there was a significant difference with alternative 5B in the two main road junctions configuration.

6.2.4 SIGNIFICANT DIFFERENCE IN RESULTS

To determine if there is a significant difference between the numerical results of the infrastructural design alternatives an independent sample T-test is executed. The significance level of 95% is used for comparing alternative 1B with the other design alternatives, a p-value ≤ 0.05 means that the null hypothesis is rejected. The null hypothesis is that there is no difference between the performance for all vehicles in the base situation (alternative 1B) and the performance of a design alternative. A p-value of ≤ 0.05 thus means that there is a significant difference in the results of the two alternatives, choosing for one or the other has a meaningful impact on the results. Substantive significance is also calculated for the comparison with alternative 1B, stating how large the difference between the results is. The substantive significance is calculated as the effect size of Cohen (1988) with equation 1 of Section 0. A negative d-value means that the mean results for an aspect of the other alternative is smaller than that of alternative 1B. An absolute value lower than or equal to 0.80 means that the results of both alternatives overlap 52.6%, these results are statistically and substantively not significant. The effect size (d-value) indicates the distance in combined standard deviation between the two means for all alternatives in Table 35.

Table 35: Statistical and substantive significance

	1A		1C		2B		5B	
	P-VALUE	EFFECT SIZE	P-VALUE	EFFECT SIZE	P-VALUE	EFFECT SIZE	P-VALUE	EFFECT SIZE
Travel time	0.00	3.03	0.00	3.40	0.00	3.88	0.11	-0.60
Travel distance	0.10	-0.63	0.02	0.91	0.00	8.21	0.69	0.15
Robustness	0.00	1.45	0.00	1.28	0.00	100.48	0.67	-0.16
Safety	0.62	-0.18	0.79	-0.10	0.44	-0.28	0.00	1.31

Statistically significant difference, better result compared to alternative 1B

The p-values for the aspect travel distance indicate that there are significant differences between the travel times of alternative 1B and those of alternatives 1A, 1C, and 2B. The travel time of alternatives 5B is statistically too close to the results of alternative 1B. On the aspect travel distance there is significant difference between the results of alternative 1B and alternatives 1C and 2B. For alternatives 1A and 5B the p-value > 0.05, so there is not enough evidence to reject the null hypothesis for these alternatives. There is no significant difference between the robustness results of 1B and 5B, as the difference between the two is a matter of decimals. The robustness results for the other three alternatives differ significantly from alternative 1B. Only alternative 5B is significantly different from 1B on the aspect safety, all other alternatives have higher p-values. This can be explained by the small amount of total conflicts on this small road traffic system.

The better results in this configuration are all not significant. Only some results with higher values for travel time, travel distance, robustness, and safety are significantly different.

6.3 FUNCTIONALITIES AT THE PIER

In the base situation pier B has bus parking with platforms for the passengers to get in and out on the side of the building and on the aircraft stands. The aircraft stands around pier B are exclusively designed for narrow body aircraft, not for wide body aircraft. Pier B has offices of handling companies on the ground level of the building, with their vehicles parked at the side of the building. The focus is on how these functionalities could theoretically influence the performance of an alternative.

Bus stations and parking

The bus parking at the side of the building limits the possible design alternatives because people could only get in and out of the bus in clockwise designs. The clockwise or counter clockwise design should not have a large impact on the performance of a road traffic system with two main road junctions, but could have an effect on the number of conflicts. The counter clockwise design does have a positive impact on the travel time on the pier B configuration, because the route along the pier to bypass the slow vehicles is more easily reached.

The bus parking also causes more traffic to enter and exit the pier road traffic system. Busses travel with 30 km/h, and make up a third of the traffic flow. With less vehicles on the road traffic system the amount of waiting time, and thus total travel time, could go down. The number of conflicts is also expected to decrease.

Type of aircraft stand
The 13 aircraft stands around pier B are designed for narrow body aircraft. Narrow bodies require almost the same handling process as wide bodies, but the amount of handling vehicles needed for the processes are less for narrow bodies. But because the aircraft stands for wide bodies are much larger, the amount of aircraft stands would be cut in half if the aircraft stands were designed for wide bodies. The extra handling vehicles needed for one wide body aircraft instead of a narrow body would not outweigh the difference in aircraft stands.

The number of aircrafts designated to each pier is not evenly distributed along the piers. Pier B does not handle many aircrafts in one day, while other piers handle more. The number of aircrafts handled influences the traffic on the road traffic system. If a large amount of vehicles travel on the road traffic system around the pier, designs with overtaking possibilities perform better.

Presence of handling companies
On the ground level of almost all piers at AAS are offices of ground handling companies, the offices have parking in front of the building for a share of their handling vehicles and their trucks. At the moment there is a need for parking spaces around the piers for these vehicles. If the need for parking spaces grows the alternatives with parking bays at the side of the building are more attractive because of their parking space. If the companies should leave the ground level of the terminal more surface could be added to the road surface, which creates opportunities for new infrastructural design alternatives.

6.4 SUB CONCLUSION: INFLUENCE OF CHARACTERISTIC ELEMENTS ON OUTCOME

In this chapter sub question 5 is answered: How do the characteristic elements of a pier relate to the most effective infrastructural design alternative of the airside road traffic system? The road traffic system of AAS consists of one main road with five piers that are independent subsystems and two piers that are an integral part of the road traffic system. The ground handling companies are spread throughout the entire road traffic system, therefore each pier has different functionalities. These different configurations and functionalities affect travel time, travel distance, robustness, and safety.

The configuration of the road traffic system influences the number of possible routes a vehicle can take. In a road traffic system where the pier is an integral part the traffic has multiple route options from their origin to their destinations, which allows fast through traffic to bypass the slow vehicles by taking a different route. When the pier is an independent subsystems attached to the main road at two junctions, there is only one route for through traffic. Depending on the configuration of the independent subsystem there are multiple or single routes for the destination traffic. The road traffic system configurations with the pier as an integral part of the road traffic system and with the pier as an independent subsystems attached to the main road are visualised in Figure 38.

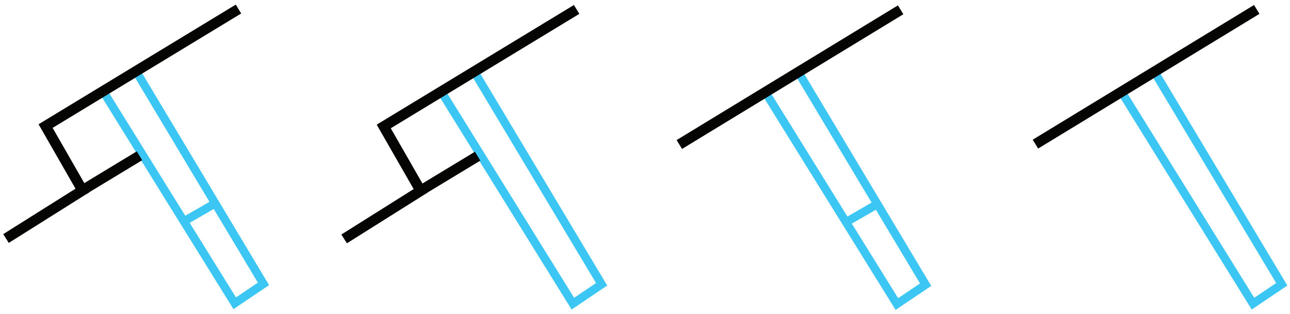


Figure 38: The pier in different configurations

The best road section designs of the road traffic system around the pier are not affected by the configuration of the pier. Shared space designs have the lowest total travel times and the lowest percentages of extra travel time. The vehicles in the two-way alternatives have the lowest total travel distance. And the least conflicts occur in the one-way alternative with two lanes. For travel time and safety the best junction designs in all configurations are equal crossing with turning lanes. The best junction designs on the aspect travel distance and robustness are affected by the configuration of the pier. In the integral pier configuration with an extra junction with the main road the best junction design is the equal crossing on the aspect travel distance, in the independent pier subsystem configuration with two main road junctions the equal crossing with turning lanes has the lowest travel distance. On the aspect robustness the *voorrangsplein* has the smallest percentage of extra travel time in the integral pier configuration, but with just two main road junctions the best junction design is the equal crossing with turning lanes.

The outcome of best alternatives stays the same in most aspects, while other aspects are more easily affected. The best infrastructural designs of the road traffic system on the aspects travel time and safety are not affected by the configuration of the pier. Shared space in combination with the equal crossing with turning lanes always has the smallest total amount of travel time. And the smallest amount of conflicts occur in the one-way design in combination with the equal crossing with turning lanes. The best travel distance is two-way and equal crossings with turning lanes for the integral pier configuration and with only a slight advantage over the two-way equal crossing with turning lanes alternative the two-way and equal crossing is the best alternative for the independent pier subsystem configuration. The lowest percentage of extra travel time in the accident scenario was measured in shared space with the *voorrangsplein* in the integral pier configuration and in shared space and equal crossing with tuning lanes alternative in the independent pier subsystem configuration. The results and best alternative outcomes in the aspects travel time, travel distance, and safety are stable in all configurations. While changing the pier configuration has a diverse effect on the results and outcomes in the aspect robustness.

The functionalities of the pier mostly influence the number of vehicles in the road traffic system and the possibilities for design alternatives. The outcomes of best alternatives per aspect are most likely not influenced by the functionalities of the pier. Adding or removing connections between the main road and the access roads of the road traffic system has the largest influence on the outcome of best alternatives for the aspects travel distances and robustness because of the dominant through traffic at AAS. Changing the configuration of the access roads with passage roads through the pier only has a small effect on the best alternative outcome, because only less than half of the road users are part of the destination traffic and an even smaller part of the road users have their origin and destination on the same pier.

7 ASSESSMENT AND IMPLEMENTATION

This chapter is on the assessment and implementation of the design alternatives. First, the assessment framework is discussed. Second, the design alternatives on pier B are assessed. Third, the alternatives applied in the general application are assessed. Fourth, the implementation process for infrastructural interventions in the existing road traffic system is discussed.

The assessment of the design alternatives depends on how the stakeholders appreciate the aspects travel time, travel distance, robustness, safety, surface used, and costs. The implementation process is described to fit the range of design alternatives presented in this research.

7.1 ASSESSMENT FRAMEWORK

The assessment is the base of an advice to the stakeholders. The effects of the design on the performance and specifications of the road traffic system are assessed with a multi criteria analysis. The goal of a multi criteria analysis is the weighing of different alternatives substantiated by multiple criteria (Ministerie van Financiën, 1992). The aspects in this research are diverse and explicit evaluation criteria, and certain aspects should be counted more in the final scores. Therefore a multi criteria analyses is used for this assessment. The interests of the relevant stakeholders are used to determine the weights of the aspects.

7.1.1 STAKEHOLDERS

The relevant stakeholders are the key participants and to be kept satisfied stakeholders identified in the stakeholder analysis of Section 2.7. The key stakeholders are the departments PMA, ADI, and CMC, the bus company, the handling companies, and the authority officers. The stakeholders that have to be kept satisfied are the kMar, Customs, and the department Development. The emergency service and department Maintenance & Control have to be kept informed, and are not actively part of the decision making process.

The key stakeholders and to be kept satisfied stakeholders are divided into groups based on their interest in the decision making process and what their most important aspect is. These stakeholder groups are:

1. Operations: departments PMA, ADI, and CMC
2. Handling: the bus company and the handling companies
3. Enforcement: authority officers, the kMar and Customs
4. Development: department Development

7.1.2 WEIGHT SETS

In this research the weights are determined with paired comparison according to the method analytical hierarchy process (AHP method) (Ministerie van Financiën, 1992). The aspects are compared in pairs for each of the stakeholder groups. The scale of comparison ranging from equal to extreme by Saaty and Vargas (1991) is used to compare the pairs, see Table 36.

Table 36: Judgement values in the scale of comparison (Saaty & Vargas, 1991)

SCALE	DEGREE OF PREFERENCE
1	Equal importance
3	Moderate importance of one factor over another
5	Strong or essential importance
7	Very strong importance
9	Extreme importance

A pair wise comparison matrix is filled with the judgment values. When a row criteria is more important than the column criteria the actual judgement value is filled in, when the row criteria is less important the inverse judgement value is filled in. The upper triangular matrix is filled in with these values, after which the bottom triangular matrix is filled with the inverse values of the values in the upper triangular matrix.

The comparison matrix is normalised by dividing a value by the sum of the column and taking the average values of the rows as the normalised weights.

The consistency ratio (equation 2) makes sure that the original preference judgements are consistent. A consistency ratio (CR) is equal to or smaller than 0.1 is acceptable. When the CR is acceptable the judgement values are consistent.

$$CR = \frac{CI}{RI} \qquad CI = \frac{\lambda_{max} - n}{n-1} \qquad RI = 1.24 \tag{2}$$

CR	*Consistency ratio*
CI	*Consistency index*
RI	*Random index for a matrix of the 6th order (Saaty, 1980)*
λ_{max}	*Principle eigen value*
n	*Order of the matrix*

1. Operations

The departments PMA, ADI, and CMC find safety and robustness the most important. The paired comparison of aspects in Table 37 further specifies what aspect is more important per pair.

Table 37: Pair wise comparison matrix of operations

Factor	Travel time	Travel distance	Robustness	Safety	Surface used	Costs
Travel time	1	3	1/3	1/5	1/3	3
Travel distance	1/3	1	1/5	1/5	1/3	3
Robustness	3	5	1	1/3	1	5
Safety	5	5	3	1	3	7
Surface used	3	3	1	1/3	1	5
Costs	1/3	1/3	1/5	1/7	1/5	1
Total	12.67	17.33	5.73	2.21	5.87	24.00

The aspects robustness and surface used are considered of equal importance for this stakeholder group. Safety is of very strong importance compared to the aspect costs. The lowest total score of safety indicates that safety is the most important aspect. The normalised comparison matrix results in the weights for this stakeholder group, which can be found in Table 38.

