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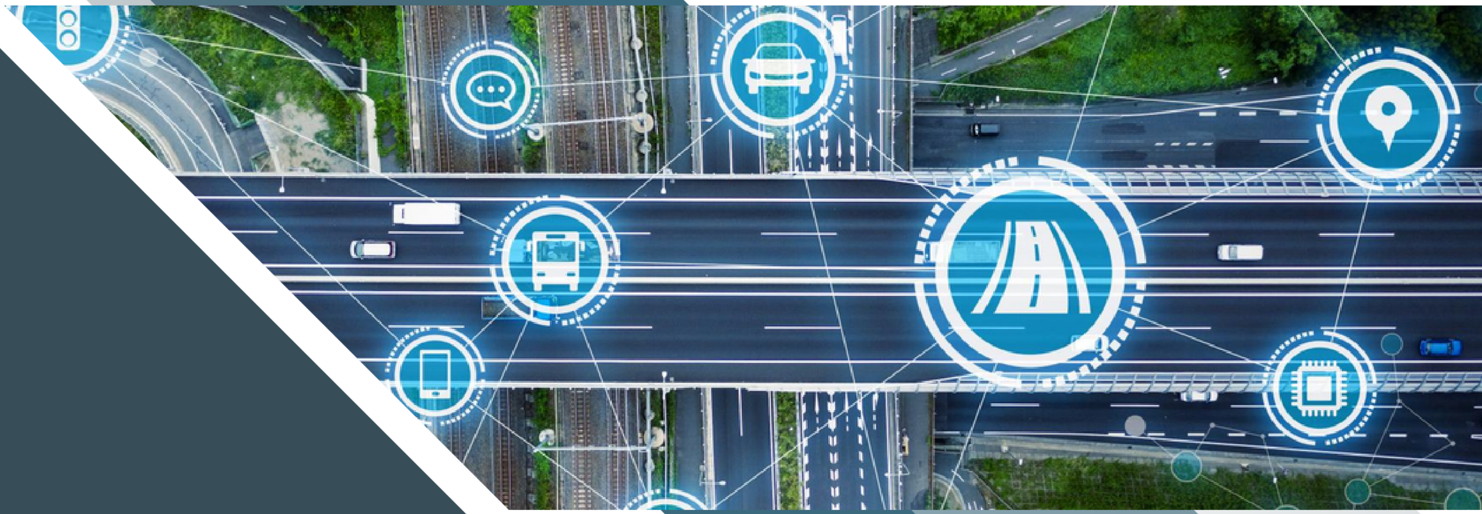
MOBILITY AS A SERVICE AND DYNAMIC TRAFFIC MANAGEMENT: OPTIMIZING THE SYSTEM



HOW TRAFFIC CONGESTION CAN BE REDUCED BY INFLUENCING DRIVER BEHAVIOR

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Mobility as a Service and Dynamic Traffic Management: Optimizing the System

How traffic congestion can be reduced by influencing driver behavior

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Executive Summary

Over the years, the demand for mobility of people has been ever-increasing. The number of people being transported per year and the number of different transport modes have increased. Despite a dip in this duing the Covid-19 pandemic, people are moving more than ever before. Especially in recent years, a new group of transportation modes has emerged; shared mobility in the form of scooters, mopeds and bikes that can be booked through smartphone apps. These services are rapidly growing and some first attempts of integration with public transport hubs can be seen. However, the planning of these multimodal trips is complicated, both in a logistic organization point of view and a user's point of view.

This is where Mobility as a Service (MaaS) comes into play. MaaS is the concept of having most of the available transport modes in one app. This way multimodal trips can be easily planned and paid for by the user. MaaS apps like Gaiyo have been on the rise recently, but are struggling to find their place in the travel planning market next to giants like Google Maps, Waze, and the NS app in the Dutch context. Furthermore, in terms of system interests, MaaS could be used for traffic management purposes. This way, people can be guided to different modalities than the most popular mode of transport: the car. From this, a vision came to life in which MaaS is used in Dynamic Traffic Management (DTM). DTM consists of measures that attempt to influence people's travel behavior according to possible congestion on roads, mostly highways. Examples of this are adapting speed limits, or opening extra lanes, in order to increase the road's capacity temporarily.

This vision of MaaS in DTM is explored during this research. This will attempt to better redistribute trips over multiple transportation modes and with this partially solve traffic congestion. This way, the entire mobility system can be optimized to its best use and to decrease overall travel times. It is necessary to research the feasibility of this vision, in order to know wheter this should be something that should be implemented in cities like Den Bosch. To research this, the study is based on three sub-questions, which together will answer the main research question: 'To what extent does using MaaS as a DTM measure work to reduce car traffic congestion in rush hour at highway junction Empel in Den Bosch?'

The first part of the research is based on literature reviews, in which multiple sources are evaluated to find an initial number of potential traffic volume reductions that can be expected by MaaS use. When combining the results of these multiple sources, an estimated reduction of 4% can be expected.

In the second part of the research, this 4% reduction is verified by creating a model to simulate traffic on a highway junction near Den Bosch called Empel. This model is created in a traffic simulation software called Vissim. These simulations are run for multiple possible reductions of traffic volume, to see when the current traffic congestion can be reduced or even solved. Measuring this congestion is done by measuring travel times. From this, it appears that a reduction of 8% is needed in order to lower average travel times by about 37%. The 4% suggested by the literature only reduces travel times by about 15%.

Finally, the results of the model are verified by experts during several expert interviews. These interviews also serve the purpose of researching whether an 8% reduction in traffic volume is even feasible by using MaaS as a DTM measure. The experts agreed that the results of the model are realistic. However, they also agreed that this 8% reduction suggested by the model, or even the 4% by the literature, is not feasibly achievable by using MaaS in DTM. The experts name multiple reasons for this, but the main issue is the simple fact that people are not easily influenced during their trip. They could be influenced slightly more easily before the trip, but the issue with this in the MaaS context is that they would have to plan every trip they take. This is a mental effort many people are not used to making and are not willing to do. Other factors like financial reasons for both the user and service provider, as well as comfort for the user further limit this feasibility. Some experts said that even a 1% decrease would be complicated to achieve by MaaS use in DTM.

From this, the conclusion can be drawn that MaaS, in its current form, cannot be effectively used as a DTM to reduce car traffic sufficiently in order to reduce traffic jams. However, in traffic management, any reduction of demand can be interesting. Even a decrease of less than 1% could be part of a larger solution to reduce the total car traffic demand. For this 1% to increase, serious changes in the mobility system should be made, in order to better influence people to use alternative modes of transportation.

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1. Introduction

The Netherlands is an exemplary country on the world stage when it comes to multimodal mobility options. The country holds one of the densest highway and train systems in Europe (Eurostat 2020), and options for shared mobility services like shared bikes, mopeds and cars, are evergrowing. Public transport services are regular and relatively on-time compared to its European neighbors (Statista, 2021), and strikes are rare. For this reason, public transport is widely used in the country, as well as other alternatives like biking, walking, or shared mobility services.

However, currently, it seems like this plethora of options coexist past each other. There are many different shared mobility options, all with their own app and payment system, and often these do fit with other services to facilitate multimodal mobility. Another trend is that trips done by car are almost always from door to door, instead of using other modes of transport along the way. However, sometimes a part of these trips have a public transport alternative right next to a car road. Especially when it comes to car traffic on major roads like highways, a scenario can exist where there is a major traffic jam getting passed by a train that is not at full capacity heading in the same direction. This is something that can be improved upon to make mobility more efficient.

This is the issue that this project will research and propose a solution for. This will be done by evaluating the possibility and feasibility of implementing Mobility as a Service (MaaS) in Dynamic Traffic Management (DTM). The theory behind this is that by using MaaS in DTM, MaaS will get a more competitive position in the travel planner market, since it would be possible to adapt travel advice based on congestion in any element of the mobility system. This advantage would increase the use of MaaS, which would encourage more users to use different modes of travel. This can then be variable based on congestion of car roads or full trains, to keep users away from these saturated modes.

This project will research if this idea could work, researching its effects and feasibility. To clearly state the objectives of the study, research questions are established. This consists of the main question, which is the main objective, as well as sub-questions that support the main question. The sub-questions are the questions that the sections of the research will answer. A literature review will answer the first sub-question. The second sub-question will be evaluated by running simulations of a traffic model that will be created. Expert interviews will answer the third sub-question. The questions are presented below:

Main question:

- To what extent does using MaaS as a DTM measure work to reduce car traffic congestion in rush hour at highway junction Empel in Den Bosch?

Sub-questions:

1. How much does MaaS influence the amount of private car trips conducted during peak hours, according to existing literature?
2. How much should car traffic demand be reduced by MaaS to decrease car travel times significantly, according to a traffic modeling simulation?
3. What do experts think about the idea to make MaaS work as a DTM measure to achieve the reduction in car traffic required by the simulations?

These questions will guide the report structure, which is as follows. The report will start by providing context to the problem that the research attempts to solve. This includes a research motivation, as well as a general problem statement. This section will also give dimensions to the research. This is done by presenting the research objectives and the research scope. When this is established, multiple literature reviews will be conducted. The first literature review aims to shape a context for the research. The second literature review is used to answer the first sub-question. This aims to find an indication of how much MaaS can reduce car traffic, which can act as a basis for the model that will be created for simulations. This will be quantified as a percentage, so that it can then be later compared to the results of the simulation, and it can be verified with experts. Lastly, the third literature review will shape a context for the questions that should be asked to the experts.

After the literature reviews, the methodology will be presented. In this, a model is presented which shows the steps that will be taken during the research, as well as their relations to each other. Furthermore, the data collection for the model is presented, and the questions for the expert interviews are listed. Then, the second sub-question can be answered in the section on the simulations. Firstly, the way the model was created is discussed, followed by the issues and limitations that the model faces. Then, the results of the simulations are shown, which are evaluated by answering the second sub-question.

Following the simulations are the expert interviews, which aim to answer the third sub-question. In this section, the experts to be interviewed are presented. Each expert is chosen for their unique view on the topic, which can be used to compare the different views to answer the sub-question in a discussing manner. The results of the interviews are then presented and synthesized into a general discussion. After this, all the sub-questions are answered, which can be used to answer the main question in the conclusion, which in turn is used to make a final recommendation. Lastly, the report will end with a discussion of the limitations that were faced during the research.

2. Problem Context & Research Dimensions

In this first part of the proposal, the context of the research will be presented. This will be done by evaluating the motivation for the research, giving a problem statement, and exploring the research field. Furthermore, a literature review will be conducted to assess the existing theories in the field.

In Figure 2.1 a visualization of the different layers that the mobility system exists upon (Smartwayz.nl, n.d.). It shows that infrastructure is the base of everything, on top of which lay the traffic services. Only with these layers the transportation services can exist, which in turn are needed for mobility services to exist. This visualization is used to show which layer is explored in this research. In this, the top layer of mobility services are researched, since this is where MaaS platforms are. Furthermore, DTM can be considered as a part of the traffic services. Therefore, this research spans across multiple layers.

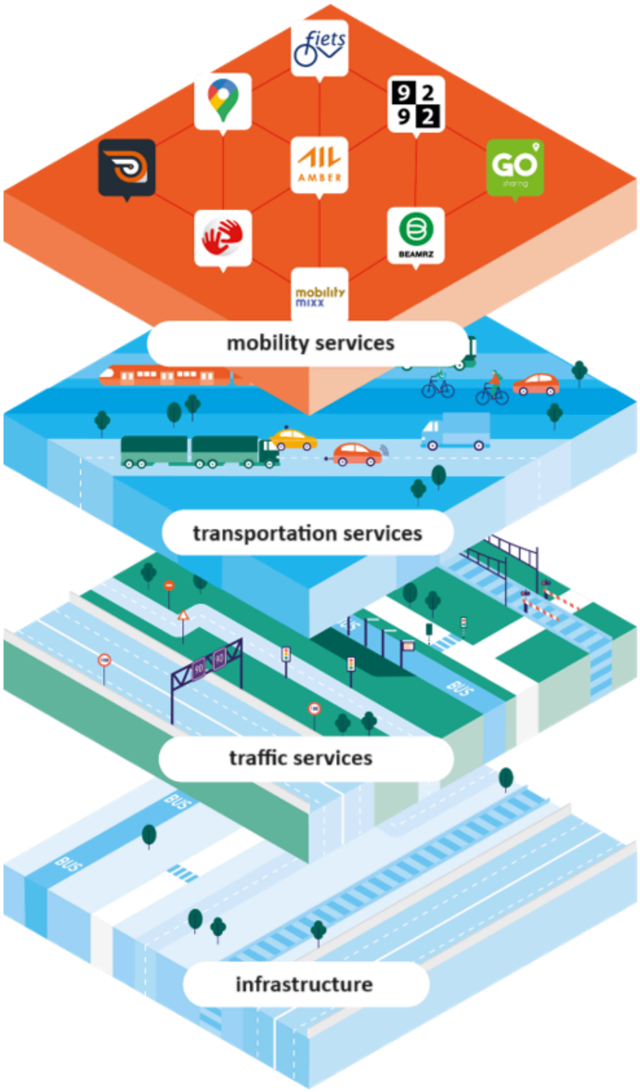

Figure 2.1: Layers of the mobility system

2.1 Research Motivation & Concepts

To explore the motivation for the research, the company of the internship is presented. Keypoint is a consultancy company in the traffic field of civil engineering. They call themselves ‘Experts at the forefront of mobility, technology and data’. This means that the company mainly focuses on combining technology and data to attempt to make mobility more efficient. With this, the company has developed interests in shared mobility, active mobility, public transport, intelligent transportation systems, and digitalization of mobility.

Keypoint started to develop an interest in MaaS. This entails mostly apps that can be used to use (often) shared mobility vehicles like shared scooters, cars, and steps, but also regular public transport. Another factor of MaaS is offering a single payment system for these different services, to make it even easier and efficient to use. Keypoint also has interests in DTM, which are measures for regulating traffic on roads depending on the traffic situation. Specifically, Keypoint has interests in the digital part of this field.

These combined interests have led to the idea of using MaaS as a DTM measure, in order to regulate traffic. This would be done by, depending on traffic conditions, leading people to MaaS alternatives when regular car roads are congested, or ideally before the congestion occurs. This could ultimately decrease traffic congestion and increase the time efficiency of trips and capacity of the number of trips in busy areas like the Randstad, especially during rush hours.

Additionally, for Keypoint as a consultancy company, the research conducted could be valuable for them to use in projects they get involved in. It could become a core part of the solutions they provide and it would give them a unique perspective on traffic management measures.

2.2 Problem Statement

Currently, there are many different modes of transport available on all sorts of levels. Internationally, the car is naturally the most well-known and widely used example. Another major form is public transport, which in the scope of the Netherlands is very well developed in its train network. Recently, alternative modes of transport have come to the Dutch market, in the form of shared mobility. This includes on-demand mobility services like renting e-bikes, scooters, and even cars. With this, public transport can also be made part of the equation. The concept of Mobility as a Service is that these different services are available together in one platform for the user to plan, book, and pay trips with these services. This makes it simpler for the user to use these different modes of transport. Today, these different modes of transport all seem to coexist past each other, instead of complementing each other by ‘communicating’ about demand and supply of each service. This lack of communication leads to situations where, for example, a highway can be full of traffic, with a train that is not at full capacity passing next to it. This makes all modes less efficient, and therefore they are not used to their full potential. Using MaaS as a DTM measure would improve this potential, as the users can be distributed in a better way over different modes of transport. This could be done by giving users a motive to choose a transportation mode that is better for the balance of the system as a whole, instead of what would be directly the fastest way.

From this, it can be found that the problem is inefficiency in the distribution of mobility trips between MaaS and regular car traffic. This is because the different modes of transport do not ‘communicate’ with each other in the sense that there is no optimized way for the user to make a balanced decision between the different modes. There are multiple apps like Google Maps, 9292, and NS reisplanner, but these do not easily summarize all options for the user to make a decision on which mode will be most efficient for the user and the mode of transport that they will take. An app that already does this better than the aforementioned, is Gaiyo, which combines as many modes as possible to give the best itinerary, as well as providing a platform to pay for all different modes in one place. The hypothesis is that these MaaS apps can be used to redistribute trips over multiple modes, in order to reduce traffic congestion.

Another major issue is that MaaS in general is not very popular compared to other traditional travel planning services like Google Maps. Users seem to prefer to stick to services they know rather than adapting to a newer one. The reasons for this are explored in this study, both in the literature review and in the expert interviews.

2.3 Research Objectives

In this research, a simulation will be developed that will show the impact and feasibility of implementing MaaS as a DTM measure. This simulation model will be validated by expert interviews to further discuss the feasibility of the implementation. The main objective of this research is to use these methods to quantify the effects of MaaS as a DTM measure, as well as to research the feasibility of implementation for this. This includes researching the conditions of what should be done for it to work properly. In the end, the research should output results on the effectiveness of using MaaS as a DTM measure, as well as the feasibility of implementing it properly. From this, a decision can be made if it is a realistic use for MaaS.

The research will be a so-called ‘intervention-oriented research’ meaning that it researches how the proposed solution will work, which will highlight the strengths and weaknesses of implementing MaaS in DTM.

2.4 Research Scope

The main objective is to research the feasibility and effectiveness of MaaS and DTM. For this, the main goal should naturally be researched, as well as other effects of implementing the idea. Furthermore, to explore the feasibility, it should be researched what should be done for MaaS to work properly in DTM. This includes researching factors that may influence the user’s choice of MaaS over car transportation and limiting factors for the quality of MaaS to work effectively.

Furthermore, a geographical scope should be applied. The area should be rich in MaaS options, as well as regular car traffic. The area that is chosen is the corridor between Utrecht and Den

Bosch. Both cities are rich in MaaS options, which can be used for the so-called ‘last-mile trips’. They also have a good train connection, which takes about 30 minutes and goes every 10 minutes in the rush hour. By car, the cities’ centers are a 45-minute drive from each other. Both cities have a significant population and many jobs, so it is a prevalent commuter route. This goes both ways, but it should be mentioned that Utrecht is the bigger city of the two. However, for this project’s time scope, modeling this entire corridor would not be feasible, therefore only one intersection will be researched. This will be the intersection close to Den Bosch, called Knooppunt Empel.

What will not be elaborated upon is how this distribution between MaaS and regular car traffic will be done. This is most likely through the development of some apps, but this is not deemed relevant to the imminent goals of Keypoint. Additionally, the development of an app is not exactly civil engineering-related. Furthermore, the target audience of MaaS is underrepresented under elderly groups since it often involves the use of apps and online payments. However, this will not be researched either as this is a factor that will always be present and will not be affected if MaaS is used as a DTM measure. The same goes for price differences between MaaS and regular car use.

The research scope is backed up by literature in section 3.1 of the literature review. In this, a general context of the field of research is created in order to establish current gaps of knowledge and discussions about the topic.

3. Literature Reviews

In this section, the literature review is presented, which leads to a few conclusions on the research dimensions, as well as exploring background knowledge and gaps in said knowledge. Furthermore, a literature review is conducted to research the impact of using MaaS as a DTM measure on car traffic, especially during rush hours. This answers the first research sub-question. Lastly, data is collected for the model, this is presented with the respective sources in the last part of this section.

It should be noted that, since the literature review of this research is heavily based on human behavioral patterns, only estimates can be made. This is because these human behaviors are complex and researching them in detail would not fit in the scope of this research. However, the literature can serve to set a context for the research, as well as give an indication of what possible results could look like. Despite the limitations, this can be done accurately enough to get this approximate indication.

3.1 Literature review Context setting

To specify what exactly should be researched, the current state of the field should be evaluated.

In the article by Ellis (2009), a brief history of mobility management is discussed. It points out that already in the 1990s the first ideas about multimodal alternatives were established in the US. However, this mostly sticks to road travel alternatives like bus shuttles, carpooling, and dial-a-ride services. This shows that the US generally prefers road transport to Europe even in multimodal transportation ideas. From this, a topographic scope should be added to the research. The main idea of the research is to use MaaS to balance mobility over different modes of transportation on different trajectories. In countries like the US, where public transport and sharing mobility are less developed than in the Netherlands, MaaS mostly means other ways of transportation that will still get into that same traffic jam as a car would have. Exceptions to this are large cities with well developed light-rail systems, but even here, the suburbs are often ill-connected in terms of public transport. Therefore, the topographic scope should be applied so that only the Dutch situation is assessed. Specifically, this study will research the situation in Den Bosch.

The second article to be analyzed is ‘Are you Responsible for Traffic Congestion?’ by Ebner et. al. (2019). This article analyzes already existing knowledge about using smart mobility for traffic demand reduction. Mostly, this is done by so-called desk research, where multiple publications about the matter are assessed. The main conclusion drawn from this is that there is still a gap of knowledge in researching how smart mobility users can become valuable actors in relieving traffic. The article suggests that this could be done by designing smart mobility services such that the demands of the users are met so that it becomes a valuable tool for the user to have. This could be done by implementing an app with multiple mobility functionalities in one to facilitate this, since it could show the user that using smart mobility is beneficial in some way.

This can be done by starting a MaaS app which has access to all the different modes, which is exactly what this study researches.

The third article is ‘Collaborative Management of Intermodal Mobility’ by Eryilmaz et. al (2014). This article discusses management options for intermodal mobility. Something worth noting is that this article is from 2014 when the MaaS we know today was a lot less developed, as well as the smartphone and application scene. Even back then there was a call for the organization of intermodal mobility. The article explores a framework where this is more organized by the service providers instead of the users. However, in the end, it is still based on user preferences as only meeting these preferences will lead to a successful result. This find calls for this research to explore what it means for a user to be satisfied and their main demands, as this is crucial for using MaaS as a DTM measure. This can be considered a major knowledge gap in the field.

The next article talks about MaaS and some challenges that can be found on a European level. The article ‘MaaS: Challenges of Implementation and Policies required’ (Li & Voege, 2017) shapes some context in terms of factors that should be taken into account when implementing MaaS. Its main concern is that innovation in the implemented area could stagnate quickly if a few major players monopolize the market. This would put a major brake on the longevity of the project as innovation is key in such a developing part of the mobility market. This is something to consider since public transport in the Netherlands has concessions between multiple different providers, but it is very regulated. A balance should be found between these large established companies and the relatively young shared mobility companies. Furthermore, it mentions the fact that most young people are using MaaS compared to older generations, but this is considered out of this project’s scope.

The final article is ‘Impacts of the Coordination of DTMs with Different Local Control Objectives Considering Their Spatial Layout’ by Guo, 2023. This article highlights what DTM is and its effects. It shows that DTM can be very effective in reducing traffic congestion, but it can also have adverse effects. This is because, when implementing multiple DTM measures, they might get in the way of each other. This can lead to undoing their positive effect, or even backfire negatively. Therefore, the author suggests that when implementing multiple DTM measures, they should be managed so that they do not interfere with each other. This should be taken into account when implementing MaaS as a DTM measure.

3.1.1 Literature Synthesis: Context setting

Now that the literature is presented, they can be synthesized into conclusions about what is already known in the field, as well as creating some parameters for the scope of the research. There has already been quite some knowledge gathered over the years on the topic. In general, since the 90s the idea of multimodal mobility optimization has been researched, first mainly in the US. However, this would work way better in European countries like the Netherlands since the MaaS services here are significantly more developed. Therefore, the research scope should be kept to a Dutch perspective strictly.

Furthermore, studies have shown that there are many factors influencing how MaaS users can become valuable actors in relieving car traffic. This can also be done the other way around, in case of overcrowding of public transport. However, these many factors are very limiting to the success of this idea. This stems from the fact that users will always choose what is most beneficial and efficient for them. Therefore, when creating a solution for this research, the demands of the user should always be met, as otherwise, the system will not work. These demands are mostly financially driven, as well as time efficiency and comfort. This is something to keep in mind for the research as it is of major relevance to the outcomes.

Lastly, some negative consequences can occur when working with MaaS and DTM. Issues like the monopolization of MaaS, as well as the target audience of MaaS being mostly young. These consequences will be present both when implementing MaaS as a DTM measure and when not, so these should not be taken into consideration during the research.

3.2 Literature Review Impact on Car Traffic

This literature review will provide further study into the first sub-question: 'How much does MaaS influence the amount of private car trips conducted during peak hours, according to existing literature?' This is done by going through four articles on the MaaS topic.

The first article to be discussed is by Hoerler et. al. (2020) This article describes the results of a survey conducted in Switzerland. The main results of that survey that are relevant to this research are that 53.9% of the surveyed were open to using MaaS specifically for weekend leisure trips. This goes against only 47.4% being open to MaaS for weekday leisure trips and 38% for commuting. This would be a large reduction, which in theory would solve many issues. However, many more factors must be considered, which will bring this number even lower.

The article further states that MaaS can only work to reduce car traffic when the demands of the users are met. These are the MaaS availability, price, transfer connection time, and the freedom of being independent of service times. These factors should be competitive with the option of taking the car, since otherwise, the user will prefer the car because it is cheaper, faster, or more comfortable. This is also a limiting factor for success since they are only optimal in the current situation. De Viet (2019) states that in the optimal situation, MaaS adoption rates among the researched group can be as high as 50%. However, this is mostly by people already using cars infrequently. It further states that for people to decrease their daily car use, a scenario is required where connections are seamless and mostly free, resulting in an 11% decrease in car traffic. This may sound like a small number, certainly compared to the estimated 38% by Hoerler et. al, however according to Engels and Marijnissen (2018) 'if there would be 10% fewer cars on the roads, congestion would be reduced by 20-50%'.

Furthermore, Hoerler et. al. (2020) state that mostly a younger audience is attracted to using MaaS, as well as people that are more frequently using public transport or other MaaS. This certainly limits the effectiveness of MaaS in reducing car traffic in the study area since the group of targeted people is limited. However, this could mean lower car use in general in the future, when this generation grows older and replaces the older, more car-bound generations. In the end, this will achieve the same goal as this research, which is to reduce traffic congestion. With this reduced traffic congestion, demand might increase again among this now young generation because of latent demand. This is demand of people wanting to use a car, but currently are not because of the traffic congestion. Reducing the congestion therefore might be temporary and induce the same demand as before.

To further support the argument that MaaS leads to less car traffic, Butler et. al. (2020) states that proper MaaS availability and useability are linked to fewer vehicle kilometers traveled, reduced parking demand, and reduced private car ownership. It uses examples of major cities like London, Helsinki, and Tokyo to illustrate this, where public transport and shared mobility make up about 25% of the total trips within the city. A similar effect would be ambitious since these are very large cities compared to Utrecht and Den Bosch, and the trips that are counted are only within the urban area. For this study, an interurban area is studied, so it is assumed that the effects will be less impactful, but it still sets the tone for a reduction in total (private) vehicle kilometers traveled. The article further brings up the idea that adequate MaaS services can reduce second car ownership. Especially in the context of this research, this could be a goal to aim for since this can also be applied to interurban trips like Utrecht - Den Bosch.