Table 38: Normalised matrix and weight set of operations

Aspect	Travel time	Travel distance	Robustness	Safety	Surface used	Costs	Weight
Travel time	0.08	0.17	0.06	0.09	0.06	0.13	0.17
Travel distance	0.03	0.06	0.03	0.09	0.06	0.13	0.07
Robustness	0.24	0.29	0.17	0.15	0.17	0.21	0.20
Safety	0.39	0.29	0.52	0.45	0.51	0.29	0.41
Surface used	0.24	0.17	0.17	0.15	0.17	0.21	0.19
Costs	0.03	0.02	0.03	0.06	0.03	0.04	0.04

The consistency ratio for this stakeholder group is 0.10, which means that the judgement values were consistent and the weight set is acceptable.

2. Handling

Fast and reliable travel times and direct routes are important for the bus company and handling companies. The paired comparison of aspects in Table 39 further specifies what aspect is more important per pair.

Table 39: Pair wise comparison matrix of handling

Factor	Travel time	Travel distance	Robustness	Safety	Surface used	Costs
Travel time	1	1	3	3	5	7
Travel distance	1	1	1/3	3	5	5
Robustness	1/3	3	1	1	5	7
Safety	1/3	1/3	1	1	3	5
Surface used	1/5	1/5	1/5	1/3	1	3
Costs	1/7	1/5	1/7	1/5	1/3	1
Total	3.01	5.73	5.68	8.53	19.33	28.00

The aspects travel time and travel distance are of equal importance, just as the aspects robustness and safety. Travel time and robustness are both considered of strong importance when they are compared with the aspect costs. Costs are considered the least important for all paired comparisons, which results in the highest total score. The normalised comparison matrix results in the weights for this stakeholder group, which can be found in Table 40.

Table 40: Normalised matrix and weight set of handling

Aspect	Travel time	Travel distance	Robustness	Safety	Surface used	Costs	Weight
Travel time	0.33	0.17	0.53	0.35	0.26	0.25	0.32
Travel distance	0.33	0.17	0.06	0.35	0.26	0.18	0.23
Robustness	0.11	0.52	0.18	0.12	0.26	0.25	0.24
Safety	0.11	0.06	0.18	0.12	0.16	0.18	0.13
Surface used	0.07	0.03	0.04	0.04	0.05	0.11	0.06
Costs	0.05	0.03	0.03	0.02	0.02	0.04	0.03

The consistency ratio for this stakeholder group is 0.09, which means that the judgement values were consistent and the weight set is acceptable.

3. Enforcement

For the authority officers, the kMar, and Customs it is important to have access to all part of the network at all times, therefore the aspect robustness is most important. The paired comparison of aspects in further specifies what aspect is more important per pair.

Table 41: Pair wise comparison matrix of enforcement

Factor	Travel time	Travel distance	Robustness	Safety	Surface used	Costs
Travel time	1	1	1/3	1/5	3	5
Travel distance	1	1	1/5	1/5	3	5
Robustness	3	5	1	1	5	7
Safety	5	5	1	1	5	7
Surface used	1/3	1/3	1/5	1/5	1	3
Costs	1/5	1/5	1/7	1/7	1/3	1
Total	10.53	12.53	2.88	2.74	17.33	28.00

The aspects travel time and travel distance are of equal importance, just as the aspects robustness and safety. The aspects robustness and safety are considered of strong importance compared to costs in the paired comparison. The normalised comparison matrix results in the weights for this stakeholder group, which can be found in Table 42.

Table 42: Normalised matrix and weight set of enforcement

Aspect	Travel time	Travel distance	Robustness	Safety	Surface used	Costs	Weight
Travel time	0.09	0.08	0.12	0.07	0.17	0.18	0.12
Travel distance	0.09	0.08	0.07	0.07	0.17	0.18	0.11
Robustness	0.28	0.40	0.35	0.36	0.29	0.25	0.32
Safety	0.47	0.40	0.35	0.36	0.29	0.25	0.35
Surface used	0.03	0.03	0.07	0.07	0.06	0.11	0.06
Costs	0.02	0.02	0.05	0.05	0.02	0.04	0.03

The consistency ratio for this stakeholder group is 0.06, which means that the judgement values were consistent and the weight set is acceptable.

4. Development

The department Development finds the amount of surface used and cost important. The paired comparison of aspects in Table 43 further specifies what aspect is more important per pair.

Table 43: Pair wise comparison matrix of development

Factor	Travel time	Travel distance	Robustness	Safety	Surface used	Costs
Travel time	1	3	1/3	1/3	1/5	1/5
Travel distance	1/3	1	1/3	1/3	1/5	1/5
Robustness	3	3	1	1/3	1/5	1/3
Safety	3	3	3	1	1/3	1
Surface used	5	5	5	3	1	3
Costs	5	5	3	1	1/3	1
Total	17.33	20.00	12.67	6.00	2.27	5.73

In this stakeholder group the aspects safety and costs are considered equal. The other comparison pairs all have moderate and strong importance over each other, and there is no very strong importance pair. Travel distance is the least important, whereas surface used is the most important. The normalised comparison matrix results in the weights for this stakeholder group, which can be found in Table 44.

Table 44: Normalised matrix and weight set of development

Aspect	Travel time	Travel distance	Robustness	Safety	Surface used	Costs	Weight
Travel time	0.06	0.15	0.03	0.06	0.09	0.03	0.07
Travel distance	0.02	0.05	0.03	0.06	0.09	0.03	0.05
Robustness	0.17	0.15	0.08	0.06	0.09	0.06	0.10
Safety	0.17	0.15	0.24	0.17	0.15	0.17	0.17
Surface used	0.29	0.25	0.39	0.50	0.44	0.52	0.40
Costs	0.29	0.25	0.24	0.17	0.15	0.17	0.21

The consistency ratio for this stakeholder group is 0.07, which means that the judgement values were consistent and the weight set is acceptable.

All weight sets

The weight sets are determined for the four stakeholder groups. But another possibility is that all aspects are considered equal. To test the sensitivity of the assessment, the four weight sets of the stakeholders and a weight set with equal weights are used to assess the design alternatives.

Table 45: All weight sets

Aspect	Equal	Operations	Handling	Enforcement	Development
Travel time	0.17	0.17	0.32	0.12	0.07
Travel distance	0.17	0.07	0.23	0.11	0.05
Robustness	0.17	0.20	0.24	0.32	0.10
Safety	0.17	0.41	0.13	0.35	0.17
Surface used	0.17	0.19	0.06	0.06	0.40
Costs	0.17	0.04	0.03	0.03	0.21

For operations the weight for safety is more than twice the size of safety in the equal situation. The travel time weight of handling is almost twice as high. For enforcement robustness and safety are both much higher than in the equal weights. For development the weight of surface used is much higher. For operations, handling, and enforcement the weights of costs are much lower compared to the equal weights.

7.2 ASSESSMENT OF RESULTS OF PIER B

Twelve design alternatives were applied to the airside road traffic system of AAS for a simulation study. The results of the simulations, the SSAM analysis, and the designs specifications are assessed to determine the most effective design for pier B. Table 46 is a summary of the results of all alternatives. The results of travel time, travel distance, robustness, and safety are all from Chapter 5. The rear end conflicts that occurred due to limitations in VISSIM were subtracted from the results of safety. For the assessment the adapted safety results are used. The specifications of surface used and costs are taken from section 3.4.1.

Table 46: Aspects of the design alternatives

	1A	1B	1C	2A	2B	3A	3B	4A	4B	5A	5B	5C
Travel time [h]	48.0	44.8	47.4	52.4	51.4	53.3	51.5	53.6	50.4	45.4	44.6	48.2
Travel distance [km]	545.7	545.1	551.2	614.0	610.7	619.0	618.1	624.1	609.1	546.2	546.0	555.9
Robustness	5.3%	6.0%	2.7%	6.9%	7.2%	7.0%	6.5%	8.6%	8.1%	4.5%	5.2%	2.9%
Safety [conflicts]	15.3	15.3 *	15.4	15.3	14.1 *	18.5	18.4 *	19.2	18.2 *	17.7	17.9 *	17.7
Surface used [m^2]	10650	10650	10650	10650	10650	10400	10400	10450	10450	10650	10650	10650
Costs [€]	14600	0	24000	19600	5000	19600	5000	19600	5000	19600	5000	29000

*) Adaptedl results.

7.2.1 STANDARDIZED EFFECT SCORES

The effects of the design of the road traffic system of the pier on the aspects are standardized with the method of maximum standardization. With this method the ratios between the effect scores become clear (van Herwijnen, Koomen, & Beinat, 2002). The highest values of travel time, travel distance, robustness, safety, surface used, and costs are considered the worst results. With the calculation of standardized effect scores this is taken into account. The standardized effect scores are calculated with equation 3, and presented in Table 47.

$$E_{ij} = \frac{max_j + min_j - score_{ij}}{max_j} \qquad (3)$$

E_{ij}	*Standardized effect score of alternative i on criterion j*
max_j	*Maximum value of criterion j*
min_j	*Minimum value of criterion j*
$score_{ij}$	*Score of alternative i on criterion j*

The total effects of a design are calculated with the standardized effect scores of Table 47 and weights for each criterion.

Table 47: Standardized effect scores of pier B

	1B	1A	1C	2A	2B	3A	3B	4A	4B	5A	5B	5C
Travel time	1.00	0.94	0.95	0.85	0.87	0.84	0.87	0.83	0.89	0.98	1.00	0.93
Travel distance	1.00	1.00	0.99	0.89	0.89	0.88	0.88	0.87	0.90	1.00	1.00	0.98
Robustness	0.61	0.70	1.00	0.51	0.47	0.49	0.56	0.31	0.37	0.78	0.70	0.98
Safety	0.94	0.94	0.93	0.94	1.00	0.77	0.78	0.73	0.79	0.81	0.80	0.81
Surface used	0.98	0.98	0.98	0.98	0.98	1.00	1.00	1.00	1.00	0.98	0.98	0.98
Costs	1.00	0.50	0.17	0.32	0.83	0.32	0.83	0.32	0.83	0.32	0.83	0.00

The standardized effect scores represent the effects of the designs without valuating the aspects. This overview of effects gives a systematic overview of the consequences of the design alternatives. Alternative 1B is the design in the base situation, and is therefore considered first.

When weights are added to the standardized effect scores the total effect scores are calculated. The four stakeholder groups discussed in Section 7.1 all have different weight sets. Different weight sets can results in different most effective designs, and should be taken into account with the advice. The standardized effect scores can be re-used in further research with new weight sets.

7.2.2 Total effect scores

The total effect scores of the design alternatives are the results of the weight sets (Table 45) multiplied by the standardized effect scores (Table 47). The total effect scores of the design alternatives for all 4 weight sets are presented in Table 48, as well as the weight set of equal weights.

Table 48: Total effect scores of the stakeholder groups

Stakeholder group	1B	1A	1C	2A	2B	3A	3B	4A	4B	5A	5B	5C
Equal aspects	0.92	0.84	0.84	0.75	0.84	0.72	0.82	0.68	0.80	0.81	0.88	0.78
Operations	0.96	0.95	1.00	0.88	0.92	0.81	0.85	0.76	0.82	0.92	0.92	0.93
Handling	0.90	0.88	0.95	0.78	0.80	0.75	0.79	0.70	0.76	0.90	0.90	0.91
Enforcement	0.85	0.86	0.94	0.77	0.79	0.70	0.74	0.63	0.69	0.84	0.83	0.88
Development	0.94	0.84	0.80	0.77	0.89	0.75	0.87	0.72	0.85	0.79	0.89	0.74

🟩 Best result 🟨 Second best result

When equal weights are applied the design of the base situation is considered the most effective, and the shared space and equal crossings with turning lanes has the second best result.

For the stakeholder groups operations, handling, and enforcement the aspects safety and robustness are more important in the weight sets. Operations consist of the departments PMA, ADI, and CMC. Handling consists of the bus company and the handling companies. Enforcement consists of the authority officers, the kMar and Customs. For these stakeholder groups alternative 1C is the most effective alternative. The differences in weights for these groups are only small, while the cost weight is much lower than in the equal weight set and for the stakeholder group development. It can be concluded that the low weight value for the aspect costs has a lot of influence on the best alternative, while smaller weight changes have far less effect on the best alternative.

The weight sets of stakeholder group development, consisting of the department Development, favours the aspects surface used and costs. Together with the equal weights the results of their assessment is that alternative 1B is the most effective design. Which means that the base situation cannot be improved, but the one-way and equal crossings with turning lanes gives the second best result.

The effect of the weights can best be visualised by comparing the stacking the aspect scores of the stakeholder groups operations and development. Figure 39 and Figure 40 visually represent the total scores per aspect with the weight sets of stakeholder group operations and stakeholder group development respectively. The influence of the low weights for surface used and costs can be seen when comparing Figure 39 and Figure 40. The higher weights of costs change the entire graph.