Taking this into account, multiple scenarios can be taken into consideration. It would be wise to take the most pessimistic scenario, so that the effects are not overestimated, and the limiting factors are also taken into account. This leads to taking 38% for specifically commuting traffic of the estimated 11% total reduction, leading to an estimated reduction of car use of about 4%. Of course, this is a drastic simplification of the situation, but it gives a good indication of the range of impact of the reduction. These numbers can indicate what should be expected for the later parts of the research.

3.2.1 Literature Synthesis: Answering sub-question 1

With this literature, the first research sub-question can be answered: ‘How much does MaaS influence the amount of private car trips conducted during peak hours, according to existing literature?’. As was mentioned before, for specifically commuter traffic, the willingness to adopt MaaS instead of the car is 38% according to a survey conducted by Hoerler et. al. (2020). This is only in very favorable scenarios, which do not exist for this project’s research area. Therefore this number is considered a vast overestimation. Another study by De Viet (2019), estimates car traffic reduction as an effect of MaaS implementation to be 11% in the ideal scenario, where most services provided by MaaS are free. This is also not the case in the current situation, since nor public transport or shared mobility are fre in the Netherlands. The 11% reduction is only 11% from the 38% of the people willing to use MaaS. Therefore, when multiplying these numbers, a reduction of the total traffic of 4% can be expected. This number is a combination of two vast overestimations, which will be verified with experts later in the research.

However, several reasons make this estimate too high. The literature mentions multiple limiting factors to the effectiveness of MaaS to reduce car traffic. The numbers are based on perfect situations, where the availability of MaaS is very well organized and prices of use are low or even free. Besides price and availability, the seamlessness of connections between multiple services, as well as giving up the freedom that comes with car use are limiting factors. Furthermore, other variables play a role in MaaS effectiveness, for example, older people are less willing to adapt to newer services like shared mobility, and overall previous experiences with MaaS can improve the willingness to give up the car. Additionally, De Vries (2022) describes the factors that decide the success of alternative mobility options depend on accessibility, availability, affordability, understandability, and useability. These factors often need to be more well-established compared to private cars, which can also cause limitations for the success of MaaS. Based on these limiting factors, 4% is the absolute maximum possible decrease in car use, so a range of 2-4% is taken to answer the sub-question numerically, depending on the aforementioned factors. These factors will be verified by experts later in the research.

Furthermore, using MaaS as a DTM measure is supposed to facilitate the accessibility of MaaS when planning a trip for the user. Butler et. al. (2020) states that when MaaS becomes more easily usable and available, it can be directly linked to fewer vehicle kilometers traveled, as well as a decrease in parking demand and private car ownership. This is overall a positive effect of MaaS' correlation to reducing car traffic since this means (private) car use decreases. Even if this directly would only have a small effect, the article also mentions that a significant reduction in second car ownership can be expected. This is a positive result for the first sub-question since it helps to achieve the goal of reducing car traffic overall.

3.3 Literature Review Feasibility

The last literature review that needs to be conducted is for feasibility. This will provide a background for the expert interviews to base the questions on, combined with the results of the model. These expert interviews will then be used to answer the third sub-question: 'What do experts think about the idea to make MaaS work as a DTM measure to achieve the reduction in car traffic required by the simulations' The articles that will be evaluated all aim to research the challenges MaaS faces when it comes to being used by a larger audience. These articles are Li & Voege (2017), Butler et. al. (2021), and Storme et. al. (2020).

What the articles have in common is that they all see MaaS not as a replacement for cars, but as another option next to it. Specifically, Storme et. al. (2020) mention that MaaS can be used more frequently by commuters, mostly between large cities, but not necessarily for leisure trips. This is because transporting goods like bags or suitcases, public transport, and shared mobility options are simply less convenient than a car. Furthermore, leisure trips are only sometimes to well-connected areas, which is where the availability of services offered by MaaS still needs to be developed more. The reason that MaaS is more popular for commutes is because commutes follow a certain schedule. The user can take the same train every day and does not need an extra navigation system to know the way, as well as remember the timing of said train to get the best possible connection. However, since this becomes a habit, users will stop using MaaS if the advice is the same each day. This is why this argument of routine also works against MaaS, since one of the main reasons for MaaS to be lacking in its growth is because people are used to their routine, where the liberty and convenience of a car are a major factor.

Furthermore, Li & Voege (2017) and Butler et. al. (2021) mention that not only the demand has several limiting factors, but the supply side of MaaS also experiences some issues. For MaaS to work properly, multiple criteria should be met. Firstly, the area should have an adequate public transport system. This is necessary as public transport services act as the main intercity alternative to cars. Especially for the corridor between Utrecht and Den Bosch, which has a direct train connection. This in itself is only valuable if the train stations are then well connected to other parts of the city, either by public transport or other shared vehicles like bikes and mopeds. Furthermore, the public transport service should be able to be paid through e-tickets for the payment to be done through the platform, either for single trips or subscriptions. Next to proper public transport availability, there should also be an adequate amount of vehicle-sharing facilities like shared scooters and sharedbikes, which also should be able to be paid for online. Both the public transport parties and the vehicle-sharing parties should be willing to open their data to a third-party application that would host the MaaS platform in order for the platform to offer their services. Additionally, the MaaS platform will want to take a cut of the revenue. This is where most projects come to a dead end since the multiple stakeholders do not want to cooperate, which is often motivated by a difference in their visions. However, in the Netherlands, the MaaS apps largely have access to data from mobility service providers. This may change in the future, but currently, it is well-established. Additionally, people generally do not like to change their habits for something new, which is why MaaS mostly fails to appeal to older generations, but also regular car users and public transport users.

In addition, Li & Voege (2017) also mention a concern that currently there is a competitive market between different MaaS platforms, which manages to keep the prices relatively low. However, when MaaS becomes more widely used, even in an international context, the market may get monopolized by only a few major players. This could stagnate further innovation and increase the prices for the users. However, in the event of growth of MaaS use, more companies may pop up, further diversifying the market.

Lastly, the works of literature evaluated earlier also hold a general narrative that MaaS only works when it tends to the wishes and needs of the user. This is because the user will always choose the option that is most cost and time-efficient for them, or other factors like comfort or climate impact. This makes it more difficult to guide users to choose the option that is most optimal for the system as a whole. This is a major constraint for MaaS to work as a DTM to reduce car traffic since car traffic would be best reduced if the user would choose the option that is most optimal for the system.

From this literature review, a context is set for the expert interviews. With this, questions will be created which will aim to look for solutions for the limitations and problems that MaaS faces which were found in the literature. This will be elaborated upon in section 6.

4. Methodology

The methodology of this project can be divided into three categories, each answering one sub-question of the main research question. To give an illustration, a model is provided in Figure 4.1.

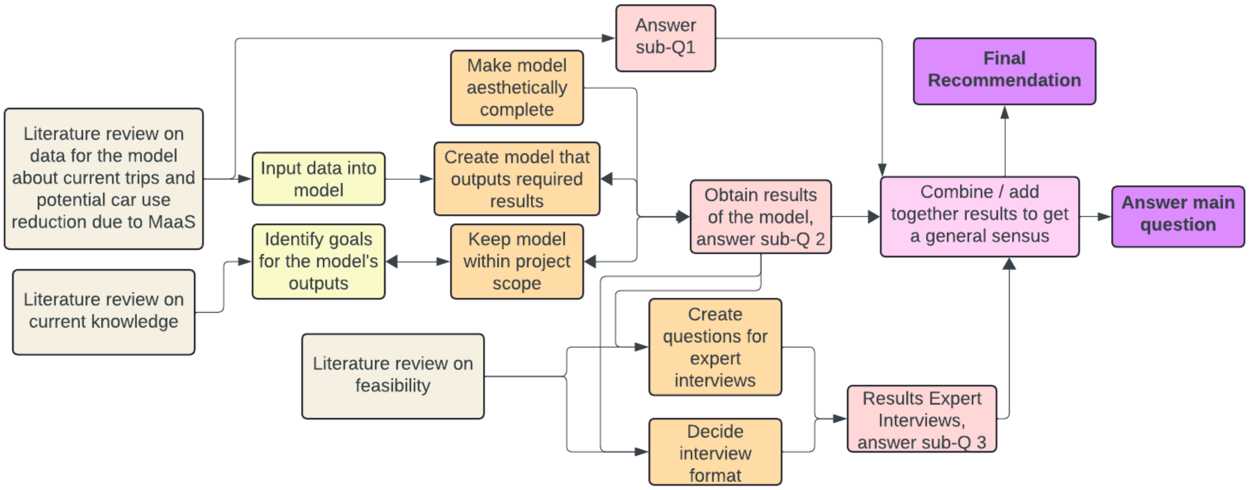

Figure 4.1: Research Model

Firstly, the research starts with multiple literature reviews. These consist of the literature review on the current knowledge, which was conducted in this report. This literature is used to identify the goals and scope of the project, which was evaluated in section 3.1 of this report. This will later be used to keep the simulation model within the project's scope. Furthermore, inputs for Vissim should be gathered, which is done through NDW and Tomtom Move, which will be further explained in section 4.1. With this another literature review is conducted. This literature researches the effects of MaaS use on car traffic reduction, as presented in section 3.2. This is used to answer sub-question 1. Lastly, the literature review on feasibility evaluates current knowledge on the feasibility of MaaS as a DTM, which will generate questions and decide the format for the expert interviews. This will be done together with the results of the model, which can be validated through expert interviews as well.

Following the literature reviews is the modeling and simulation in Vissim. In this part, a model is created of Knooppunt Empel, a highway intersection near Den Bosch between the A59 and the A2. This model will be used to simulate traffic at the intersection. First, this will be done with the current situation data provided by NDW and Tomtom Move. Then, the possible reduction in car traffic as an effect of using MaaS as a DTM measure is put into the model by reducing the car traffic volume. This will be done in a trial-and-error manner, to find the exact reduction in traffic volume needed for the traffic jams to be reduced. This way, the effects of car traffic reduction can be shown quantitatively, and the expected reduction by MaaS can be compared to the actual needed reduction. The exact details of the model building and the results of the simulation are presented in section 5. Furthermore, the model is checked at all times to make sure that it stays within the project's scope. It also should be aesthetically complete, as it has to be presentable to a broad audience. The results of the model together with these factors will answer the second sub-question of the research questions.

Then, several expert interviews will be conducted. This will have two purposes; to validate the simulation results and to fill the knowledge gaps explored during the literature review on feasibility. The validation of the model is required since it only considers the optimal scenario, and it misses out on several key factors influencing the traffic flow in the area. The results can thus be checked with the experts to see if they are realistic.

To explore the feasibility of using MaaS in DTM, the experts will be challenged with questions based on the gaps of knowledge that were found in the literature review, as well as some more direct questions on what is necessary to make MaaS work effectively as a DTM measure. This will be done in a semi-open structure, where some questions are prepared beforehand, but there is room for a discussion. The results of these expert interviews will be used to answer the third sub-question of the research.

Finally, the results of the conducted research and the answers to the sub-questions will be used to answer the main research question. This will be done by first synthesizing the results into one, which can then be used to answer the main question both quantitatively and qualitatively. Next to this, a final recommendation is made for further research.

4.1 Data Collection

The data collection is a crucial part of the project since it determines the accuracy of the model. For this, a highly credible source should be used. This will be NDW Dexter.

NDW Dexter will provide data on the volume and speed of traffic at certain points. It does this by using the many detection loops in the Dutch highways. This can be done for any scope of time, as accurately as intervals of 1 minute. However, the issue with taking such a small interval is that anomalies of the data will be overrepresented in the model. Therefore, a larger interval of 5 minutes is taken. This data will be used to know the total inputs required to model into Vissim. An overall view as well as a zoom-in in the NDW Dexter map can be seen in the figure below.

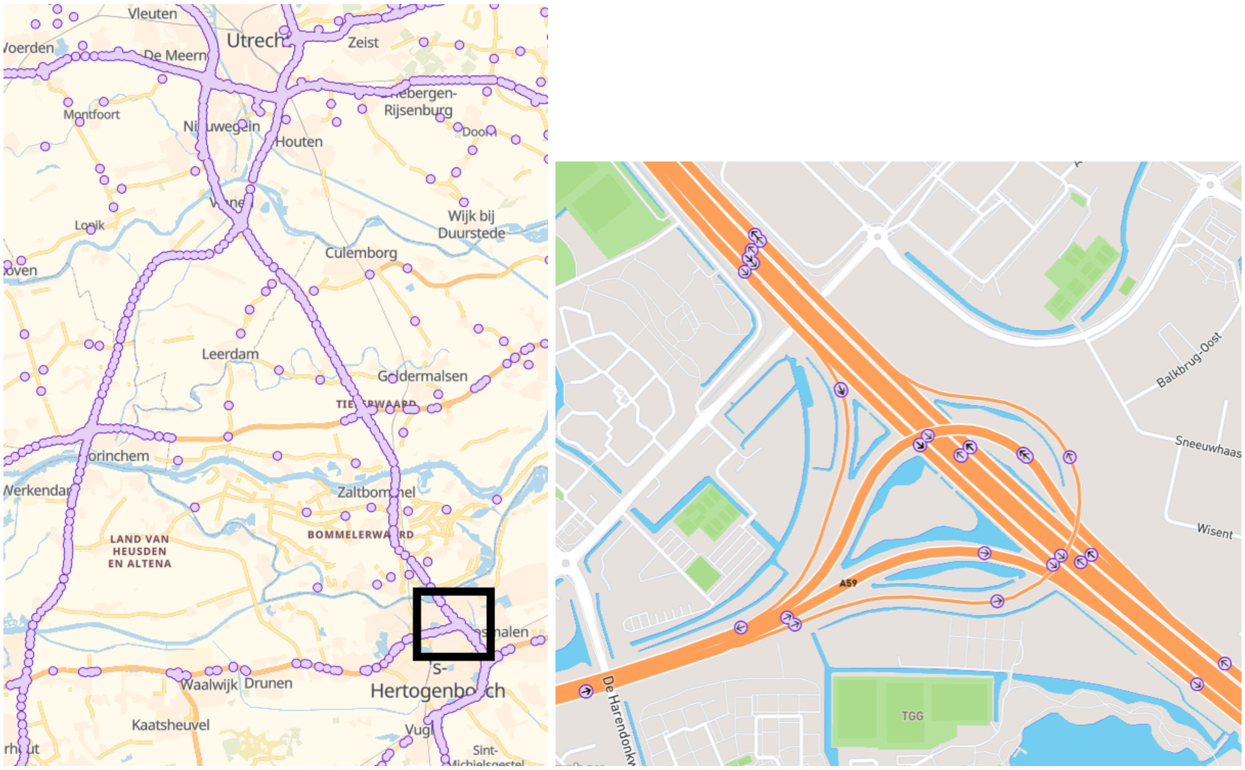

Figure 4.2: NDW Dexter data points

The loops measure traffic volumes at all times. To get an accurate representation of traffic during rush hour, a fitting timespan should be chosen. This should be during peak hours on the busiest days of the week. Generally in the Netherlands, this is on Tuesdays and Thursdays between 6:00 and 10:00. The evening rush hour is also very busy, but usually more spread out, therefore only the morning rush hour will be taken into account. To make sure that the chosen days on which the data is collected are not heavily influenced by outside factors like weather, the morning rush hour of 4 Tuesdays and Thursdays are collected. This should be done in a period where no major construction works were conducted, as this would influence the traffic. This was verified by using another database of the NDW, called Melvin. This showed that during the period of the 14th until the 17th week of 2024, there were no major construction works. There were also no national holidays during the working days in these weeks, which would also have influenced the results. Therefore, the times of the data collection are the 2nd, 4th, 9th, 11th, 16th, 18th, 23rd, and 25th of April 2024, between 6:00 and 10:00. The location of the selected data points can be seen highlighted in dark purple in Figure 4.3.

Figure 4.3: Selected data points

In addition to the data acquired by NDW, more specific data should be found to input the route choice accurately into the Vissim model. For this, data from Tomtom Move is used. This is data based on so-called selected links that show the routes that traffic takes along the selected road segment. See Figure 4.4, in which a selected link can for the Empel junction. This shows the percentages of each route that feeds into the link in order to determine the ratios between the different routes.

The data will give percentages of the number of traffic taking each route of the intersection. To get this data, four selected links are chosen; two north of the intersection on the Maasbrug A2 in both directions and two on the A59, between the intersection and exit 47 in both directions. These percentages will then be taken and inputted directly into the vehicle routes tab of Vissim. However, there is a drawback to using this software, since it only gathers data from users with a Tomtom device. Nowadays, this number is quite low, since mobile apps like Google Maps have taken over the market. Still, only having a subset of the total number of cars at the intersection is already to get a general sense of the directions that they are taking.

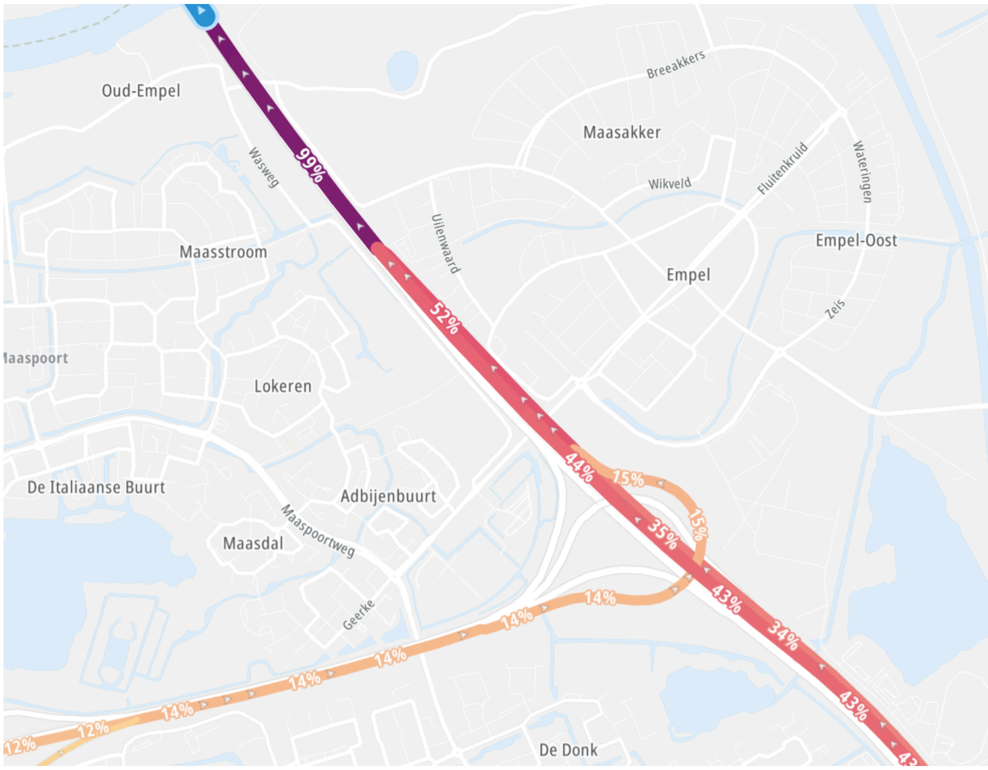

Figure 4.4: Selected link

4.2 Creating the Model

To conduct a simulation, a model needed to be created first. Creating the model was done using the satellite view overlay in Vissim. With this, the model could be created with significant accuracy. The model is shown in full and zoomed in in Figures 4.5 and 4.6 below. Figure 4.6 contains the numbers of each direction, which are named in Table 4.1 below.

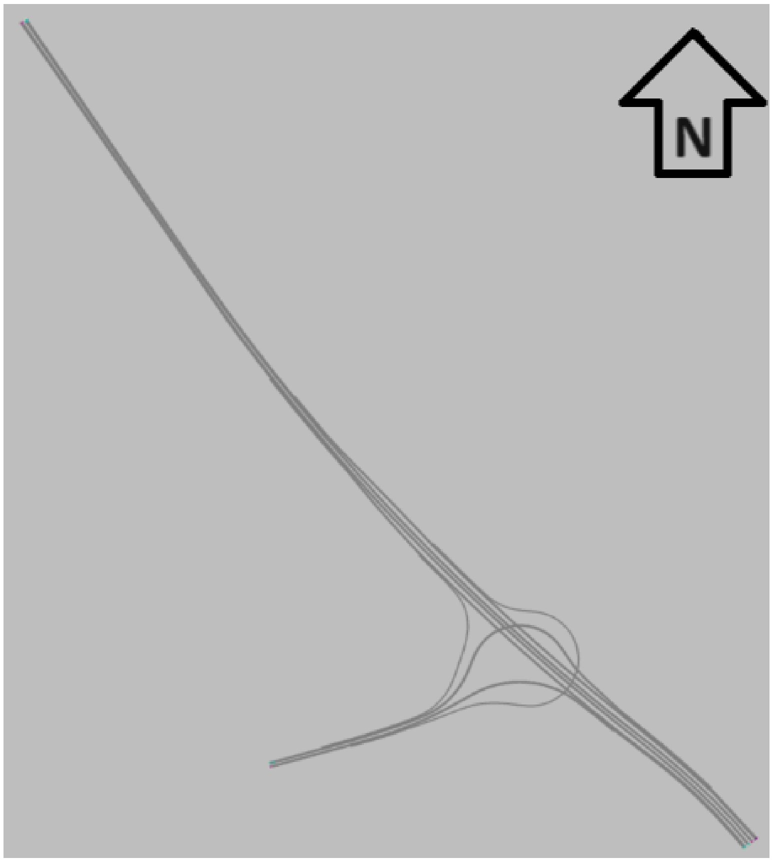

Figure 4.5: Vissim model full view

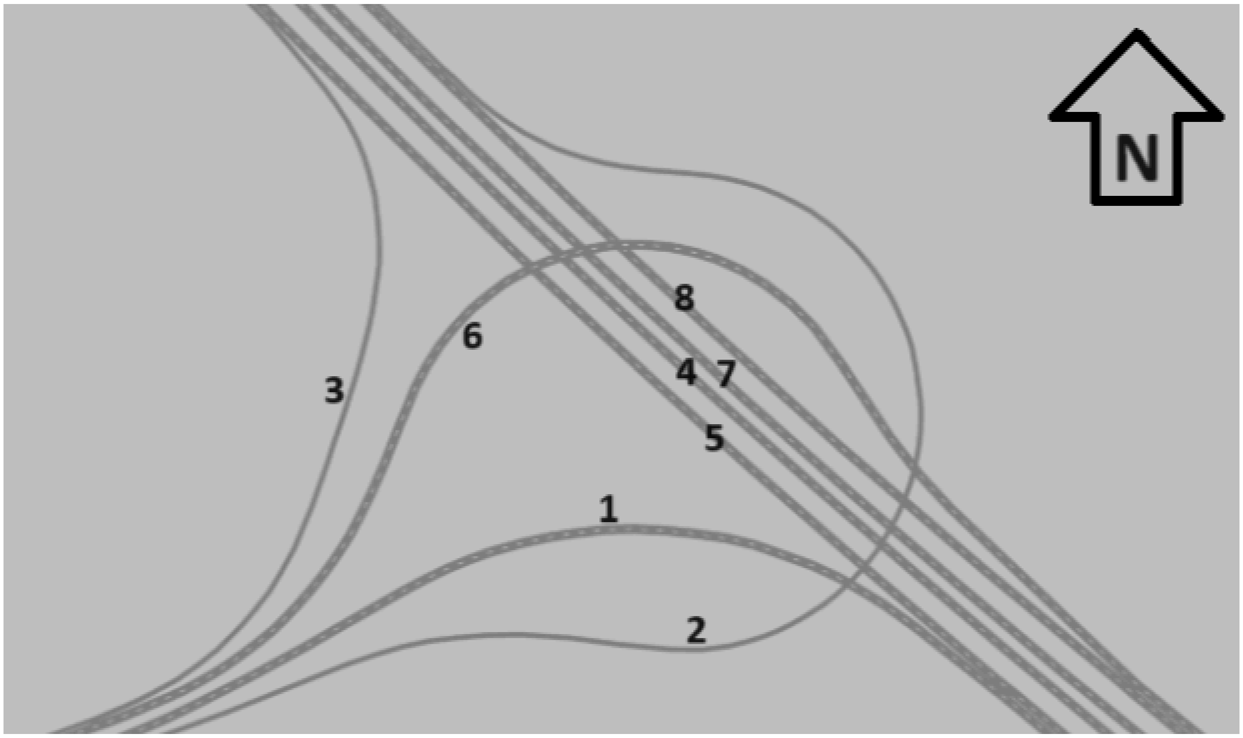

Figure 4.6: Vissim Model zoomed in

The model uses inputs taken from NDW Dexter and outputs this as car traffic onto the model. The inputs taken are at the start nodes of the model on the A59 in the eastern direction, on the A2 in the southern direction, and on the A2 in the northern direction, for both the main road and the parallel roads separately. The traffic volumes from NDW are provided per lane, which is a level of detail that cannot be modeled into Vissim, therefore the volumes are combined into one single volume per road. Furthermore, the data is provided in timesteps of 5 minutes, for each Tuesday and Thursday of April 2024, as discussed before in section 4.1. The data for each day is combined into an average for each timestep, which is then inputted into Vissim in said timesteps. These calculations are conducted in Excel, since this is where the data from NDW is exported.

Each possible route has a measurement point at its start and end nodes, to measure the travel times of each vehicle. Travel times are necessary to measure since these will show the difference in delays between the current situation and the situation where traffic is possibly decreased by using MaaS as a DTM measure. Each route is named based on its origin and destination, which can be seen in Table 4.1, together with travel times in free flow conditions, which was obtained by running the model with low vehicle volumes:

Table 4.1: Names of routes with free-flow travel times

Name of route	**Average travel time (s)**
1: West to South	73
2: West to North	172
3: North to West	141
4: North to South through main road	142
5: North to South through parallel road	142
6: South to West	93
7: South to North through main road	142
8: South to North through parallel road	142

The share of vehicles taking each route also determines each possible route. This is done using the data from Tomtom Move, which yields percentages per route option. These are directly inputted into Vissim to create a situation similar to the real-life one.

4.3 Interview Questions

To answer the third sub-question; ‘What do experts think about the idea to make MaaS work as a DTM measure to achieve the reduction in car traffic required by the simulations’, expert interviews will be conducted. In this, experts will be challenged with questions in a semi-open interview structure, with space for free conversation, but it is guided along a few main questions. This is because the interviews are all meant to ask the same questions from different perspectives. These different perspectives are achieved by interviewing experts from various positions. The experts are all Dutch, therefore the interviews will be conducted in Dutch.