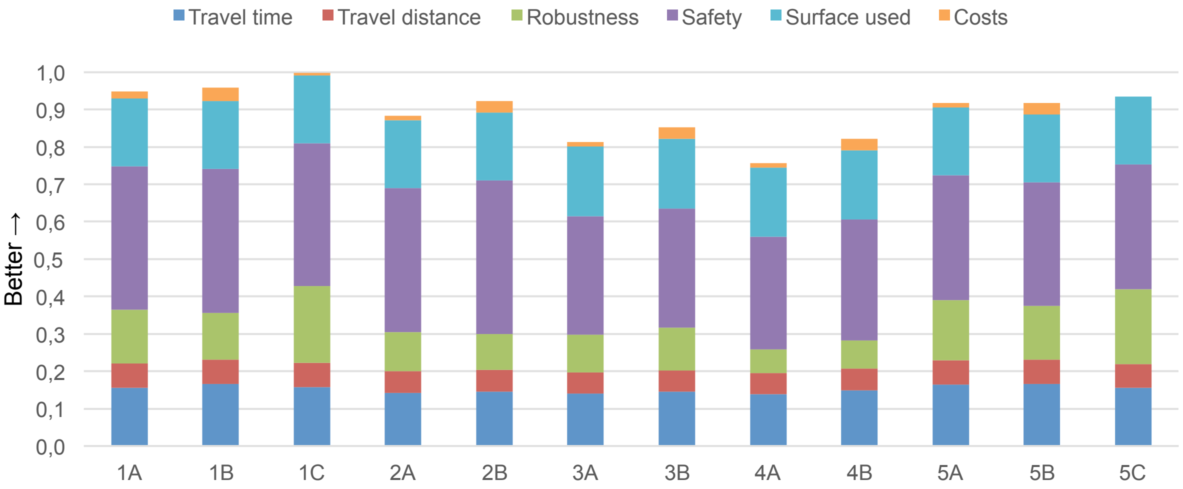


Figure 39: Total effect scores for operations

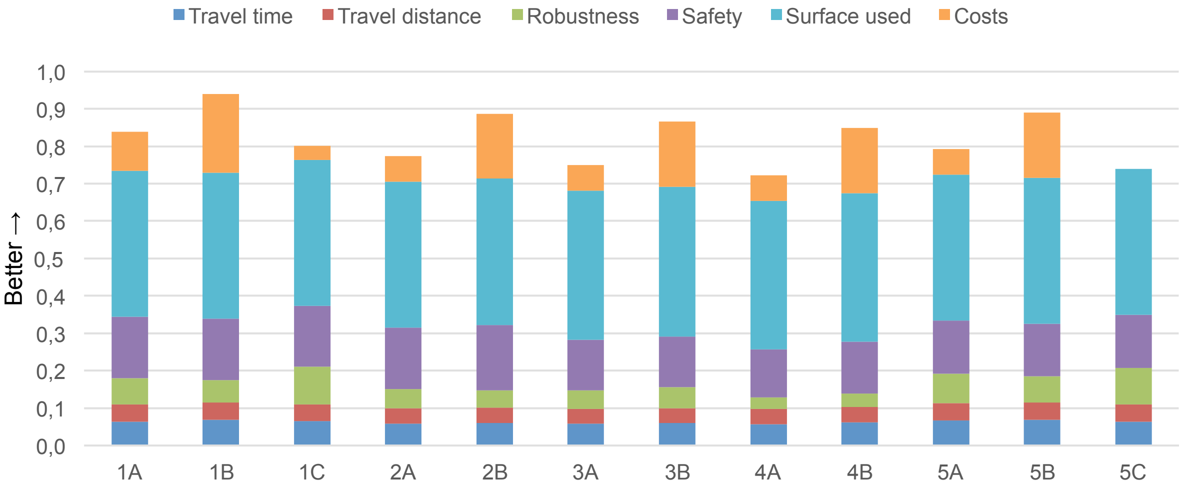


Figure 40: Total effect scores for development

For the majority of the stakeholder groups alternative 1C is the most effective design. Only the advice for the department Development would be that the design of the base situation is the most effective, with the one-way with equal crossings and turning lanes as the second best. It can be concluded that the total effect score is the most sensitive to changes in the cost-weight. The assessment is robust on the other aspects. Based on this assessment the advice for best design of the road traffic system around the piers to the stakeholders is design alternative 1C: the two-way with *voorrangsplein* design.

The three stakeholder groups operations, handling, and enforcement all find robustness one of the most important aspects, this reflects in the higher total effect scores for two-way and shared space. The department development has the safest design alternative as the second best, while the stakeholder group operations find safety the most important. Because the stakeholder group operations has conflicting interests and preferences the safest design alternative is only fifth best, for this alternative the positive results for safety do not outweigh the negative values of travel time, travel distance, and robustness.

7.2.3 STAKEHOLDERS INVOLVEMENT

The results of the assessment are sensitive to changes in the cost weight. When consensus is desired it is important to involve all stakeholders early in the design process. The department Development is a stakeholder that has to be kept satisfied, so early discussion of the importance of one aspects compared to another is necessary when consensus is desired. The other three stakeholders have mostly the same goal and desired effects and their weight sets are almost the same.

During the decision making process the desires of the stakeholder groups and their participation in the process can also lead to the creation of new design options, or looking at the problem from a new perspective. The results of this assessment are the top 2 design alternatives that meet the desires of the each stakeholder group. Further research into the top 2 design alternatives is required to make a founded decision.

7.3 ASSESSMENT OF RESULTS OF GENERAL APPLICATION

The effects of the design on the performance and specifications of the road traffic system in the general application are also assessed with a multi criteria analysis.

7.3.1 PIER CONFIGURATION WITH TWO MAIN ROAD JUNCTIONS

Part of this research was the general application of the results, therefore the assessment is also applied to the pier configuration with two main road junctions as shown in Figure 41. The results and design specifications of travel time, travel distance, robustness, safety, surface used, and costs from the pier configuration with two main roads of Section 6.1 are also assessed with the same weight sets. This pier is not an existing pier at AAS, but a fictional pier with the same functionalities as pier B but without the third connection to the main road.

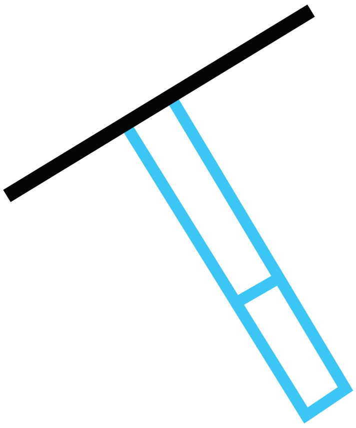


Figure 41: Pier configuration with two main road junctions

Table 49 is a summary of the results of all alternatives in the general configuration with two main road junctions.

Table 49: Aspects of the design alternatives in the two main road junctions configuration

	1A	1B	1C	2B	5B
Travel time [h]	34.0	30.7	34.8	33.4	30.3
Travel distance [km]	405.8	406.4	429.3	444.1	407.3
Robustness	15.1%	11.0 %	11.0 %	100 %	10.3 %
Safety [conflicts]	4.2	4.6	4.5	4.1	7.7
Surface used [m^2]	8165	8165	8165	8165	8165
Costs [€]	14600	0	24000	5000	5000

The standardised effect scores are calculated with the method of maximum standardisation of equation 3 of the previous section. The standardized effect scores of this configuration are presented in Table 50. Alternative 1B is the design in the base situation, and is therefore considered first.

The standardized effect scores represent the effects of the designs without valuating the aspects. This overview of effects gives a systematic overview of the consequences of the design alternatives. When weights are added to the standardized effect scores the total effect scores are calculated. The four stakeholder groups discussed in Section 7.1 all have different weight sets. Different weight sets can results in different most effective designs, and should be taken into account with the advice. The standardized effect scores can be re-used in further research with new weight sets.

Table 50: Standardised effect scores

	1B	1A	1C	2B	5B
Travel time	0.99	0.89	0.87	0.91	1.00
Travel distance	1.00	1.00	0.95	0.91	1.00
Robustness	0.98	0.93	1.00	0.08	0.98
Safety	0.94	0.99	0.95	1.00	0.53
Surface used	1.00	1.00	1.00	1.00	1.00
Costs	1.00	0.39	0.00	0.79	0.79

The weight sets of Table 45 on page 72 are used to calculate the total effect scores for the stakeholder groups. The results of the total effect scores of all stakeholder groups and with equal weights are presented in Table 51.

Table 51: Total effect scores

	1B	1A	1C	2B	5B
Equal aspects	0.98	0.87	0.79	0.78	0.88
Operations	1.04	1.01	0.99	0.85	0.87
Handling	0.98	0.93	0.91	0.73	0.93
Enforcement	0.97	0.94	0.93	0.68	0.82
Development	0.99	0.98	0.98	0.90	0.92

🟩 Best result 🟨 Second best result

The weight sets of the stakeholder groups operations, handling, and enforcement are close together, the weight set of development is more close to the weight set of equal weights. Therefore only the graphs of the total effect scores of the groups operations and development are visually represented in Figure 42. Alternative 1B is the most effective design alternative when equal weights are used and for all stakeholder groups. The total scores of alternative 1B stay almost the same no matter the weights. Alternative 2B scores significantly worse in this pier configuration compared to pier B due to the low score of robustness. The extra travel time of the one-way alternative is 100% because traffic cannot exit the pier when the only exit point is blocked, while on pier B there were two exits to the main road.

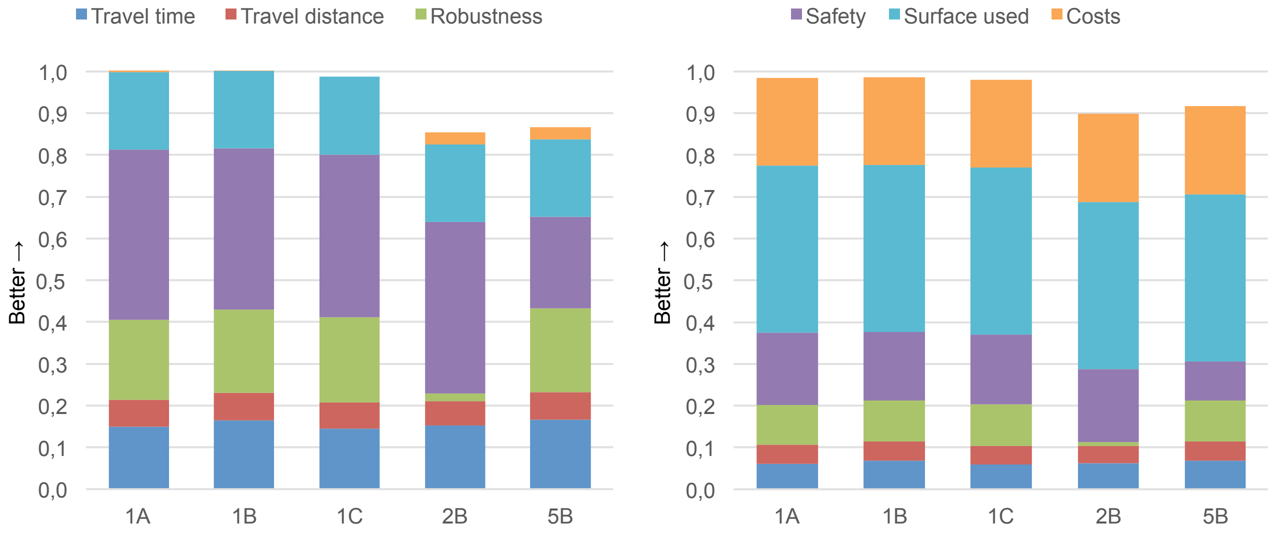


Figure 42: Total effect scores for operations (left) and development (rights)

Table 51 and Figure 42 show that the different weight sets do not influence the results of best alternative for this general configuration with limited designs. Because less design alternatives are tested in this configuration the results of the design alternatives that were tested are much closer together. The most effective design is the same for all weight sets, which leads to the conclusion that the results of this assessment are not sensitive to weight changes.

7.3.2 PIER CONFIGURATION WITHOUT PASSAGE ROAD THROUGH PIER

Part of this research was the general application of the results, therefore the assessment is also applied to the pier configuration without a passage road as shown in Figure 43. The results and design specifications of travel time, travel distance, robustness, safety, surface used, and costs from the pier configuration with two main roads of Section 0 are also assessed with the same weight sets. This pier is not an existing pier at AAS, but a fictional pier with the same functionalities as pier B but without the third connection to the main road and without a passage road through the pier.

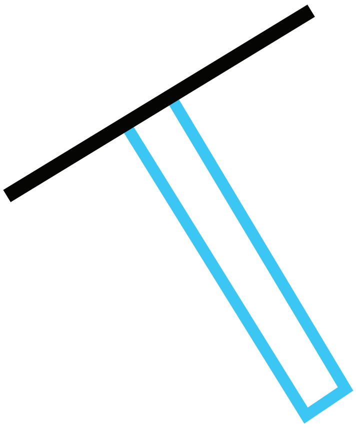


Figure 43: Pier configuration without a passage road through the pier

Table 52 is a summary of the results of all alternatives in the general pier configuration without a passage road through the pier.

Table 52: Aspects of the design alternatives in the configuration without the passage road

	1A	1B	1C	2B	5B
Travel time [h]	34.9	31.6	35.0	34.5	31.0
Travel distance [km]	416.1	420.0	425.6	475.1	421.0
Robustness	18.5 %	15.4 %	18.6 %	100 %	15.3 %
Safety [conflicts]	4.2	4.5	4.4	4.1	7.3
Surface used [m^2]	7,845	7,845	7,845	7,845	7,845
Costs [€]	14600	0	24000	5000	5000

The standardised effect scores are calculated with the method of maximum standardisation of equation 3 of the previous Section. The aspect results of this configuration are presented in Table 53. Alternative 1B is the design in the base situation, and is therefore considered first.

Table 53: Standardised effect scores

	1B	1A	1C	2B	5B
Travel time	0.99	0.89	0.89	0.90	1.00
Travel distance	0.99	1.00	0.98	0.88	0.99
Robustness	0.99	0.96	1.00	0.14	0.99
Safety	0.94	0.98	0.95	1.00	0.55
Surface used	1.00	1.00	1.00	1.00	1.00
Costs	1.00	0.39	0.00	0.79	0.79

The standardized effect scores represent the effects of the designs without valuating the aspects. This overview of effects gives a systematic overview of the consequences of the design alternatives. When weights are added to the standardized effect scores the total effect scores are calculated. The four stakeholder groups discussed in Section 7.1 all have different weight sets. Different weight sets can results in different most effective designs, and should be taken into account with the advice. The standardized effect scores can be re-used in further research with new weight sets.