The general questions that will be asked to the experts are the following:

- How is MaaS currently used, and by whom?
- What are the factors limiting MaaS to work as a DTM measure?
- What are the factors limiting the growth of MaaS in itself to become a more widely used platform?
- What could be done in the future to further improve the use of MaaS for it to work as a DTM measure?
- What is a realistic reduction of traffic that can be caused by the use of MaaS in DTM?
- How much does this reduction affect traffic jams, and is this in line with the results of the simulation?

To get the desired answers from the experts, the goal of each question should be established. Before each interview there will be some time to get to know each other, and some questions on the field that the expert is in. This, together with the first question, aims to develop an idea of how developed the market around MaaS is, and set the tone for the rest of the interview based on the expert’s view on the matter. When this is properly explored, the second question will be asked. This question aims to directly answer the part of the third research sub-question. This will show what the limitations currently are for MaaS to work as a DTM, as well as how feasible it is to implement this. This question is of major importance to the overall research. Therefore, it will be elaborated upon in detail to be able to properly explore the different views on this per expert.

5. Simulation & Results

In this section, the simulation conducted in Vissim will be presented, and its results will be shown. The simulation is run on a model of a highway intersection near Den Bosch, called Knooppunt Empel. Here, the A59 and the A2 intersect, with the A2 being the main road for cars to use in the Den Bosch - Utrecht corridor. Together with Knooppunt Everdingen, near Vianen, this intersection is one of the most important ones in the corridor. However, this intersection often sees traffic jams occurring. This makes this intersection a good example for this research since decreasing car traffic here could potentially reduce these traffic jams.

5.1 Results of the Simulation

With the abovementioned factors taken into account, the simulation could be run to obtain the results of travel times during the simulation. As mentioned before, the simulation was first run based on the data from NDW Dexter. Then, simulations were conducted with multiple reductions of traffic, being 2%, 4%, 6%, 8%, and 10% respectively. These reduction percentages were chosen based on trial-and-error. By this, it was found that significant decreases in travel time can be found per traffic volume reduction of 2%. Simulating more than a 10% decrease was deemed unrealistic, since the literature suggested a traffic reduction maximum of 4%. Already, a 10% decrease is far-fetched. Each simulation was run 10 times, which provided average travel times per direction and traffic reduction of these 10 runs. What was immediately observed is that congestion only occurred on traffic coming from the North. This concerns the routes North to West, North to South (main road), and North to South (parallel road). Therefore, only these three routes' results are visualized in Figures 5.1 to 5.3. Visualizations of the other directions can be found in Appendix A.

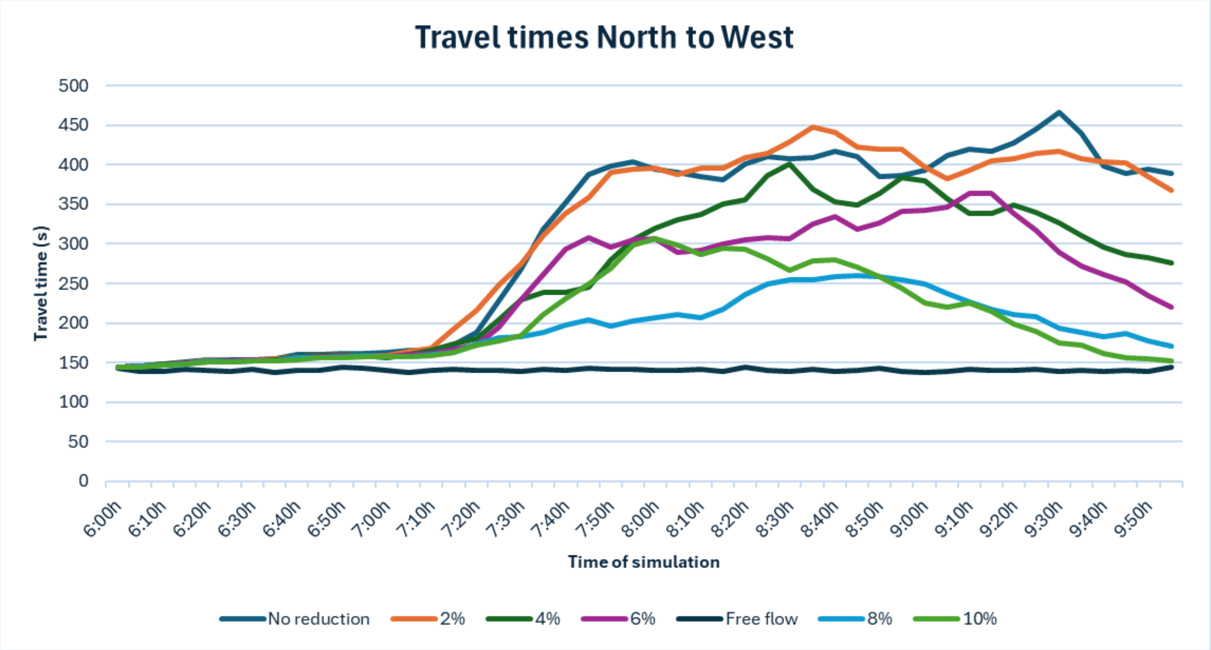

Figure 5.1: Average travel times North to West

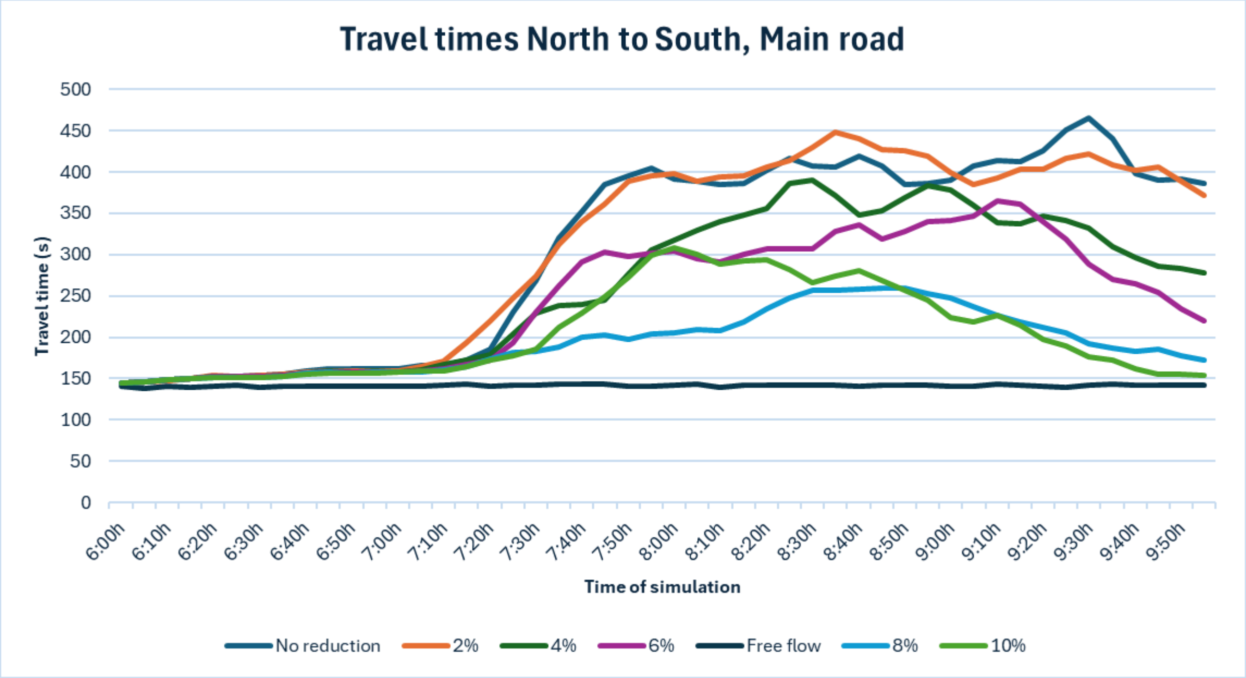

Figure 5.2: Average travel times North to South, through main road

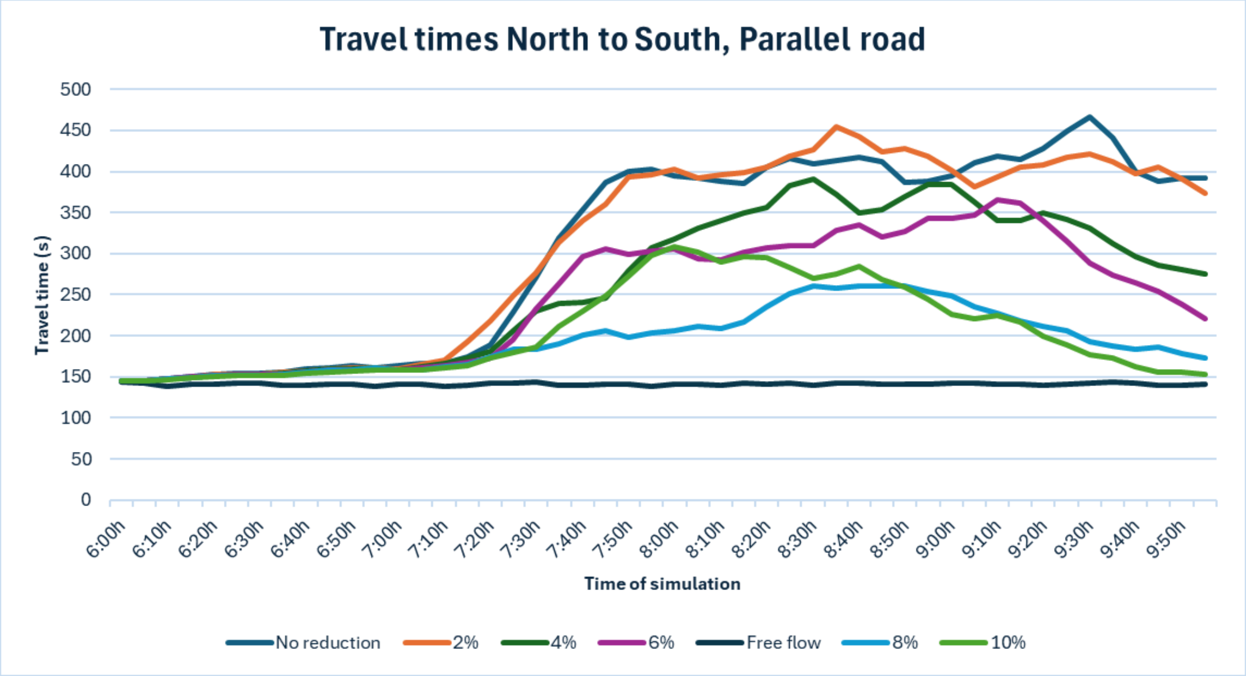

Figure 5.3: Average travel times North to South, through parallel road

Firstly, it should be mentioned that according to the literature, a reduction of 4% could be expected due to the implementation of MaaS as a DTM. This 4% already showed a decrease, although its peaks were still close to those of no reduction. The main reduction for the 4% decrease is the fact that the peak is shorter and travel times start rising later than the ones of no reduction. At a reduction of 8% significant reductions in congestion can be found throughout the whole timespan of the simulation. This is twice as much as the 4% suggested literature, but it is not a surprising result. This is because this 4% was only to give an idea of the range of impact that MaaS could have on traffic reduction. Only for 8% and 10% the congestion is finished at 10:00h, whereas the congestion is still in place at the end of the simulation for other reductions. Whether this reduction of 8% is feasible will be discussed with the experts during the interviews. Still, at 8 percent the traffic congestion cannot be said to be 'resolved', but it is already a significant decrease in travel time compared to the initial travel times with no reduction, especially between 7:30h and 10:00h.

In terms of total travel time saved of all vehicles, it can be seen that especially traffic from the North a lot of time was saved. Already at a 4% reduction of traffic, about 800 hours of total travel time were saved for all vehicles between 6:00h and 10:00h. At an 8% reduction a total travel time saving of 2000 hours is observed. For trips originating from the West and the South, total travel time reductions were less significant, since these directions are less congested in the current situation. Furthermore, it can be seen that average speeds also increase significantly for routes originating from the North. For this, routes in the current situation have average speeds of 45 to 50 km/h, with an 8% reduction this increases to 70 to 80 km/h. This significantly decreases the emissions from cars, as can be seen in Figure 5.4.