The weight sets of Table 45 on page 72 are used to calculate the total effect scores for the stakeholder groups. The results of the total effect scores of all stakeholder groups and with equal weights are presented in Table 54.

Table 54: Total effect scores for pier configuration without passage roads

STAKEHOLDER GROUP	1B	1A	1C	2B	5B
Equal aspects	0.98	0.87	0.80	0.78	0.89
Departments PMA, ADI, and CMC	1.04	1.01	0.99	0.86	0.88
Bus and handling companies	0.98	0.93	0.92	0.73	0.93
Authority officers, kMar, and Customs	0.97	0.95	0.94	0.69	0.83
Department Development	0.99	0.86	0.77	0.86	0.88

🟩 Best result 🟨 Second best result

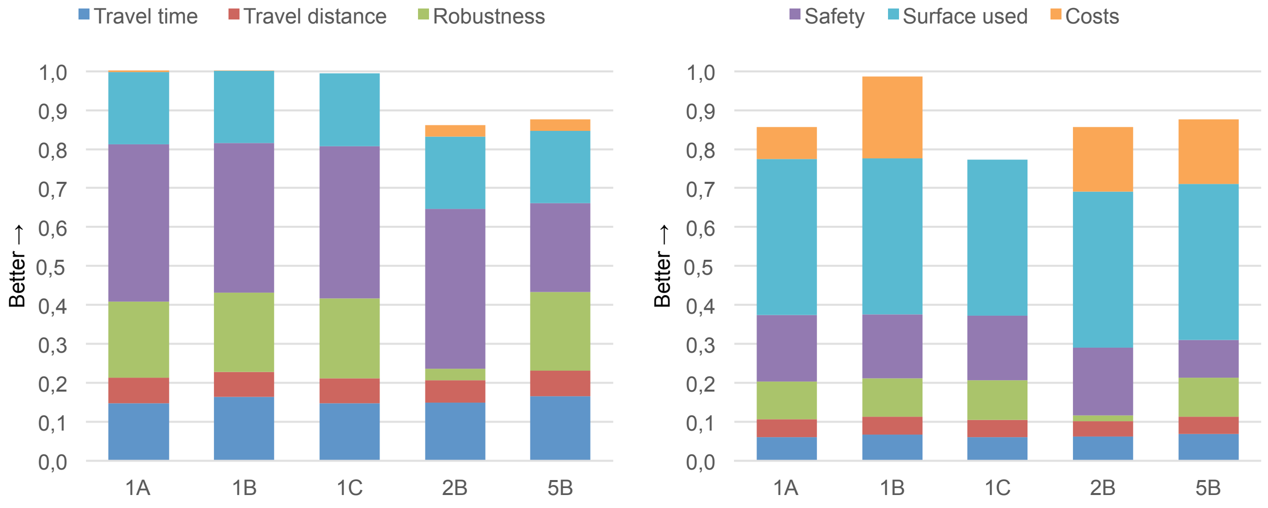


Figure 44: Total effect scores for operations (left) and development (right)

The weight sets of the stakeholder groups operations, handling, and enforcement are close together, the weight set of development is more close to the weight set of equal weights. Therefore only the graphs of the total effect scores of operations and development are visually represented in Figure 44. For this pier configuration alternative 1B is the most effective design. The differences in total effect scores between the design alternative 1A, 1B, and 1C become larger when the weight set of stakeholder group development is applied, as can be seen in Figure 44. While the total effect scores of 2B and 5B just grow.

7.4 IMPLEMENTATION OF ALTERNATIVES AT AAS

The implementation of a design alternative in the existing infrastructure of the road traffic system of AAS requires knowledge on the implementation strategy. The implementation strategy discussed in this chapter is not for a specific pier, but is specific to the situation at AAS. In this chapter the future construction works on the piers, stakeholder cooperation, the design and implementation process, and the time frame of the steps are discussed.

7.4.1 FUTURE CONSTRUCTION WORKS AT AAS

There are two already planned projects on and around the piers of AAS till 2025. These projects are highlighted in Figure 45.

The new pier A is part of the Masterplan 2020-2025 and is taken into account for the base situation. In the coming years the redesign for platform B is first executed. After the redesign of platform B construction of the new pier can begin. The time frame of pier A is 8 years starting in 2016. At the moment the road design is only conceptual, the detailing of the road design is not complete. The implementation of a design alternative can still be part of the planned construction works.

Another project is the extension in the width of the terminal building at pier C. The terminal building at the pier is going to be broader to facilitate the need for more space at the gates. The extra width of the pier hangs over the existing service road. The time frame for this extension is 3 to 5 years. The construction of the overhanging already takes nuisance into account. During the construction of the overhanging the use of pier C is limited. The implementation of a design alternative can therefore be part of the planned construction works and while not interfering with the daily operations.

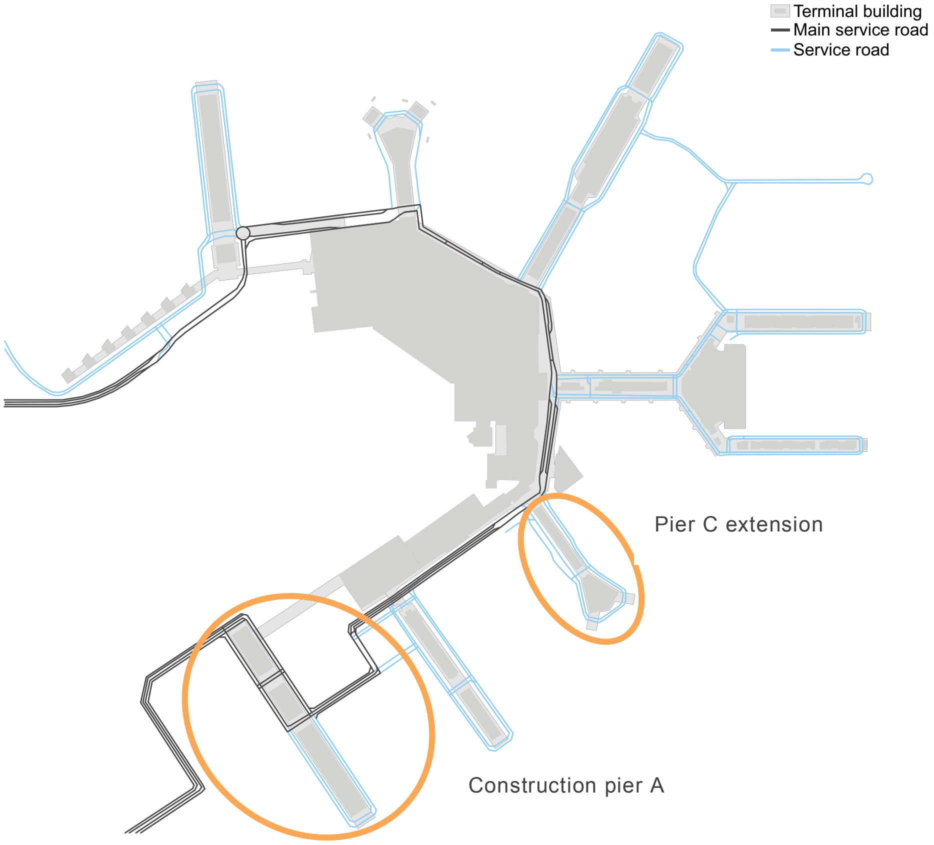


Figure 45: Future construction works at AAS till 2025

7.4.2 STAKEHOLDER COOPERATION

An overview of the stakeholders involved in the decision making process is provided in Section 2.7. The emergency services and department MO are stakeholders that have to kept informed. The kMar, Customs, and department Development have high power and low interest, and have to be kept satisfied. And the key participants that have high interest and power are the bus company, handling companies, Authority officers, and departments PMA, ADI, and CMC.

None of the stakeholders have negative interests at the moment, there is no direct opposition to a design alternative when the consequences and design of the alternative are discussed. All parties are open to change if the effects are desired. The emergency services, bus company, handling companies, Authority officers, and departments PMA, ADI, CMC, and MO all have an active attitude in the decision making process. The kMar, Customs, and department Development have a passive attitude. By motivating the passive stakeholders their interest in the project grows, which leads to a more optimal design and implementation process.

When one of the design alternatives with one-way roads is chosen, communication with the road user stakeholders is critical. The design alternatives of this research are all clockwise designed to facilitate the bus. On pier F a counter clockwise one-way situation already exists for more than 10 years. When one of the clockwise one-way designs is chosen the situation of pier F should also be changed to avoid confusion. The process of changing pier F is difficult, and is expected to delay the construction of one-way alternatives.

7.4.3 IMPLEMENTATION PROCESS

The design and implementation process of AAS is visualised in Figure 46. The steps 1 to 4 are part of this research, the steps 5 to 9 are future steps of implementation to be taken after this research. The steps are explained in this section.

The process of designing and implementing a new road section and/or junction design in existing infrastructure begins with identification of a problem. The identified problem is analysed, and then translated into concept designs by the departments PMA and ADI. An engineering company elaborates the design further into preliminary designs and makes a rough estimate of the budget size for implementation. This part of the design and implementation process is already done as part of this research. Further steps of the design and implementation process describe the steps that should be taken after this research.

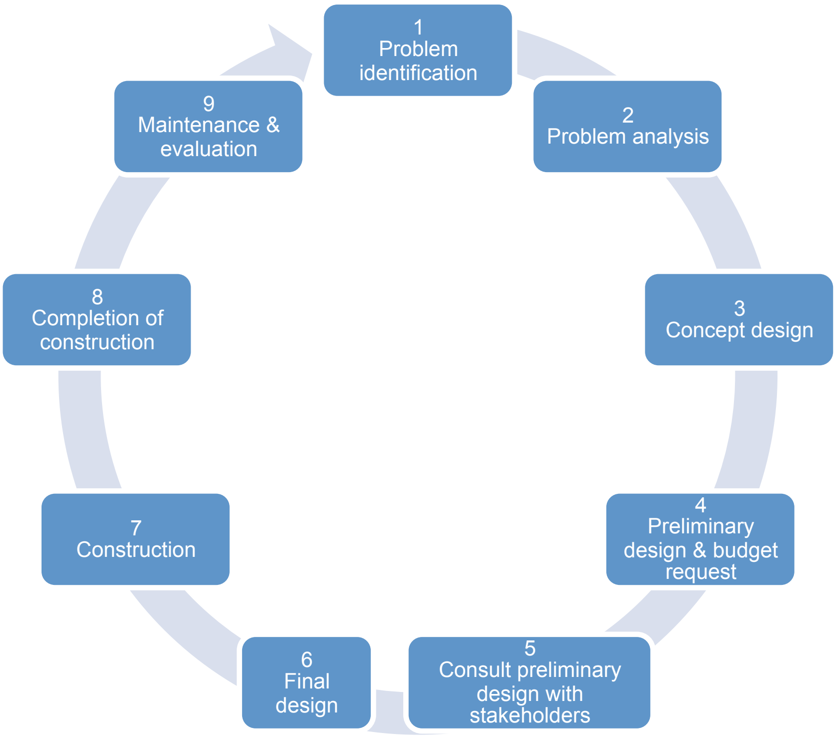


Figure 46: Design and implementation process of AAS

The preliminary designs and the estimated budget size of the engineering company are adjusted by the department PMA and ADI in consultation with the road user stakeholders the design. During this consultation period a budget request is send to the financial department of the Schiphol Group. When the budget request is approved and all key participants are in agreement the (adjusted) preliminary design is send to the department Development. The department Development translates the preliminary design into the final design.

When the final design is complete the construction of the design can begin. The department CMC oversees the implementation and keeps the stakeholders informed on when and where the construction works take place, when and where possible nuisance can be experienced, and the expected completion date. The stakeholders inform their own employees about expected nuisance during the construction. The construction works are thoroughly prepared to minimise the nuisance during construction. Preparation consists of placing new (covered) traffic signs, delivering building material, and setting up the equipment. The implementation of the design alternative takes place over the course of one or multiple night(s) outside of peak hours, to limit nuisance in the daily operations. When a combination of a new road section design and a new junction design is chosen construction starts with the service roads of the pier, and then begins construction on the junctions. With very large infrastructural projects another option is to make a road diversion that allows the traffic to bypass the construction works active during the day, this situation is not preferred by the road managers of PMA due to limited size of available road surface.

When the construction works are done a final inspection by the responsible road manager is the last step before official completion of the design. The road users stakeholders inform their employees on the new traffic situation. When the traffic situation is significantly different from the previous situation an additional campaign can bring the subject to the attention of the drivers on airside. The design alternatives proposed in this research a campaign is not deemed necessary.

After completion the refurbished part of the road traffic system still has to have maintenance works, and the effects the implementation has on the network performance and safety have to be evaluated after a couple of years.

7.4.4 TIME FRAME

At least one year before construction can start the budget request has handed in and approved by the financial department. After which preparations of about 3 weeks for the construction works begin. When changing the road section design the already placed traffic signs are uncovered and the road markings are applied in one night. The construction of a new junction takes more actual construction work and is spread over the nights of multiple weeks.

Construction on infrastructure is always planned between March and November. Road markings cannot be applied outside of this period because of bad weather conditions.

The entire design and implementation process from budget approved to completion is estimated to take 6 months for the design alternatives of this research. This includes the adjusting of the design in consultation with the road user stakeholders. This time period is based on previous experience by road managers of PMA.

7.5 SUB CONCLUSION: ASSESSMENT AND IMPLEMENTATION OF ALTERNATIVES

This chapter contains the assessment of design alternatives applied the pier B configuration and to the general configurations. And the implementation process of the design alternatives in the existing road traffic system infrastructure of AAS.

The effects of the design on the performance and specifications of the road traffic system are assessed with a multi criteria analysis. The multi criteria analysis takes the different aspects into account and lets its user differentiate between the weights of different aspects. There are four weight sets for the stakeholder groups operations, handling, enforcement, and development. The weight sets of the stakeholder groups are determined with the AHP method, where the aspects are compared in pairs and normalised into weights.

The effects of the design alternatives are standardised with the method of maximum standardisation. The standardized effect scores give a systematic overview of the consequences of the design alternatives. When weights are added to the standardized effect scores the total effect scores are calculated. Different weight sets can results in different most effective designs. The standardized effect scores can be re-used in further research with new weight sets.

The assessment of the design alternatives is based on the total effect score, which combines the weight sets with the standardized effect scores. The total effect scores show that the two-way design with the *voorrangsplein* (alternative 1C) is the most effective alternative for three of the four stakeholder groups. The second best design alternatives depend on the stakeholder group. Alternative 1B (the base situation) is the most effective for the stakeholder group department Development, the one-way and equal crossings with turning lanes alternative (2B) is the second best design alternative.

In the general pier configurations the design of the base situation with two-ways on the pier and an equal crossing with turning lanes (alternative 1B) is the best, and the one-way design and equal crossing with turning lanes (2B) is the worst result of the assessment.

The implementation of new design in the existing road traffic system infrastructure should be planned within the future works on pier C and pier A to minimise the interference with daily operations, construction time, and costs. The stakeholders that are only passively involved in the process have to be motivated be actively involved in the decision making process. The infrastructural design alternatives suggested in this research only require small infrastructural interventions. The design and implementation process has to be started a year in advance for budget requests, but when the budget is made available the process can be completed within a couple of months.

8 CONCLUSION AND DISCUSSION

In this thesis the effects of road design of the service roads around the piers on the aspects travel time, travel distance, robustness, safety, surface used, and costs are discussed. The final chapter of this report contains the findings of this research relating to the research questions, the answer to the main research question as a conclusion of this research, and implications for practice and science.

8.1 FINDINGS

The characteristics of the airside road traffic system of AAS are very diverse. The road traffic subsystems of the seven main piers all are connected to the main road at two or more junctions. The piers have different configurations, and house several functionalities on the ground level and gates on the upper level. The rules and regulation apply to the entire road traffic system. The maximum speed is 30 km/h, cycling is not allowed, wide vehicles are not allowed to drive on the east side of the system, and pedestrians do not have priority. The vehicles using the road traffic to travel between handling processes on the aircraft stands are also very diverse in dimensions, speeds, and other characteristics. The users of the road traffic system have varying degrees of interest and power in the decision making process. Together with several departments of the Schiphol Group they form the stakeholders. The departments PMA, ADI, and CMC, authority officers, the bus company, and handling companies are key participants in the decision making process.

Two-way roads, one-way roads, shared zones, equal crossings with and without turning lanes, and roundabouts are currently applied on airsides of similar airports and AAS. These designs and other public road designs of road sections and junctions that take non-removable elements and airside users into account and comply with the rules and regulations are assembled as infrastructural designs. The two-way, one-way with two lanes, one-way with parking bays, one-way with extended aircraft stands, and shared space concepts are combined with equal crossings, equal crossings with turning lanes, and the voorrangsplein. The design of the voorrangsplein is not compatible with the one-way designs. Which leaves twelve infrastructural design alternatives that can be applied to the road traffic system. Among the infrastructural design alternatives is the design of the base situation. The design specifications include surface used of each alternative and estimated costs.

The performance of the design alternatives is measured on the aspects travel time, travel distance, robustness, and safety in simulation models of the alternatives. The simulation program VISSIM is chosen because it offers a detailed study on local and strand level that can model individual and diverse vehicles on different junctions and road section designs. The simulation model measures the travel time, travel distance, and robustness. The level of safety is measured with the surrogate safety analysis program SSAM, by analysing the trajectories of the vehicles in VISSIM for conflicts. The twelve design alternatives with their specifications were implemented and simulated in the simulation program VISSIM and the surrogate safety analysis program SSAM. The simulations represent the traffic movements in 3 hours and 40 minutes on an average day of the design alternative applied to pier B.

Designs of the road traffic system that allow both clockwise and counter-clockwise traffic movement around the pier, like the two-way designs and shared space designs, result in the lowest travel times, travel distances, and percentage of extra travel time when an accident has occurred on the pier. When traffic is only allowed to travel in one direction around the pier the number of conflicts is the lowest, especially around the junctions to the main road. More complicated road section designs with overtaking areas, such as the shared space design and the designs with overtaking bays, lead to higher numbers of conflicts. But these alternatives do lead to shorter total travel times in comparison with alternatives that have one lane per direction. The results of different junction applied to the same road section design results are closer together. Which means that the effects of the design of the junctions connecting the road traffic subsystem of the pier to the main road are smaller in comparison with the effects of the design of the road sections on the pier road traffic system. The equal crossing with turning lanes results in the shortest total travel times and travel distances, and the lowest number of conflicts. The *voorrangsplein* has the lowest percentage of extra travel time. There is no alternative with the best results in all aspects, and there is no alternative that improves the performance on all aspect of the base situation. The one-way with two lanes that keeps the base design of the junction has significantly different results compared to the design of the base situation. The results of the two-way with the *voorrangsplein* design and the one-way with equal crossings design are significantly different from the results of the base design on all aspects but one. The results of shared space in combination with the base junction design are not significantly different from the results of the base situation on any aspect.

Pier B is an integral part of the road traffic system, and through traffic and destination traffic uses the service roads around the piers. Other configurations found on the airside of AAS are piers that are independent road traffic subsystems attached to the main road, with or without passage roads through the pier. These independent road traffic systems of the pier are used exclusively by destination traffic. The configuration influences the number of possible routes a vehicle can take, and therefore the results of travel time, travel distance, and robustness. The effects the design alternatives have on travel time, travel distance, robustness, and safety are mostly not dependant on the configuration of the road traffic system. The road section design with the best performances does not change when the configuration of the road traffic system changes. But the best junction designs for the aspects travel distance and robustness do change. Changing the functionalities of a pier has an evenly spread effect on the results, and would therefore not change the outcome.

The assessment of the design alternatives is based on the interests of the departments PMA, ADI, and CMC, the authority officers, the bus company and handling companies, the kMar and Customs, and the department Development. The weight sets of the stakeholder groups are determined with the AHP method, where the aspects are compared in pairs and translated into weights. The effects of the design alternatives are standardised with the method of maximum standardisation. This overview of effects gives a systematic overview of the consequences of the design alternatives. Based on the assessments of the majority of the stakeholder groups the two-way design with the *voorrangsplein* is the best alternative for pier B. In the general pier configurations the design of the base situation with two-ways on the pier and equal crossings with turning lanes is the best. The infrastructural design alternatives suggested in this research only require small infrastructural interventions, when the budget is made available the process can be completed within a couple of months.

8.2 CONCLUSION

The *main research question* of this research is: How can the design of the airside road traffic system around the piers of Amsterdam Airport Schiphol be improved in terms of travel time, travel distance, robustness, safety, surface used, and costs?

In this research twelve infrastructural design alternatives compiled of the combinations of road section and junction designs are tested on the airside road traffic system around pier B. Five of these infrastructural design alternatives were also tested on general pier configurations to test their effect on these road traffic systems. Among the set of five and the set of twelve alternatives is the design of the base situation. The twelve infrastructural design alternatives tested in this research all improved at least one aspect of the research aspects. The aspect cost was not improved by any of the twelve design alternatives. There was no design alternative that improved all aspects.

The design of the base situation is two-way on the service roads and equal crossings with turning lanes. The two-way design without turning lanes improved the robustness and safety for all road system configurations, and improved the travel distance in the configurations with piers as independent subsystems. The two-way design with *voorrangspleinen* improved the robustness in all configurations and safety around pier B. The one-way design with two lanes and junctions without turning lanes improved the safety around pier B, and was not applied to other configurations. The one-way design and equal crossings with turning lanes improved the safety in all road system configurations. The one-way designs with parking bays and extended aircraft stands allowed for extra parking space and reduced the surface appointed to the road around pier B, the designs were not tested on other configurations. The shared space designs with equal crossings and with *voorrangspleinen* were only tested on pier B and improved the robustness of the road traffic system. The shared space design and equal crossings with turning lanes improved the travel time and robustness for pier B and more independent piers.

Based on the assessments of the majority of the stakeholder groups the two-way design with *voorrangspleinen* is the best design for pier B. The shared space design and equal crossings with turning lanes or *voorrangspleinen* also score better than the base design in the assessments. In the general pier configurations the two-ways design and equal crossings with turning lanes is the best, and the second best results are for the two-way design and equal crossings.

This research simulated the design alternatives that could be implemented within the existing road traffic system and comply with the rules and regulation of AAS, and analysed the results. For a specific pier, pier

B, all twelve design alternatives were tested, and for a more general concept of a pier five relevant design alternatives were also tested. The configurations of the road traffic system affected the results of the design alternatives in a small way. The alternatives were assessed and with the effect scores the results can be applied to other systems. It can therefore be concluded that the scientific objective of this research "to develop a systematic approach to apply the effects that different infrastructural design alternatives have on the airside road traffic systems of the pier, depending on the characteristics of the airside road traffic system" has been reached.

8.3 IMPLICATIONS FOR PRACTICE

Chapter 3 provides an overview of the implementation of the road section concepts two-way, one-way, and shared space on airside road traffic systems around the world. There is one design in the two-way concept that can be applied to all kinds of airside road traffic systems with expansion possibilities. There are five design options with or without parking in the one-way concept, for clockwise and counter-clockwise traffic movements. And the concept of shared space can be executed on a road traffic system or on the entire apron. Chapter 3 also provides an overview of the implementation of the junction concepts equal crossing, roundabout, and *voorrangsplein* to airsides. The equal crossing with and without turning lanes can be applied to global airside road traffic systems, the banned left turns equal crossing should not be applied to airside road traffic systems with piers as independent road subsystems. Roundabouts in diverse dimensions can also be applied to different kinds of road traffic systems. And the *voorrangsplein* is a new design that can be applied to road traffic systems with small road dimensions.

Not all design options mentioned in Chapter 3 of this study could be applied to the airside road traffic system of AAS due to spatial, user, or policy limitations. The twelve combinations of road section and junction design that can be applied to the airside road traffic system of AAS are translated onto pier B in simulation models for the normal scenario and the accident scenario. The simulations models can be used by the Schiphol Group for further studies into small changes in the design of the infrastructure, pedestrians in the shared space designs, and the effects of future developments.

This research contains an assessment of the design alternatives based on the importance of travel time, travel distance, robustness, safety, surface used, and costs. The two-way alternative with the *voorrangsplein* is the best alternative, but does not show a significant difference in the number of conflicts on airside. The one-way and equal crossings with turning lanes design does have significant different results compared to the base design, but is considered the fifth best. The effects of the design alternatives are standardised with the method of maximum standardisation. This overview of effects gives a systematic overview of the consequences of the design alternatives. The standardized effect scores can be re-used in further research with new weight sets.

Consultation and collaboration of representatives from the departments PMA, ADI, and CMC, the authority officers, the bus company, the handling companies, the kMar and Customs, and department Development is the next step into the implementation process. When the one-way design is implemented in the clockwise design of this research, the traffic direction of pier F should be changed to clockwise as well. Careful consideration is therefore advised. The implementation of a new design should be phased, adjusting the situation at smaller piers first.

8.4 IMPLICATIONS FOR SCIENCE

The principles of shared space for vehicles are implemented in the simulation program VISSIM with overtaking zones of overlapping road sections. With priority rules the overtaking actions of the vehicles depended on the traffic on the opposing lane. The application of shared space used by vehicles on road sections of this research can be used as an addition to further studies on shared space.

The effects on safety are normally not researched in simulation models. This research looked at safety as one aspect of consideration, and therefore a simulation model was used in this research. In this research, the application SSAM analysed the trajectories of the simulated vehicles to determine where conflicts arise. With SSAM it is possible to predict the safety of a design, instead of analysing the effects of an implemented design. The use, parameters, and limitations of SSAM are discussed in this research.

The configuration of a pier does not have a large effect on the results of travel time, travel distance, robustness, and safety of a design. The results of pier B and the general configurations can be used as indicators to predict the effects of the designs and possible design variations on other airside road traffic systems and similar traffic systems. Repeating this research on airside road traffic systems of other similar airports could give insights into the general application of infrastructural designs and their expected effects.

8.5 RECOMMENDATIONS FOR FURTHER RESEARCH

At the moment the Schiphol Group has no data on the vehicle movements on airside. There was no historical data on vehicle movements available in this research, and only the road users have live data. Further research should focus on the driving conditions on airside and their translations into simulation models. The simulation model could become part of traffic management and the distribution of traffic on the network if live data on the traffic situation was made available for the model.

The design specifications of design alternatives included parking, surface used, and costs. In this research only construction costs were taken into account due to a lack of key figures. Costs are taken into account in the assessment of the design alternatives, and should be further investigated. For a more thorough grasp on the costs, research costs, investment costs, costs that arise due to construction nuisance, and maintenance costs should also be calculated for all alternatives.

The concept of shared space for vehicles are implemented in the simulation program VISSIM with overtaking zones of overlapping road sections. However, the speed of the vehicles was not adjusted to opposing traffic, there were no pedestrians in the model, and there was no communication between road users. For future research, the application of shared space in this model should be calibrated to the driving behaviour on airside.