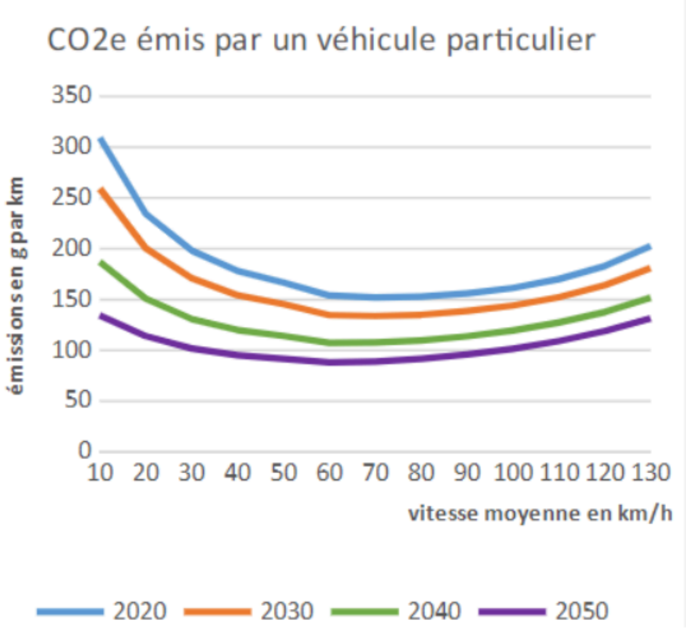

Figure 5.4: CO2 emissions per average speed (Cerema, 2021)

As can be seen, the most fuel efficient speeds are around 70 to 80 km/h. Therefore, this reduction in traffic will significantly reduce CO2 emissions. Additionally, the average speeds also include times where cars drive slower or even idle in the congestion, which is tied to even higher emissions. This thus further reduces CO2 emissions, on top of the 8% of trips that could no longer be conducted by car but by other services provided by MaaS, which, according to Gaiyo is 95% carbon neutral.

Furthermore, what can be seen from the model is that even in the current situation the travel time does not increase significantly until 7:00h, which indicates free flow for this period. The travel times do slightly increase during this period, to about 30 seconds more than the actual free flow times on average. However, after 7:00h, more traffic gets into the model, and the first congestions occur. In general, these congestions are less extreme for larger traffic reductions. However, sometimes lines overlap, which for example indicates the 10% reduction having greater travel times than the 8% reduction. Intuitively this makes little sense, but it can be explained by the fact that the standard deviations of the average travel times severely increase in accordance with the travel times. This is visualized in Figures 5.5 to 5.7 below.

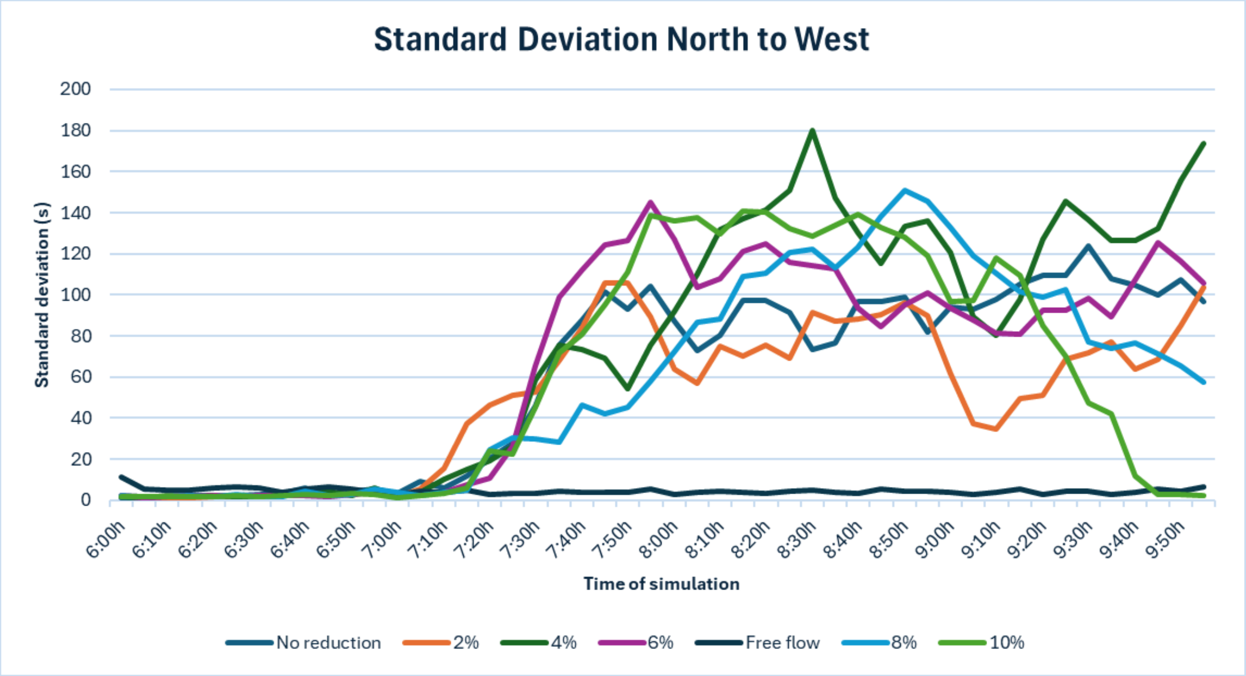

Figure 5.5: Standard deviations per traffic reduction over time on route North to West

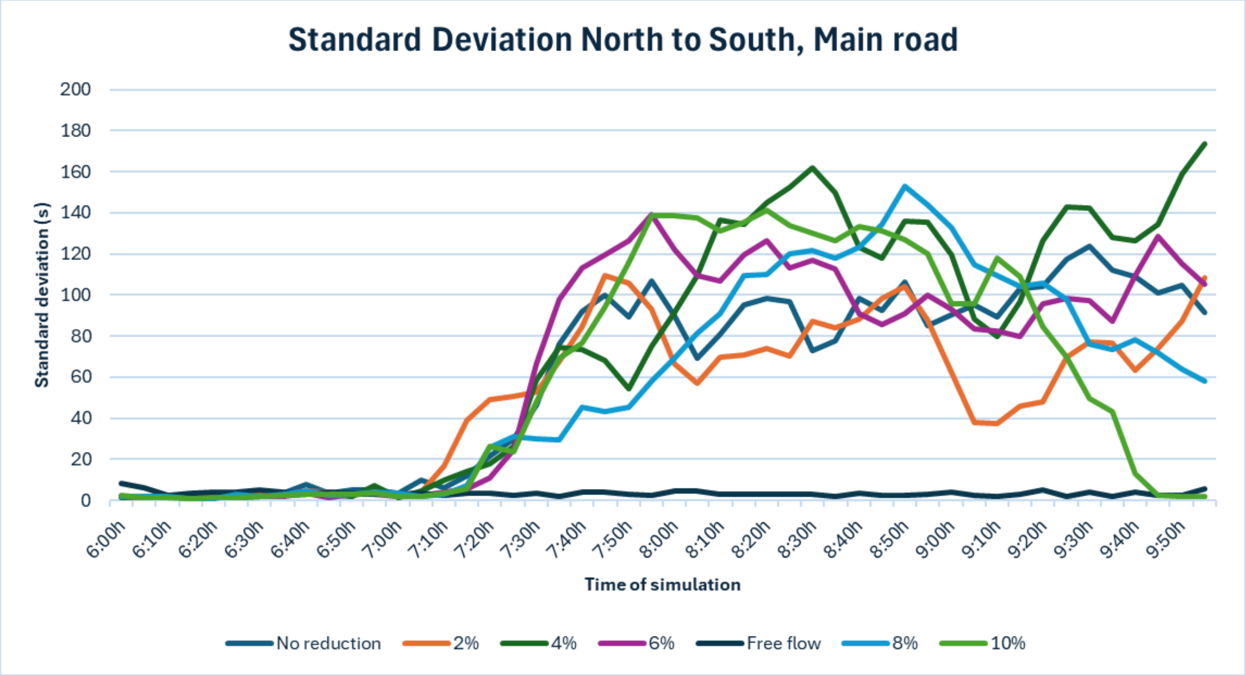

Figure 5.6: Standard deviations per traffic reduction over time on route North to South, Main road

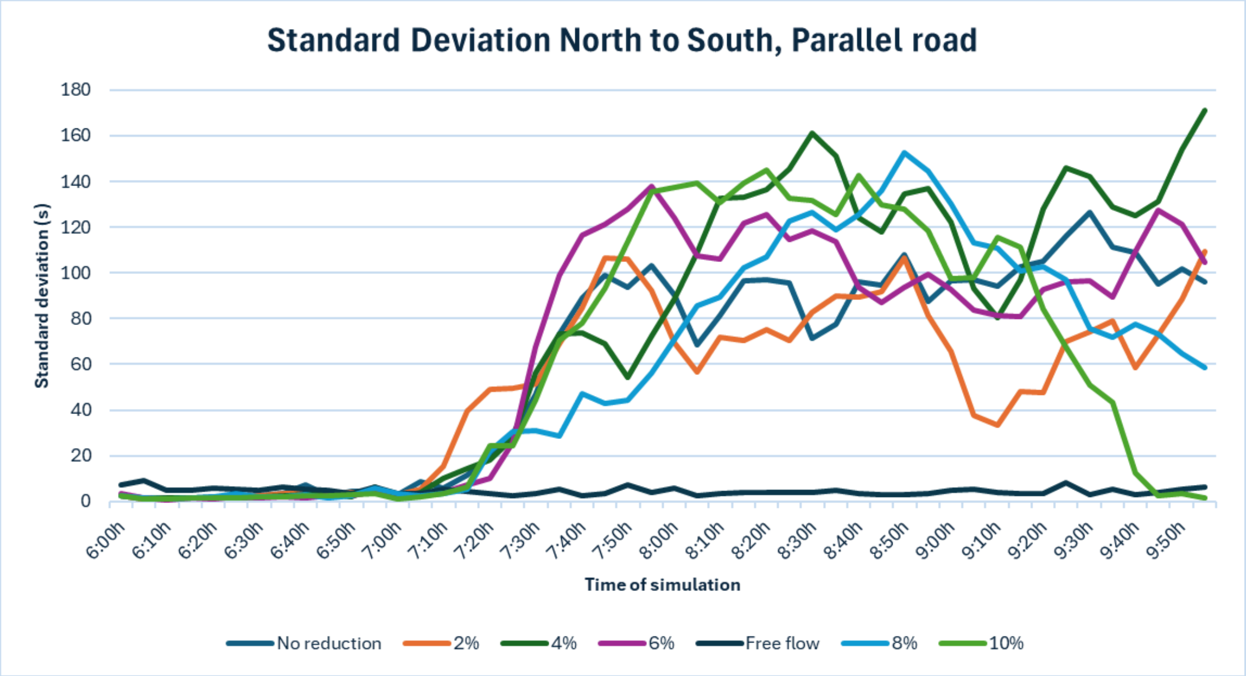

Figure 5.7: Standard deviations per traffic reduction over time on route North to South, Parallel road

As can be seen, the standard deviations are quite significant, with values as high as 180 seconds. This creates a major variability in the model's results, which can explain the anomalies in the travel time results. Furthermore, there seems to be little correlation between the traffic reduction and standard deviation. Only in times of free flow, the standard deviation is kept relatively low. These numbers are a major limit to the accuracy of the model, and therefore these numbers can only be taken as an indication, rather than an accurate representation of the real-world scenario.

This standard deviation is slightly influenced by the amount of runs that were conducted during the simulations. For example, when the same simulations were run with only 5 runs, the route from North to West had standard deviations that can be seen in Figure 5.8 below. When comparing this to Figure 5.5, it can be seen that there are a few peaks that are higher in the simulation with 5 runs than the simulation with 10 runs. Furthermore, the standard deviation for 5 runs seem to be more random than with 10 runs. In general, the averages are more accurate for 10 runs than for 5 runs.

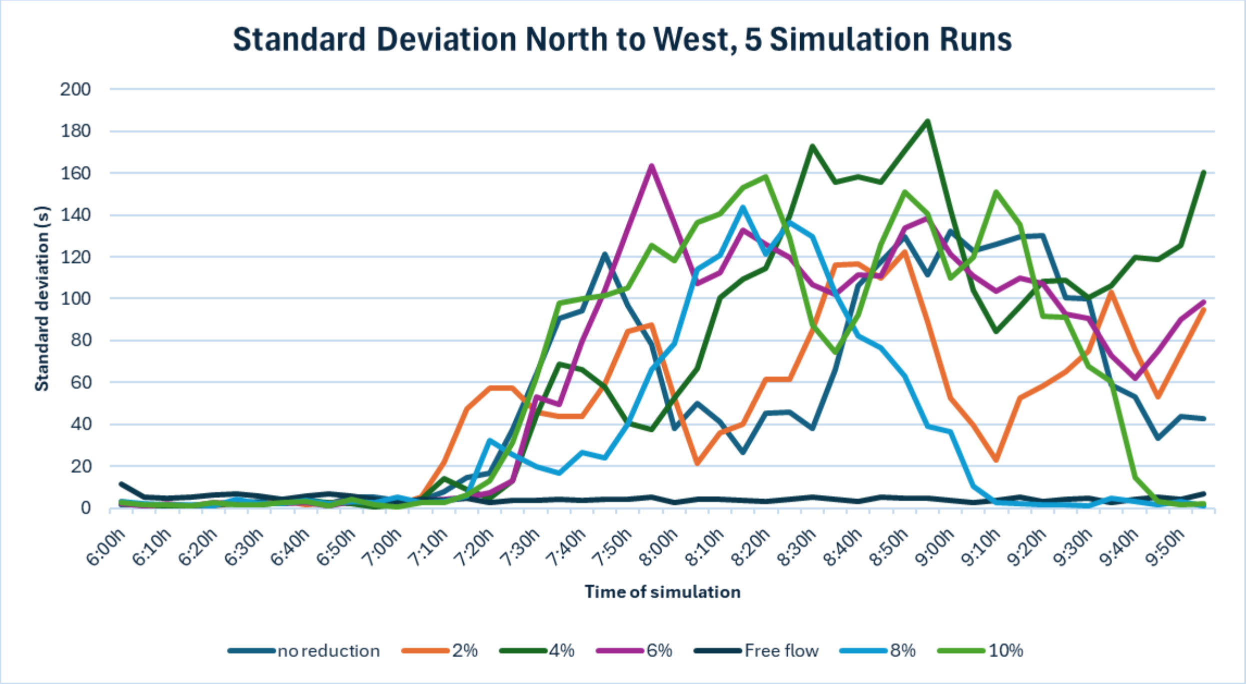

Figure 5.8: Standard deviation North To West for 5 simulation runs

What is curious about the reduction in travel time is the relationship between the reduction in traffic volume and the travel time, as these seem to not be linearly related. When looking at the route from North to West as an example, the average reduction in percentages can be found, as shown in Figure 5.9, based on the average of all time intervals per percentage of traffic reduction.