The number of conflicts in the design alternatives was determined with vehicle trajectories in the application SSAM. When more information on the vehicle movements on airside is available the number of conflicts can be related to the predicted number of crashes. The simulation program VISSIM essentially models safe behaviour, unless unsafe distances are programmed. Research on the driving behaviour on the airside of AAS and the implementation of real world vehicle interactions in VISSIM is necessary for future studies.

Policy alternatives were not part of this research, and should be considered for further simulations and research. The results of this research should be combined with the previous researched on the airside road traffic system by Borsboom (2012) and van der Horst (2014) to have a complete overview of the entire road traffic system and the possible improvements.

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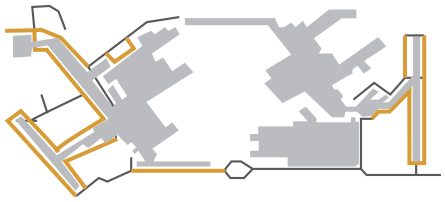
Appendix A: Research on other airports

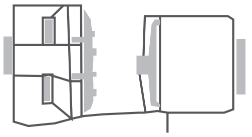
Information on flight movements, size of the terrain, number of runways, and the number of aircraft stands were found on the airport' websites. Terminal configuration and traffic system was derived from data available on Google Earth (Google, 2015).

Airport	Flight movement (2014)	Terrain [ha]	Runways	Aircraft stands connected to terminal (total)	Terminal configuration	Traffic system
London Heathrow	470,695	1,277	2	125 (177)	Three terminals	Most piers 1-directional
Frankfurt	469,026	2,100	4	221	One terminal	All 2-directional
Charles de Gaulle	465,000	3,257	4	140 (317)	Three terminals	Parts 1-directional
Istanbul Ataturk	439,549	856	3	226	One terminal	All 2-directional
Schiphol	438,000	2,787	5	222	One terminal	Most piers 2-directional
JFK New York	422,425	1,995	4	125	Six terminals	All 2-directional
Munich	376,678	1,560	2	135	Two terminals	All 2-directional
Madrid	342,604	2,928	4	109	Four terminals	All 2-directional
Singapore	341,386	1,300	2	92 (134)	Three terminals	All 2-directional
Copenhagen	251,799	1,180	3	106	Two terminals	Parts 1-directional
Brisbane	113,181*	2,700	2	52 (108)	Two terminals	All 2-directional

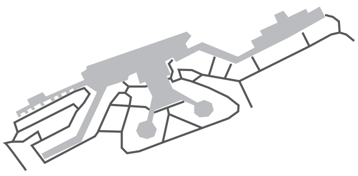
* for the year 2013/2014



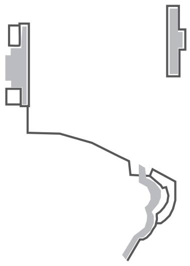
London Heathrow



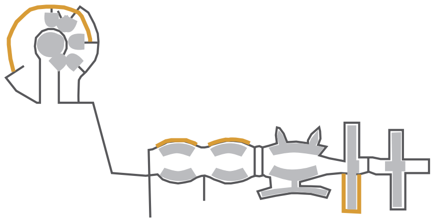
Munich



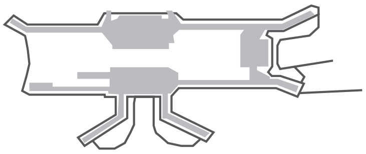
Frankfurt



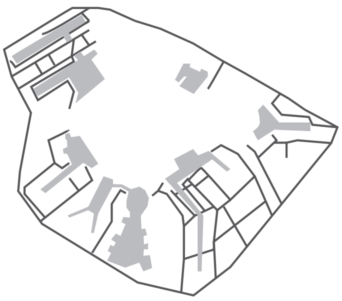
Madrid



Charles de Gaulle



Singapore



JFK New York

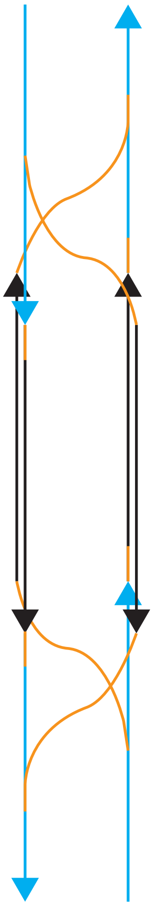
Copenhagen

Brisbane

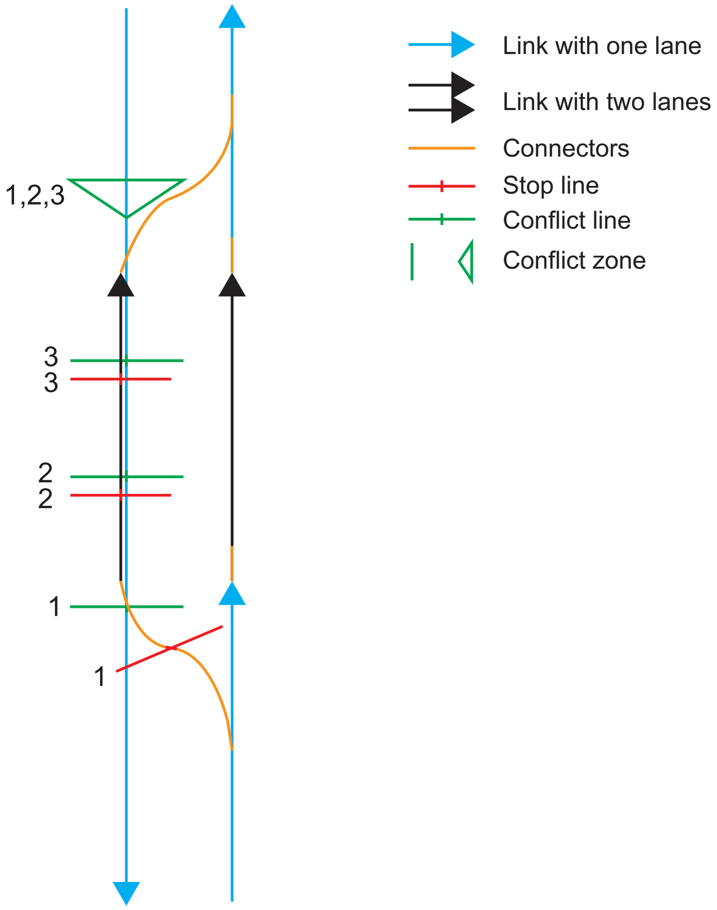
— Two-way — One-way — Shared zone

APPENDIX B: SHARED SPACE IMPLEMENTATION IN VISSIM

Normally vehicles in VISSIM can only take vehicles on their own link, without taking opposing traffic into account. The concept of shared space means that vehicles can move on the entire road, only taking other vehicles into account. Shared space is implemented in VISSIM with overlapping and opposing links. The overlapping links each have two lanes and priority rules with stop lines on one link and the conflict lines on the opposing link. With the priority rules implemented every 5 meters the vehicles can take the position of the opposing traffic into account when overtaking.



Overlapping overtaking zones



Priority rules for overtaking seen from one direction

APPENDIX C: CONFLICT ANALYSES

Conflict analysis of alternative 1B

Conflict analysis of alternative 1C

Conflict analysis of alternative 2A

Conflict analysis of alternative 3A

Conflict analysis of alternative 3B

Conflict analysis of alternative of 4A

Conflict analysis of alternative 4B

Conflict analysis of alternative 5A

Conflict analysis of alternative 5B

APPENDIX D: SIGNIFICANCE OF RESULTS

The results of the T-test including means, standard deviations, and p-values. In the legend the relevant abbrevations are explained.

ABBREVIATION	
N	Number of samples
MEAN	Mean value of all samples
STD. DEVIATION	Standard deviation of samples
SIG. (2-TAILED)	P-value

PIER B

1B vs. 1A

Group Statistics

	Infrastructural design alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	44,825	1,2086	,3121
	1A	15	48,041	1,3871	,3581
Travel distance	1B	15	545,096	7,9295	2,0474
	1A	15	545,661	8,0359	2,0749
Robustness	1B	15	,06039	,012058	,003113
	1A	15	,05273	,015795	,004078
Safety	1B	15	18,27	4,496	1,161
	1A	15	15,33	3,904	1,008

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Travel time	Equal variances assumed	,588	,450	-6,771	28	,000	-3,2161	,4750	-4,1892	-2,2431
	Equal variances not assumed			-6,771	27,485	,000	-3,2161	,4750	-4,1900	-2,2423
Travel distance	Equal variances assumed	,005	,946	-,194	28	,848	-,5650	2,9149	-6,5360	5,4060
	Equal variances not assumed			-,194	27,995	,848	-,5650	2,9149	-6,5360	5,4060
Robustness	Equal variances assumed	1,815	,189	1,492	28	,147	,007657	,005131	-,002853	,018167
	Equal variances not assumed			1,492	26,180	,148	,007657	,005131	-,002886	,018200
Safety	Equal variances assumed	,066	,799	1,908	28	,067	2,933	1,537	-,216	6,082
	Equal variances not assumed			1,908	27,460	,067	2,933	1,537	-,218	6,085

1B vs. 1C

Group Statistics

	Infrastructural design alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	44,825	1,2086	,3121
	1C	15	47,365	1,2483	,3223
Travel distance	1B	15	545,096	7,9295	2,0474
	1C	15	551,240	6,3881	1,6494
Robustness	1B	15	,06039	,012058	,003113
	1C	15	,02677	,022137	,005716
Safety	1B	15	18,27	4,496	1,161
	1C	15	15,40	3,699	,955

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Travel time	Equal variances assumed	,180	,675	-5,662	28	,000	-2,5403	,4486	-3,4593	-1,6214
	Equal variances not assumed			-5,662	27,971	,000	-2,5403	,4486	-3,4593	-1,6213
Travel distance	Equal variances assumed	1,587	,218	-2,337	28	,027	-6,1443	2,6291	-11,5298	-,7587
	Equal variances not assumed			-2,337	26,786	,027	-6,1443	2,6291	-11,5408	-,7477
Robustness	Equal variances assumed	3,842	,060	5,166	28	,000	,033625	,006509	,020292	,046957
	Equal variances not assumed			5,166	21,635	,000	,033625	,006509	,020113	,047136
Safety	Equal variances assumed	,368	,549	1,907	28	,067	2,867	1,503	-,213	5,946
	Equal variances not assumed			1,907	27,000	,067	2,867	1,503	-,218	5,951

1B vs. 2A

Group Statistics

	Infrastructural design alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	44,825	1,2086	,3121
	2A	15	52,382	1,2384	,3198
Travel distance	1B	15	545,096	7,9295	2,0474
	2A	15	614,027	10,9218	2,8200
Robustness	1B	15	,06039	,012058	,003113
	2A	15	,06847	,015156	,003913
Safety	1B	15	18,27	4,496	1,161
	2A	15	15,20	2,808	,725

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Travel time	Equal variances assumed	,050	,825	-16,915	28	,000	-7,5574	,4468	-8,4726	-6,6422
	Equal variances not assumed			-16,915	27,983	,000	-7,5574	,4468	-8,4726	-6,6422
Travel distance	Equal variances assumed	2,524	,123	-19,780	28	,000	-68,9311	3,4849	-76,0695	-61,7927
	Equal variances not assumed			-19,780	25,550	,000	-68,9311	3,4849	-76,1005	-61,7618
Robustness	Equal variances assumed	,209	,651	-1,615	28	,118	-,008076	,005001	-,018319	,002167
	Equal variances not assumed			-1,615	26,653	,118	-,008076	,005001	-,018343	,002190
Safety	Equal variances assumed	1,796	,191	2,241	28	,033	3,067	1,369	,263	5,870
	Equal variances not assumed			2,241	23,482	,035	3,067	1,369	,239	5,895

1B vs. 2B

Group Statistics

	Infrastructural design alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	44,825	1,2086	,3121
	2B	15	51,407	,7822	,2020
Travel distance	1B	15	545,096	7,9295	2,0474
	2B	15	610,709	8,4999	2,1947
Robustness	1B	15	,06039	,012058	,003113
	2B	15	,07249	,007741	,001999
Safety	1B	15	18,27	4,496	1,161
	2B	15	14,60	2,501	,646

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Travel time	Equal variances assumed	,936	,342	-17,709	28	,000	-6,5824	,3717	-7,3438	-5,8210
	Equal variances not assumed			-17,709	23,977	,000	-6,5824	,3717	-7,3496	-5,8152
Travel distance	Equal variances assumed	,346	,561	-21,861	28	,000	-65,6128	3,0014	-71,7609	-59,4647
	Equal variances not assumed			-21,861	27,866	,000	-65,6128	3,0014	-71,7622	-59,4634
Robustness	Equal variances assumed	,587	,450	-3,270	28	,003	-,012096	,003700	-,019675	-,004518
	Equal variances not assumed			-3,270	23,865	,003	-,012096	,003700	-,019734	-,004458
Safety	Equal variances assumed	2,775	,107	2,760	28	,010	3,667	1,328	,946	6,388
	Equal variances not assumed			2,760	21,911	,011	3,667	1,328	,911	6,422

1B vs. 3A

Group Statistics

	Infrastructural design alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	44,825	1,2086	,3121
	3A	15	53,261	1,0975	,2834
Travel distance	1B	15	545,096	7,9295	2,0474
	3A	15	619,005	9,5560	2,4674
Robustness	1B	15	,06039	,012058	,003113
	3A	15	,07041	,011570	,002987
Safety	1B	15	18,27	4,496	1,161
	3A	15	16,67	4,435	1,145

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Travel time	Equal variances assumed	,029	,865	-20,012	28	,000	-8,4356	,4215	-9,2990	-7,5722
	Equal variances not assumed			-20,012	27,744	,000	-8,4356	,4215	-9,2994	-7,5718
Travel distance	Equal variances assumed	,789	,382	-23,052	28	,000	-73,9093	3,2062	-80,4769	-67,3418
	Equal variances not assumed			-23,052	27,079	,000	-73,9093	3,2062	-80,4870	-67,3317
Robustness	Equal variances assumed	,002	,968	-2,323	28	,028	-,010022	,004315	-,018860	-,001184
	Equal variances not assumed			-2,323	27,952	,028	-,010022	,004315	-,018861	-,001183
Safety	Equal variances assumed	,411	,527	,981	28	,335	1,600	1,630	-1,740	4,940
	Equal variances not assumed			,981	27,995	,335	1,600	1,630	-1,740	4,940

1B vs. 3B

Group Statistics

	Infrastructural design alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	44,825	1,2086	,3121
	3B	15	51,497	1,0752	,2776
Travel distance	1B	15	545,096	7,9295	2,0474
	3B	15	618,113	10,4581	2,7003
Robustness	1B	15	,06039	,012058	,003113
	3B	15	,06490	,007196	,001858
Safety	1B	15	18,27	4,496	1,161
	3B	15	23,27	3,150	,813

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Travel time	Equal variances assumed	,009	,926	-15,975	28	,000	-6,6724	,4177	-7,5280	-5,8168
	Equal variances not assumed			-15,975	27,625	,000	-6,6724	,4177	-7,5285	-5,8163
Travel distance	Equal variances assumed	1,835	,186	-21,547	28	,000	-73,0176	3,3887	-79,9590	-66,0762
	Equal variances not assumed			-21,547	26,098	,000	-73,0176	3,3887	-79,9819	-66,0533
Robustness	Equal variances assumed	1,201	,282	-1,242	28	,224	-,004505	,003626	-,011931	,002922
	Equal variances not assumed			-1,242	22,851	,227	-,004505	,003626	-,012008	,002998
Safety	Equal variances assumed	1,293	,265	-3,528	28	,001	-5,000	1,417	-7,903	-2,097
	Equal variances not assumed			-3,528	25,078	,002	-5,000	1,417	-7,919	-2,081

1B vs. 4A

Group Statistics

	Infrastructural design alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	44,825	1,2086	,3121
	4A	15	53,631	,8477	,2189
Travel distance	1B	15	545,096	7,9295	2,0474
	4A	15	624,077	7,9900	2,0630
Robustness	1B	15	,06039	,012058	,003113
	4A	15	,08607	,014556	,003758
Safety	1B	15	18,27	4,496	1,161
	4A	15	19,33	4,731	1,222

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Travel time	Equal variances assumed	1,020	,321	-23,104	28	,000	-8,8064	,3812	-9,5872	-8,0256
	Equal variances not assumed			-23,104	25,091	,000	-8,8064	,3812	-9,5913	-8,0215
Travel distance	Equal variances assumed	,021	,885	-27,174	28	,000	-78,9809	2,9065	-84,9346	-73,0272
	Equal variances not assumed			-27,174	27,998	,000	-78,9809	2,9065	-84,9347	-73,0272
Robustness	Equal variances assumed	,022	,882	-5,261	28	,000	-,025677	,004880	-,035674	-,015680
	Equal variances not assumed			-5,261	27,063	,000	-,025677	,004880	-,035689	-,015664
Safety	Equal variances assumed	,140	,711	-,633	28	,532	-1,067	1,685	-4,518	2,385
	Equal variances not assumed			-,633	27,927	,532	-1,067	1,685	-4,519	2,385

1B vs. 4B

Group Statistics

	Infrastructural design alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	44,825	1,2086	,3121
	4B	15	50,382	1,2312	,3179
Travel distance	1B	15	545,096	7,9295	2,0474
	4B	15	609,074	11,0838	2,8618
Robustness	1B	15	,06039	,012058	,003113
	4B	15	,08090	,009292	,002399
Safety	1B	15	18,27	4,496	1,161
	4B	15	19,27	4,803	1,240

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Travel time	Equal variances assumed	,023	,880	-12,475	28	,000	-5,5571	,4455	-6,4696	-4,6446
	Equal variances not assumed			-12,475	27,990	,000	-5,5571	,4455	-6,4696	-4,6445
Travel distance	Equal variances assumed	3,263	,082	-18,182	28	,000	-63,9783	3,5188	-71,1862	-56,7704
	Equal variances not assumed			-18,182	25,356	,000	-63,9783	3,5188	-71,2202	-56,7363
Robustness	Equal variances assumed	,121	,731	-5,217	28	,000	-,020506	,003931	-,028557	-,012454
	Equal variances not assumed			-5,217	26,293	,000	-,020506	,003931	-,028581	-,012431
Safety	Equal variances assumed	,478	,495	-,589	28	,561	-1,000	1,699	-4,479	2,479
	Equal variances not assumed			-,589	27,878	,561	-1,000	1,699	-4,480	2,480

1B vs. 5A

Group Statistics

	Infrastructural design alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	44,825	1,2086	,3121
	5A	15	45,400	1,4744	,3807
Travel distance	1B	15	545,096	7,9295	2,0474
	5A	15	546,217	8,0051	2,0669
Robustness	1B	15	,06039	,012058	,003113
	5A	15	,04545	,008334	,002152
Safety	1B	15	18,27	4,496	1,161
	5A	15	17,67	3,086	,797

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Travel time	Equal variances assumed	1,068	,310	-1,169	28	,252	-,5753	,4923	-1,5836	,4331
	Equal variances not assumed			-1,169	26,962	,253	-,5753	,4923	-1,5854	,4348
Travel distance	Equal variances assumed	,001	,977	-,385	28	,703	-1,1213	2,9093	-7,0807	4,8380
	Equal variances not assumed			-,385	27,997	,703	-1,1213	2,9093	-7,0807	4,8381
Robustness	Equal variances assumed	,731	,400	3,947	28	,000	,014938	,003785	,007186	,022690
	Equal variances not assumed			3,947	24,891	,001	,014938	,003785	,007142	,022734
Safety	Equal variances assumed	,927	,344	,426	28	,673	,600	1,408	-2,284	3,484
	Equal variances not assumed			,426	24,797	,674	,600	1,408	-2,301	3,501

1B vs. 5B

Group Statistics

	Infrastructural design alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	44,825	1,2086	,3121
	5B	15	44,578	1,4016	,3619
Travel distance	1B	15	545,096	7,9295	2,0474
	5B	15	546,002	7,9952	2,0643
Robustness	1B	15	,06039	,012058	,003113
	5B	15	,05237	,010806	,002790
Safety	1B	15	18,27	4,496	1,161
	5B	15	20,87	4,068	1,050

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Travel time	Equal variances assumed	,429	,518	,518	28	,609	,2474	,4778	-,7314	1,2262
	Equal variances not assumed			,518	27,407	,609	,2474	,4778	-,7324	1,2272
Travel distance	Equal variances assumed	,000	,994	-,312	28	,758	-,9063	2,9075	-6,8619	5,0494
	Equal variances not assumed			-,312	27,998	,758	-,9063	2,9075	-6,8619	5,0494
Robustness	Equal variances assumed	,001	,981	1,918	28	,065	,008018	,004181	-,000545	,016582
	Equal variances not assumed			1,918	27,670	,065	,008018	,004181	-,000550	,016586
Safety	Equal variances assumed	,013	,911	-1,661	28	,108	-2,600	1,566	-5,807	,607
	Equal variances not assumed			-1,661	27,726	,108	-2,600	1,566	-5,808	,608

1B vs. 5C

Group Statistics

	Infrastructural design alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	44,825	1,2086	,3121
	5C	15	48,169	1,1371	,2936
Travel distance	1B	15	545,096	7,9295	2,0474
	5C	15	555,899	6,9129	1,7849
Robustness	1B	15	,06039	,012058	,003113
	5C	15	,02858	,025232	,006515
Safety	1B	15	18,27	4,496	1,161
	5C	15	17,73	3,150	,813

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Travel time	Equal variances assumed	,039	,845	-7,804	28	,000	-3,3437	,4285	-4,2214	-2,4661
	Equal variances not assumed			-7,804	27,896	,000	-3,3437	,4285	-4,2215	-2,4659
Travel distance	Equal variances assumed	1,043	,316	-3,977	28	,000	-10,8036	2,7162	-16,3675	-5,2397
	Equal variances not assumed			-3,977	27,489	,000	-10,8036	2,7162	-16,3721	-5,2351
Robustness	Equal variances assumed	6,279	,018	4,406	28	,000	,031811	,007221	,017020	,046601
	Equal variances not assumed			4,406	20,077	,000	,031811	,007221	,016753	,046869
Safety	Equal variances assumed	1,104	,302	,376	28	,710	,533	1,417	-2,370	3,437
	Equal variances not assumed			,376	25,078	,710	,533	1,417	-2,385	3,452

PIER CONFIGURATION WITH TWO MAIN ROAD JUNCTIONS

1B vs. 1A

Group Statistics

	alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	30,681	,8100	,2091
	1A	15	34,041	1,3142	,3393
Travel distance	1B	15	406,385	4,4721	1,1547
	1A	15	412,424	29,8003	7,6944
Robustness	1B	15	,10964	,006362	,001643
	1A	15	,15139	,030379	,007844
Safety	1B	15	4,60	1,454	,375
	1A	15	4,20	1,521	,393

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Travel time	Equal variances assumed	4,654	,040	-8,430	28	,000	-3,3604	,3986	-4,1769	-2,5439
	Equal variances not assumed			-8,430	23,294	,000	-3,3604	,3986	-4,1844	-2,5364
Travel distance	Equal variances assumed	2,420	,131	-,776	28	,444	-6,0393	7,7806	-21,9770	9,8985
	Equal variances not assumed			-,776	14,630	,450	-6,0393	7,7806	-22,6597	10,5812
Robustness	Equal variances assumed	9,363	,005	-5,209	28	,000	-,041747	,008014	-,058163	-,025331
	Equal variances not assumed			-5,209	15,226	,000	-,041747	,008014	-,058806	-,024687
Safety	Equal variances assumed	,375	,545	,736	28	,468	,400	,543	-,713	1,513
	Equal variances not assumed			,736	27,943	,468	,400	,543	-,713	1,513

1B vs. 1C

	alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	30,681	,8100	,2091
	1C	15	34,789	,9016	,2328
Travel distance	1B	15	406,385	4,4721	1,1547
	1C	15	429,271	6,1149	1,5789
Robustness	1B	15	,10964	,006362	,001643
	1C	15	,11002	,023042	,005949
Safety	1B	15	4,60	1,454	,375
	1C	15	4,53	1,457	,376

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Travel time	Equal variances assumed	,667	,421	-13,129	28	,000	-4,1085	,3129	-4,7495	-3,4675
	Equal variances not assumed			-13,129	27,685	,000	-4,1085	,3129	-4,7499	-3,4672
Travel distance	Equal variances assumed	2,101	,158	-11,700	28	,000	-22,8859	1,9560	-26,8926	-18,8791
	Equal variances not assumed			-11,700	25,645	,000	-22,8859	1,9560	-26,9093	-18,8625
Robustness	Equal variances assumed	34,883	,000	-,061	28	,952	-,000376	,006172	-,013019	,012267
	Equal variances not assumed			-,061	16,122	,952	-,000376	,006172	-,013452	,012700
Safety	Equal variances assumed	,050	,824	,125	28	,901	,067	,532	-1,022	1,155
	Equal variances not assumed			,125	28,000	,901	,067	,532	-1,022	1,155

1B vs. 2B

Group Statistics

	alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	30,681	,8100	,2091
	2B	15	33,409	,5421	,1400
Travel distance	1B	15	406,385	4,4721	1,1547
	2B	15	444,120	4,4721	1,1547
Robustness	1B	15	,10964	,006362	,001643
	2B	15	1,00000	,000000	,000000
Safety	1B	15	4,60	1,454	,375
	2B	15	4,13	1,407	,363

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Travel time	Equal variances assumed	1,441	,240	-10,839	28	,000	-2,7277	,2517	-3,2432	-2,2122
	Equal variances not assumed			-10,839	24,447	,000	-2,7277	,2517	-3,2466	-2,2088
Travel distance	Equal variances assumed	,000	1,000	-23,108	28	,000	-37,7350	1,6330	-41,0800	-34,3900
	Equal variances not assumed			-23,108	28,000	,000	-37,7350	1,6330	-41,0800	-34,3900
Robustness	Equal variances assumed	38,857	,000	-542,022	28	,000	-,890359	,001643	-,893724	-,886994
	Equal variances not assumed			-542,022	14,000	,000	-,890359	,001643	-,893882	-,886836
Safety	Equal variances assumed	,160	,692	,893	28	,379	,467	,523	-,604	1,537
	Equal variances not assumed			,893	27,970	,379	,467	,523	-,604	1,537

1B vs. 5B

Group Statistics

	alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	30,681	,8100	,2091
	5B	15	30,336	,9204	,2377
Travel distance	1B	15	406,385	4,4721	1,1547
	5B	15	407,300	4,4721	1,1547
Robustness	1B	15	,10964	,006362	,001643
	5B	15	,10295	,007099	,001833
Safety	1B	15	4,60	1,454	,375
	5B	15	7,73	1,944	,502