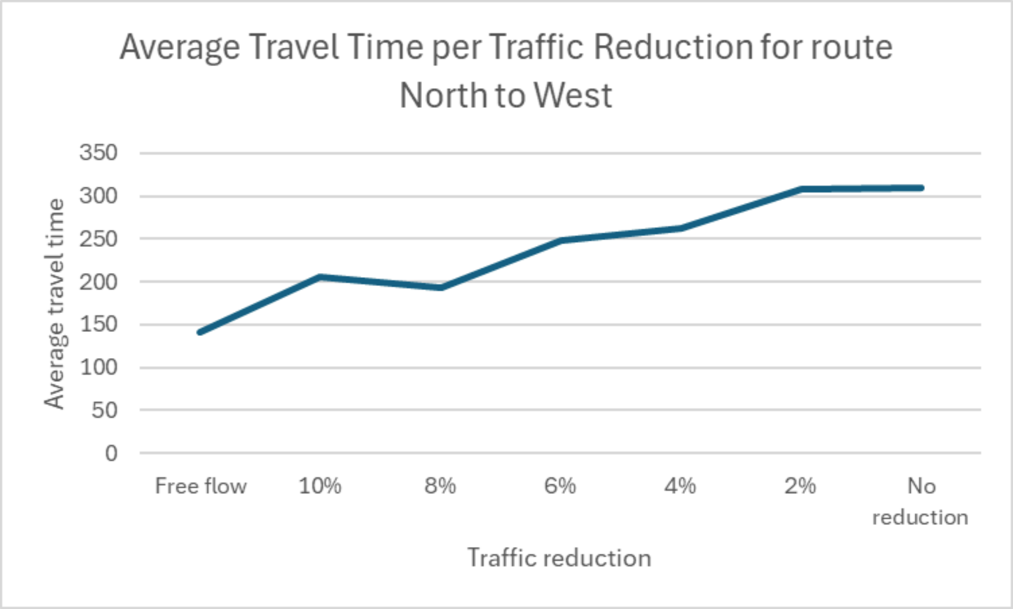

Figure 5.9: Average travel time per traffic reduction for route North to West

However, this is a known concept in traffic management, Li et al. (2019) describe the relationship between traffic volume and travel time as a non-linear function. In this, it can be seen that even a small reduction in traffic can lead to a relatively large decrease in travel time. The closer the traffic volume comes to the free flow state, the less impact a decrease in traffic volume will have on the travel time.

The average travel time reduction caused by the suggested 4% in the literature only reduced travel times by about 15%, compared to the 55% travel time reduction at free flow. The most optimal traffic volume reduction was found to be at 8%, which results in a travel time reduction of 37%.

5.2 Answering Sub-question 2

The second sub-question of this research is ‘How much should car traffic demand be reduced by MaaS to decrease car travel times significantly, according to a traffic modeling simulation?’ It was found that the suggested 4% achievable traffic reduction by MaaS reduces the average travel time by about 15%, compared to 55% at free flow. The most optimal traffic reduction was found to be at 8%, since this resulted in a travel time reduction of about 37%.

This answer can only be taken as an estimate, since there are many limitations to the model’s realism. This is caused by factors that cannot be modeled properly, such as the weather, road conditions, and driver behavior. Furthermore, the results of the simulations showed to have large standard deviations, up to 180 seconds. This creates a major uncertainty in the simulation results. The realism of these numbers will be verified in the expert interviews, and the feasibility of achieving these numbers by using MaaS in DTM will be discussed.

6. Expert Interviews & Results

As the last part of this research, expert interviews will be conducted. This will help verify the results of the simulations conducted and aims to answer questions about what should be done for MaaS to work in DTM. It should be noted that each expert has their own specialization and perspective, therefore not all interview questions can be asked in the same way to all.

The structure of this section is as follows; firstly, the experts to be interviewed are presented. Followed by this are the results of the interviews, and the conclusions that can be drawn from them. Finally, concluding this section will be answers to sub-question 3.

6.1 Experts to be Interviewed

The first expert to be interviewed is Gerard Martens, from Martens Verkeersadvies. Martens is an expert in the field of traffic management and smart mobility, which he worked on for more than 25 years in consultancy companies called Arane and AGV, before starting his own consultancy firm. In these years, he has specialized in researching DTM, and more recently into how to get DTM more in-car through navigation apps.

The second expert is Joost Verdiesen, who works as a traffic planner for the municipality of Den Bosch. In this job, he is involved in projects of the municipality in the fields of traffic management, smart mobility, and traffic modeling. In addition, Verdiesen worked for Rijkswaterstaat in the past, in which he held the position of traffic expert. Interviewing Verdiesen will provide a more general perspective on what the limitations are for MaaS in the municipality of Den Bosch. This is relevant since this is in the geographical scope of the research.

The third expert is Ronnie Quaink, who works at Keypoint as a project manager of the VM-IVRA project by Rijkswaterstaat. This project researches traffic management information for route decisions. Quaink is also closely involved with DTM, which can give a perspective from the DTM side of the research. He also specializes in verification processes, which can help to verify the results of the model, to see if these are realistic.

The fourth expert is Thijs Muizelaar, from Gaiyo. Gaiyo is one of the MaaS providers in the Netherlands. Muizelaar has been working for Gaiyo since 2018, in which he holds the position of Business Development Manager. This position in Gaiyo is important to this research since it will provide a perspective from the MaaS provider's point of view, which the other experts cannot offer in detail like Muizelaar can.

6.2 Results of the Interviews

In this section, the results of the interviews are presented in chronological order.

6.2.1 Traffic Manager: Gerard Martens

As mentioned, Gerard Martens was the first expert to be interviewed. During this interview, his perspective was explored, which mostly came from a DTM point of view. For this reason, questions about MaaS use alone could not be explored in detail.

In general, Martens' perspective on the success of any DTM today is not positive. He explained that this can be linked to the rapid change to in-car information, for example, mobile apps like Google Maps. These apps change the way people navigate, from navigation mostly influenced by roadside signs in the past to almost entirely being based on mobile apps. Attempts to change people's navigation behavior through these apps have thus far not been very successful. This is because very often, the trip mode and route are chosen before the start. Martens mentions a report called Slim Sturen (Ali & v.d. Ven, 2024), which researches influencing behavior through in-car information systems. The main conclusion from this is that it is not nearly as effective as wished for. This is a major limit to the success of using MaaS as DTM during the trip since essentially it works similarly. To illustrate, in the context of in-car DTM use, an idea where a MaaS platform would tell the user to change modes during their trip is discussed. However, this is not deemed realistic since people are not easily influenced in-car. Furthermore, influencing users before the trip starts will be complicated, since users will always use the fastest or cheapest option, sometimes they may choose comfort as a main criterion. For people to choose a mode that is not necessarily in these criteria would rarely happen. In the interview, several incentives were discussed, but Martens mentioned that these rarely work effectively.

These conclusions answer the interview question 'What are the factors limiting MaaS to work as a DTM measure?'. They also indicate what could be done in the future for MaaS to work as a DTM measure, since some options are discussed, with the result of it not working efficiently enough for it to be a serious measure that should be considered. Martens also mentions that currently MaaS and DTM seem to exist past each other and that DTM could be used to complement MaaS instead of vice versa. This could enhance the level of detail that MaaS can offer about different modes. For example, if other DTM measures are present on the route, this can be communicated to the MaaS providers for them to further play into this measure to better estimate car traffic.

Martens says improvements in the future may not have the desired effect, since people are often habit and comfort-driven, making it difficult to switch to another app advising to change their way of traveling. He mentions that this is mostly psychological, and thus not in the scope of the study. However, he does mention that especially at big events, where a lot of people need to be moved at the same time, MaaS would work very well. By this, people can be introduced to MaaS and get used to it. Furthermore, there is always the argument of climate impact that can be used. Generally, taking public transport and sharing vehicles has a smaller impact on climate change than taking the car, since these services are often electrical.

Finally, the results of the simulations were discussed. Martens says that a 8% reduction in traffic to reduce traffic jams is realistic. However, when asked if this reduction is achievable by MaaS use in DTM, he said a lot needed to be done. Even the 4% found in the literature review seemed far-fetched. These numbers are more realistic in large cities or for trips between them, which is the case of this study. However, the many limitations discussed should be considered. Another concern Martens discussed is latent demand. In this case, this is possible car traffic that is not taking the car right now, but will if there is more capacity or less demand on the road. On top of this, demand seems to be evergrowing, so the question is, even if these numbers were achieved, how long its benefits would last.

6.2.2 Den Bosch Municipality: Joost Verdiesen

Based on his experience, Joost Verdiesen’s perspective mostly revolves around the effectiveness of MaaS to reduce car traffic. He has been involved in a project that attempted to find alternatives to reduce traffic jams by enlarging a road with extra lanes, one of these being the promotion of MaaS use. This aligns quite well with the objectives of this research.

Verdiesen mentioned that MaaS was far from being popular enough for it to make an impact car demand reduction. This is despite the fact that the amount of actual MaaS users was overestimated due to a mistake. In his view, MaaS has trouble growing because, especially for routine trips like commutes, people are not constantly looking for alternatives. Only for less routine trips, or when people have to change their routines, they will be more likely to explore other alternatives. He also mentions that MaaS use can increase by giving people incentives to start trying it. This directly will not reduce car traffic, but in the long run it might. He mentions incentives like giving people a free start budget when they download a MaaS app, so that they can experience it for free initially. A version of this has worked before, Verdiesen mentions an example where sharing bikes were rented for free as a try-out, which resulted in the experiment having to shut down early because it was too popular. The question then remains if this popularity can be maintained if costs are added. Either way, this could be a good way to get people to start using MaaS, which essentially is the first step in making it work in DTM. Additionally, he mentioned that it is complicated to know who is using MaaS, if it is mostly previous car users or people that were mostly using alternative modalities either way.

Furthermore, Verdiesen says that it is hard for MaaS to work in DTM. He says that many factors would make it difficult to influence people to change transport modes during their trip. An example of this is the idea of guiding a car user to a train station, to continue their trip by train. This could be justified by the fact that the user can therefore avoid traffic. However, this only works for people who have a destination where public transport and sharing mobility is available. Furthermore, they might have many other reasons, like needing to transport heavy bags, or picking someone up along the way. These are factors that cannot be taken into account by MaaS platforms, which further limits the possibilities of MaaS in DTM. He also mentions that people who take the car generally are often not willing to change their way of transportation and that they would rather accept extra time the traffic jam puts upon them. Another issue with this idea is that in the case of private car use, the car is left at a train station, where it will also need to be picked up again.

Verdiesen also mentions that MaaS can be effective in terms of pre-trip information. With this, more people could be convinced to use a different transport mode. However, this only affects a very small number of users, since there are so many conditions that cannot be considered by a MaaS app. MaaS apps could also attempt to predict traffic based on the time the user plans their trip. With this, a suggestion could be given that the user should take the train to work so that they will be able to take the train back, which might save time by avoiding the evening rush hour.

In terms of the effect that MaaS can have on reducing car traffic, Verdiesen says that a reduction of 4% is already very large. He says that even a 1% reduction would already be a quite significant reduction. The results of the model can be deemed realistic, in the sense that a reduction of 8% is needed to decrease traffic congestions significantly, but a reduction of 8% is certainly not feasible by MaaS as a DTM alone. Verdiesen also mentions that through MaaS apps people could be advised to avoid the rush hours by traveling at different times. By combining multiple measures like this, better percentages can be achieved, although Verdiesen is still not convinced that this would be enough to achieve the 7% that is required to solve the congestion problem according to the model.

6.2.3 Keypoint: Ronnie Quaink

Ronnie Quaink is the project manager of the VM-IVRA project of Rijkswaterstaat. In this project, sharing data between traffic managers and service providers is used to improve the overall efficiency of both. The reason for this is to be able to accommodate for the change in how people navigate, from being based on roadside signs to now being fully dependent on navigation apps. Often, these apps will guide users in ways that they are not supposed to go, like school areas or village centers. By improving the communication between the traffic manager and the service providers, these situations can be avoided and traffic safety can be improved. The idea for this is to avoid these areas by rerouting the car traffic, however, this could also be done with MaaS, by telling users to continue their trip by public transport. However, like Martens, Quaink says that this will only affect a very limited number of people and will therefore not solve congestion on its own. Even pre-trip MaaS use will most likely not achieve the numbers from the simulations.