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Travel time	Equal variances assumed	,747	,395	1,090	28	,285	,3449	,3166	-,3035	,9934
	Equal variances not assumed			1,090	27,555	,285	,3449	,3166	-,3040	,9939
Travel distance	Equal variances assumed	,000	1,000	-,560	28	,580	-,9150	1,6330	-4,2600	2,4300
	Equal variances not assumed			-,560	28,000	,580	-,9150	1,6330	-4,2600	2,4300
Robustness	Equal variances assumed	,009	,925	2,718	28	,011	,006690	,002461	,001648	,011732
	Equal variances not assumed			2,718	27,670	,011	,006690	,002461	,001645	,011734
Safety	Equal variances assumed	1,855	,184	-4,998	28	,000	-3,133	,627	-4,417	-1,849
	Equal variances not assumed			-4,998	25,928	,000	-3,133	,627	-4,422	-1,845

PIER CONFIGURATION WITH TWO MAIN ROAD JUNCTIONS

1B vs. 1A

Group Statistics

	alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	31,571	,7987	,2062
	1A	15	34,914	1,3399	,3460
Travel distance	1B	15	420,042	6,3438	1,6380
	1A	15	416,096	6,2751	1,6202
Robustness	1B	15	,15434	,011902	,003073
	1A	15	,18503	,027434	,007083
Safety	1B	15	4,53	1,807	,467
	1A	15	4,20	1,781	,460

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Travel time	Equal variances assumed	3,239	,083	-8,302	28	,000	-3,3438	,4028	-4,1688	-2,5188
	Equal variances not assumed			-8,302	22,834	,000	-3,3438	,4028	-4,1773	-2,5103
Travel distance	Equal variances assumed	,002	,966	1,713	28	,098	3,9466	2,3039	-,7728	8,6660
	Equal variances not assumed			1,713	27,997	,098	3,9466	2,3039	-,7728	8,6660
Robustness	Equal variances assumed	4,648	,040	-3,974	28	,000	-,030684	,007721	-,046501	-,014868
	Equal variances not assumed			-3,974	19,090	,001	-,030684	,007721	-,046840	-,014528
Safety	Equal variances assumed	,020	,889	,509	28	,615	,333	,655	-1,009	1,675
	Equal variances not assumed			,509	27,994	,615	,333	,655	-1,009	1,675

1B vs. 1C

Group Statistics

	alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	31,571	,7987	,2062
	1C	15	34,995	1,1791	,3044
Travel distance	1B	15	420,042	6,3438	1,6380
	1C	15	425,606	5,8967	1,5225
Robustness	1B	15	,15434	,011902	,003073
	1C	15	,18589	,032887	,008491
Safety	1B	15	4,53	1,807	,467
	1C	15	4,40	,507	,131

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Travel time	Equal variances assumed	2,127	,156	-9,313	28	,000	-3,4244	,3677	-4,1776	-2,6712
	Equal variances not assumed			-9,313	24,613	,000	-3,4244	,3677	-4,1823	-2,6665
Travel distance	Equal variances assumed	,362	,552	-2,488	28	,019	-5,5639	2,2363	-10,1448	-,9831
	Equal variances not assumed			-2,488	27,852	,019	-5,5639	2,2363	-10,1459	-,9820
Robustness	Equal variances assumed	9,885	,004	-3,493	28	,002	-,031546	,009030	-,050044	-,013048
	Equal variances not assumed			-3,493	17,606	,003	-,031546	,009030	-,050549	-,012543
Safety	Equal variances assumed	13,100	,001	,275	28	,785	,133	,485	-,860	1,126
	Equal variances not assumed			,275	16,191	,787	,133	,485	-,893	1,160

1B vs. 2B

Group Statistics

	alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	31,571	,7987	,2062
	2B	15	34,533	,7262	,1875
Travel distance	1B	15	420,042	6,3438	1,6380
	2B	15	475,083	7,0511	1,8206
Robustness	1B	15	,15434	,011902	,003073
	2B	15	1,00000	,000000	,000000
Safety	1B	15	4,53	1,807	,467
	2B	15	4,07	1,438	,371

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Travel time	Equal variances assumed	,000	,996	-10,630	28	,000	-2,9627	,2787	-3,5336	-2,3918
	Equal variances not assumed			-10,630	27,750	,000	-2,9627	,2787	-3,5339	-2,3916
Travel distance	Equal variances assumed	,285	,598	-22,475	28	,000	-55,0402	2,4490	-60,0567	-50,0237
	Equal variances not assumed			-22,475	27,693	,000	-55,0402	2,4490	-60,0592	-50,0212
Robustness	Equal variances assumed	12,597	,001	-275,176	28	,000	-,845656	,003073	-,851951	-,839361
	Equal variances not assumed			-275,176	14,000	,000	-,845656	,003073	-,852248	-,839065
Safety	Equal variances assumed	,758	,391	,783	28	,440	,467	,596	-,755	1,688
	Equal variances not assumed			,783	26,651	,441	,467	,596	-,758	1,691

1B vs. 5B

Group Statistics

	alternative	N	Mean	Std. Deviation	Std. Error Mean
Travel time	1B	15	31,571	,7987	,2062
	5B	15	31,045	,9405	,2428
Travel distance	1B	15	420,042	6,3438	1,6380
	5B	15	420,979	6,3452	1,6383
Robustness	1B	15	,15434	,011902	,003073
	5B	15	,15275	,007665	,001979
Safety	1B	15	4,53	1,807	,467
	5B	15	7,33	2,410	,622

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Travel time	Equal variances assumed	1,223	,278	1,649	28	,110	,5253	,3186	-,1273	1,1779
	Equal variances not assumed			1,649	27,284	,111	,5253	,3186	-,1281	1,1786
Travel distance	Equal variances assumed	,000	,999	-,404	28	,689	-,9369	2,3167	-5,6824	3,8086
	Equal variances not assumed			-,404	28,000	,689	-,9369	2,3167	-5,6824	3,8086
Robustness	Equal variances assumed	,723	,402	,436	28	,666	,001593	,003655	-,005894	,009081
	Equal variances not assumed			,436	23,909	,667	,001593	,003655	-,005953	,009139
Safety	Equal variances assumed	1,446	,239	-3,600	28	,001	-2,800	,778	-4,393	-1,207
	Equal variances not assumed			-3,600	25,962	,001	-2,800	,778	-4,399	-1,201

APPENDIX E: USE OF ROAD SECTIONS

In the pier configuration of pier B four road sections were measured on the average number of cars per hour during the entire simulation run. The mean results of all 15 runs are presented the table.

	TOTAL TRAFFIC [VEH/H]	THIRD CONNECTION TO MAIN ROAD			PASSAGE ROAD THROUGH PIER		
		A TO C [veh/h]	C TO A [veh/h]	Compared to total traffic	A TO C [veh/h]	C TO A [veh/h]	Compared to total traffic
1A	440	23.9	80.9	23.8%	19.8	18.0	8.6%
1B	440	29.9	75.1	22.5%	19.8	20.1	9.1%
1C	440	24.0	70.1	21.4%	19.8	20.3	9.1%
2A	440	1.9	61.8	14.5%	0	61.8	14.0%
2B	440	1.9	56.2	13.2%	0	60.0	13.6%
3A	440	1.9	60.9	14.3%	0	60.3	13.7%
3B	440	1.9	61.6	14.4%	0	61.6	14.0%
4A	440	9.5	58.8	15.5%	0	60.0	13.6%
4B	440	1.9	54.3	12.8%	0	54.6	12.4%
5A	440	23.9	74.7	22.4%	19.2	20.2	9.0%
5B	440	23.9	73.9	22.2%	19.8	20.2	9.1%
5C	440	24.3	63.0	19.8%	20.1	20.4	9.2%

APPENDIX F: INTERVIEWS

Interview with a project manager Airside KLM
30-11-2015 & 6-1-2016

The interview with a project manager Airside of KLM was a semi-formal conversation where I could ask questions to the project manager and a road manager at PMA of the Schiphol Group.

If the traffic situation is clear it becomes safer. With one-way traffic drivers have to make a detour (extra travel time) but that will just take some getting used to a new situation. When applying one-way other changes should also take place (like the relocation of departments).

The technical services take up a lot of parking spaces, it is not clear if all the cars are used. The vehicles of aqua services are spread out around pier E, which makes it difficult to locate the designated car. The traffic intensity of the service roads around the piers will go up when vehicles are not allowed to permanently park their vehicle in the centre locations around pier C, D, and E.

The handling services (water, toilet, tow, cleaning) are handled in blocks of time for each aircraft, these time blocks are planned with a planning system for each handling service.

Future developments:

- The Boeing 747's (half loaders) are taken out of rotation, the Airbus A350 is the replacing aircraft. Which means less dolly's and a little less baggage trains.
- Electric vehicles

To consider:

- Width of the road (6 metres per lane would be better)
- More aircraft movements
- Junctions
- Bring back or create underpasses through the terminal building
- Busses now have doors on the right, maybe consider changing them to the left (or both sides)

High loaders and baggage trains only drive about 5 to 10 km/hour. The busses can drive faster but because of (standing) passengers in the bus, the bus will not overtake the slow drivers.

Pier G has a broad set-up, while the to-be-built pier A will be a tighter fit.

The one-way situation of pier F has been implemented about 15 years ago.

Construction on the road is always communicated to KLM, after which an operational announcement is made to the staff. There is frequent communication between the Schiphol Group and the airlines.

Incidents that happen on the service roads are stand-alone, they will always be solved with the means available, robustness in terms of incidents therefore does not have a great value compared to the other aspects such as travel time.

Location of departments:

- Technical services (vans, nitrogen facilities, tire trucks) on pier D and F
- Baggage facilities on pier B, C, D, E, and F
- Tow services on buffer G (only small and small/medium tows drive on the service roads)
- Aqua services (toilet/water) on pier E
- KLC (busses to KLM cityhopper): pier B

Parking around pier E and F. Parking spots are realised but not used in the way they were meant. Drivers want to park close to their destination. Changing the behaviour of people is also important.

Discipline and rules are important -> (internal) enforcement of the rules

A reduction in the speed is a sore point, travel time is considered very important. A fast handling process is important, time is money.

Almost no negative comments heard about the one-way situation of pier F, only complaints from the high loaders about their longer route.

Pier C and F are considered difficult to drive because of difficult shape of the head of the pier, and the angled entrances to the aircraft stands. Pier D is only difficult when services have to be at both ends of the tuning fork in one run.

A wide-body aircraft needs 1 ramp snake, a transporter, a high loader, and 1 or 2 catering trucks extra compared to a narrow body aircraft. A combination aircraft (freight and passengers) needs 2 high loaders. Smaller aircraft at the south of pier B only need one catering truck.

Self-driving/autonomous vehicles are not to be expected in the near future, electric vehicles can be implemented sooner.

For the coming years the problems with parking facilities has to be tackled, so there is a good base.

Interview with a manager Airside services of KLM

1-12-2015

The interview with a manager Airside services of KLM equipment services took place at their office, after which I got to photograph the ground vehicles.

Around the edge of pier F a lot of large vehicles (towing vehicles) are parked, which take up a lot of space which could be used for traffic. If they parked at buffer G this would create more space at the pier, which would mean more calmness.

Drivers experience more calmness because of the one-way situation around pier F.

There are a lot of wide vehicles, and at pier C and D opposite traffic usually deviates slightly when approaching these large vehicles. Loaders cannot pass each other at certain points.

Around pier E a lot of small carts are located, which makes it more difficult to manoeuvre.

When implementing a new system/situation the most important thing is enforcing the new rules, by giving warnings and sanctions the rules will stick better.

Changes in the fleet: the toilet vehicles will become eco vehicles.

The overtaking lanes on the *Rinse Hofstraweg* are often used.

The lifespan of the vehicles on airside are 5 to 10 years with a lot of maintenance.

The experience for pedestrians is that it is unsafe at certain points towards and on the buffers. Around the piers there are mostly sidewalks.

For safety reasons the vehicles all have a light, which lights up if they are driving the below the maximum speed of the vehicle. It goes out when the vehicle drives faster than the maximum speed of the vehicle. On certain points on the service road network the speed of the vehicles is also measured and shown to the drivers.

Awareness is very important, awareness of the rules and of the traffic situation. At the gates to airside posters and flyers try to create awareness.

Interview with a road manager at the Department PMA of the Schiphol Group

23-05-2015

The interview with Coen van der Zwaag, a road manager at the department PMA, took place at the Schiphol Group office.

Construction is always planned outside the peak hours, in one night or on multiple nights. Detours of the road are only used when there is no other choice. Like the relocation of the main road between pier D and E because of the overhanging. For small infrastructural changes like the design alternatives a detour is not necessary.

Future developments:

- Expansion pier C in the width. The terminal building will be entirely stripped to the skeleton and completely rebuild with overhangings over the service road. The time horizon is 3 to 5 years.
- Pier A will also be built, and is planned to be ready in 2024. Detailing of the roads of the pier are not yet done.

A voorrangsplein will take a few weeks for construction. To make the design more recognisable as a type of roundabout there should be signs on the main road. Otherwise people will not understand.

Concept versions go the engineering agencies that estimate the budget. Plans go to Asset management in the final design phase, or PLUS for larger projects. Before that the plans are send to stakeholders. ADI and PMA are responsible for the preliminary design. CMC leads the execution and inform the stakeholders.

Final completion is done by the responsible road manager.

The departments have the largest influence on the decision making process.

All of the design alternatives can be completed within 6 months. The budget has to be requested and approved before the decision making process can continue. Budgets requests have to handed in a year before hand.

Costs are very dependant on the pier, the soil conditions, underground wiring, underground baggage halls, and underground pipes.

Communicating the counter clockwise to clockwise one-way for pier F will be very tough. The situation has been there the last 10 years. And users find it hard to adjust their behaviour. Therefore early communication is necessary.

When for one-way is implemented the traffic signs are already placed on the sides of roads with covers over them. In one night the covers are removed and the new situation is in effect.

Markings are never applied between November and March because of the weather conditions. The rain and frost damages the markings.