Furthermore, Quaink mentions that the main factor causing the slow growth of MaaS is related to the fact that people generally do not like to change their habits, especially for routine trips like commutes. This is also something that was mentioned by Verdiesen. Furthermore, Quaink mentions that a large group of current car traffic are people who will not easily change their behavior into using other transport modes. However, the group of people who see the car as one of multiple options could be better targeted for using MaaS, but this group is relatively small. A few factors he mentions that influence this are people who are driving lease vehicles, using cars to transport goods, peace of mind, comfort, or have origins or destinations that are badly serviced by public transport or sharing mobility. Especially the peace of mind factor is a main limitation, as the quality of the connection to a different mode is never guaranteed. This would make the MaaS experience often more stressful and complicated than simply joining the traffic jam.

Quaink also shares the concern of latent demand, which has been a major limiting factor in traffic management for years. He says that using MaaS as DTM will not solve this issue alone, however, he hopes that this latent demand will decrease over time, as a younger generation will replace the older, more car-bound, generation. This younger generation could be more open to different transport modes and therefore decrease the general demand for car traffic.

6.2.4 Gaiyo: Thijs Muizelaar

Thijs Muizelaar has worked for Gaiyo since 2018 as a Business Development Manager. This gives him a general overview of what Gaiyo is doing, which can offer the business perspective of MaaS. In general, Muizelaar is optimistic about the future of MaaS apps like Gaiyo. He mentions a pilot project that was conducted by Gaiyo in Utrecht, which was very successful and lead to a reduction in second car ownership and CO2 emissions by transportation. This was possible by having a large amount of supply of sharing vehicles available.

However, when it comes to the context of this research, Muizelaar is less optimistic. He says that commutes are nearly out of the question for MaaS. This has to do with habits, as well as the fact that public transportation subscriptions or other fees are seldom refunded by the company, while traveled kilometers by car are. Especially this financial motivation is the main limitation. To improve on this a lot of financial measures are needed, as well as other measures like fiscal measures or severely adapting parking policies. Furthermore, if companies would compensate public transport instead of private car kilometers, a major motive to use public transport would be created. Muizelaar says that it is possible to make MaaS use a frequently used option next to regular car traffic for incidental trips. However, many more options should become available for this to seriously reduce car use and even (second) car ownership. MaaS could also be used for more regular trips like commutes, but with the condition that the costs for the user should be about equal as it would be for using the car. To achieve this, large investments need to be made by the service providers, which in today’s scenario is not realistic. However, these investments could be funded by the government as a part of their emission reduction plans.

Furthermore, Muizelaar explains the lack of growth of MaaS platforms with the fact that people generally are not used to planning every trip they make. However, using MaaS apps always requires planning and comparing different modes. This is a mental effort many people need to be used to and are not willing to make. Additionally, the freedom that comes with being able to leave at any time by car is a crucial factor that is missing when using public transport or sharing mobility. For this, the planning part of MaaS apps should be drastically simplified. However, for MaaS to work more efficiently, more information should be known about the trip the user is making, in order to accommodate their demands. These two issues are contradicting and therefore complicated to solve. Furthermore, MaaS solves an issue that many people do not have or see. Many people are not interested in using multimodal transportation to get to their destination, and even if they do, they often do not mind having multiple apps on their smartphones. Lastly, Muizelaar mentions that the MaaS business case is not in a good position in a market dominated by very large companies.

When asked about the possibility of implementing MaaS in DTM, Muizelaar explains that it is possible in theory, but that in practice it will not have a significant impact on reducing traffic congestion. In general, people are not easily influenced during their trip. The main example that was discussed is the idea of telling the user to stop his trip by car and drive to the nearest train station to continue his trip by train. According to Muizelaar, this will rarely improve the user’s total travel time, since the route back will also have to be done multimodally, in order to take back his private car. However, there are more possibilities for pre-trip route choice influencing by MaaS. This can have a more significant effect than on-trip measures, but still not enough to solve traffic congestion. In theory, the reduction required by the simulation is feasible by using MaaS in DTM, but in practice, this will most likely not work. Muizelaar especially mentions the financial constraints for this. The simple fact that most companies do not compensate for trips by public transport makes people often avoid taking public transport for their commutes. Furthermore, there are also many costs for the service providers. Getting more people in public transport means that its capacity has to increase, which is very costly. The same goes for sharing mobility services.

6.3 Answering Sub-question 3

The third and last sub-question of this research is: ‘What do experts think about the idea to make MaaS work as a DTM measure to achieve the reduction in car traffic required by the simulations’ The different experts mostly agreed on the answer to this question, as they all said that it was not realistic. Many reasons were given for this, with the main reason being the simple fact that people do not like to change their behavior, especially during their trip. Behavior is more easily changed before the start of the trip, especially for incidental trips. However, for more routine trips like commutes, people are generally unwilling to change their transport mode. When asked if the required results by the model were feasible by using MaaS as DTM, all experts agreed that this would not be possible. They said that on-trip less than 1% would accept a change of transport mode. Pre-trip this number could increase slightly, but certainly not reaching the numbers of reduction as per the simulations. The experts also expressed concerns for the so-called latent demand, which might see this reduction in traffic very quickly be filled up again to the previous status quo.

The main reason for this unwillingness to change behavior is that people generally do not plan each trip they make, especially routine ones like commutes. This is a mental effort that people are not used to, but is necessary for the use of MaaS. In the near future, this issue could be partially solved by using a form of artificial intelligence. However, this also demands a behavior change, which is difficult to influence. Furthermore, MaaS travel advice is not consistent and can change per day. This creates an uncertainty in people’s daily routines that they are not used to when driving a car. Additionally, for the context of commutes, trips are often only compensated by companies in kilometers traveled by car. Costs for public transport and sharing mobility generally are not. This gives another financial reason for the user not to use alternative modes that MaaS would offer. On top of this, in order for MaaS to significantly get more users into sharing mobility and public transport, these services themselves would have to make serious investments. Especially during rush hour, public transport services like trains are already very full. An increase in capacity would be required if MaaS would work successfully. On the other hand, this increase in capacity can also work to increase MaaS popularity and therefore its effectiveness as a DTM. To further increase this popularity, pilots have been conducted in the past, which have mostly been successful. These pilots can slowly grow the use of MaaS, which could make the objective of this research more feasible in the future. However, the general consensus by the experts that a lot needs to be done for MaaS to become a major player in the travel industry, and that its use in DTM cannot be effective enough to significantly reduce traffic congestion.

7. Conclusion & Recommendation

In this second to last paragraph of this report, a conclusion will be drawn from the research by synthesizing the answers to the sub-questions into an answer to the main question. The main question of this research is: ‘To what extent does using MaaS as a DTM measure work to reduce car traffic congestion and possible conflicts in rush hour at highway junction Empel in Den Bosch?’

The first part of the research was aimed at finding how much reduction in traffic could be expected by MaaS use, based on a literature review. This gave a general idea of what to expect for the rest of the research. It was found that according to literature, MaaS use alone could reduce car traffic by about 4%. This answers the first sub-question of the research.

After this, a model was created of the Empel highway intersection near Den Bosch, the Netherlands. This model was used to run simulations on the intersection based on real-life data from NDW Dexter, in order to see the current congestion at the intersection. This showed that, mainly for the routes coming from the North, the intersection experiences major congestion during rush hours. With this knowledge, simulations were run with less traffic than the current situation, to see at which point the traffic congestion would relatively improve. The simulations were run at traffic reductions of 2%, 4%, 6%, 8%, 10%, and at free flow respectively. It was found that the most optimal reduction compared to the current situation and the free flow was at 8% traffic reduction. Therefore, the numbers according to the literature were shown to not be enough to solve the problem. In the bigger picture of the research field, this impacts multiple layers of the mobility system as was shown in Figure 2.1. Not only do these results relate to mobility services, as this is the category of MaaS platforms, they also relate to transportation services, as these are the vehicles that should be removed to reduce congestions. These results answer the second sub-question of the research, which establishes how much reduction in vehicle traffic is needed to reduce congestion.

To verify these results, expert interviews were conducted. The experts all agreed that an 8% traffic reduction by MaaS use in DTM was not feasible, some even said that a 1% decrease in traffic would be a large number. Even pre-trip MaaS use could not achieve this 8%. The main reasons that were given for this are comfort and financial reasons. People simply do not like to change their behavior, especially for routine trips like commutes. Furthermore, more widespread use of MaaS would create new necessary investments for the service providers, which they are not always willing to do. For the user, it is also often cheaper to take the car, since employers often only compensate trips per kilometer traveled by car, and not the prices that are attached to public transportation or sharing mobility. Lastly, the experts mentioned that the MaaS market only touches a very niche side of the market, since MaaS use is only feasible for trips with origins and destinations at well-connected areas by public transport. They mentioned that many of the people using the car today are using it because either their origin or destination are ill-connected by public transport.

Using the gathered knowledge during this research, the main question can be answered. MaaS can be used as a DTM to very little extent because of personal habits, financial reasons and because of the lack of connections by public transport that can compete the efficiency of the car. According to experts, not even 1% of today's traffic could be positively affected by this result. This number is far from the necessary 8% to significantly reduce traffic congestion on the Empel highway intersection, according to the simulations. Combining these results, the hypothesis that MaaS could be used as a DTM to reduce traffic congestion is not feasible in the current situation. This result is based on knowledge that was already available within the field of traffic management. However, combining the effectivity of MaaS in DTM to reduce car traffic with the necessary traffic reduction to minimize congestions fills a gap of knowledge in the field, as was found in the literature review.

Considering the above, a recommendation can be made. Firstly, a lot needs to be done for MaaS to work as a DTM for on-trip behavior change to reduce traffic congestion. This can be further researched, but in the current situation it is deemed not feasible. For MaaS to work as a DTM for pre-trip behavior change to reduce traffic congestion is more realistic. Further research could be conducted to see what can be done to further boost MaaS popularity. This way, more car traffic can be reduced pre-trip, in the context of this research. This is because MaaS platforms currently are not used by enough people to effectively make a difference in changing people to different modes of transport. However, MaaS platforms are growing rapidly and could become more relevant in the near future.

8. Discussion

This section will discuss the main limitations of the research and the assumptions made.

Firstly, the scope of this research should be discussed. The initial scope for the study was the corridor between Utrecht and Den Bosch since this is where Keypoint has conducted studies before. However, because of the timeframe of this research, the corridor was cut down to a single highway intersection near Den Bosch called Empel. With this, the initial goal of seeing the effects over the entire corridor cannot be reached. However, the most important sections in terms of traffic congestion in this corridor are the intersections. This intersection specifically is very important since any traffic to and from Den Bosch in the direction of Utrecht has to pass here. In the end, the results of the simulations are expected to be relatively similar compared to those of a potential model of the entire corridor. Possibly, this model would require an even larger decrease in traffic volume, since this would include Utrecht, which generally experiences more traffic than Den Bosch.

During the creating of the model, a few issues were encountered during the simulation. The ‘drivers’ in the model do not always behave as expected during the simulation. Behavior that can often be observed is cars staying in a certain lane until a few meters before their exit, which results in them stopping to cross multiple lanes, blocking all traffic behind them. This is something that would rarely happen in a real-life scenario, which is why this issue should be solved.

An attempt to solve this problem was made by changing variables in the driver behavior of the model. This was done by increasing the aggressiveness of the driver’s behavior. This way, a smaller headway would be required for the car to merge into the next lane, which would make it lane changes more frequent to avoid getting stuck. Furthermore, the so-called ‘look-ahead distance’ was increased. This variable decides how far ahead the driver can ‘look’. Increasing this improved driver behavior, since the driver had more time to realize that a lane change had to be done. These variables solved the problem, but not entirely. This behavior issue is a known factor in Vissim, therefore fully solving it would be out of the timeframe of this project. This is a major limitation to the realism of the model, but it can be deemed sufficient for this project.

Some other limitations are that certain real-life driver behavior cannot be modeled. This includes mostly psychological factors, like the way people react to the narrowing of a road, or having trees along the road. However, one thing that could be adapted to make the driver's behavior more realistic is the speed limit. On most road sections of the model during the timeframe of the morning rush hour, a speed limit of 100 km/h is enforced. However, some of the curves have a recommended speed limit of 70 km/h. This was modeled such that the cars strictly follow this recommended speed.

As for the evaluation of the model, it was not possible to receive data for each single vehicle of the model, but rather only averages per time interval of 5 minutes. This limits the possibility of the model to show data about emissions and possible conflicts between cars. This would have given an extra layer of detail to the model, which could have added to the relevance of the research. Also, data provided by NDW within the provided license, it was not possible to establish a ratio between regular cars and heavier vehicles like buses and trucks. Therefore, all vehicles of the model are shown as cars.

Additionally, for the evaluation of the results of the simulations, there were a few issues. On top of the travel times, the plan was to obtain additional information like emissions and conflicts between cars. However, this was not possible to be done, since the software did not allow it. Resources to solve these issues were outdated, and a solution was not found. For this reason, only travel times were obtained as results of the model. On top of this, it was not possible to obtain data per vehicle. This made it complicated to make distributions and box plots to visualize the uncertainty in the simulations. What could be obtained, however, were the standard deviations, which were sometimes as high as 180 seconds. This shows a major variation in the results of the simulations, further limiting its accuracy.

Furthermore, the expert interviews revealed several gaps of knowledge in the research. These are factors that influence the success of MaaS in DTM, mostly tied to human behavior. These factors were considered outside of the scope of this study, but they remain very relevant for this research. This, together with the influence of MaaS on latent behavior should be further studied. The issue of latent demand may cause any progress made by MaaS use on traffic reduction to be very quickly undone. This regularly happens when road sections are widened, or any other measure to increase the capacity of a road. In principle, this is what happens when attempting to reduce traffic by MaaS use, so it could have the same fate.

Lastly, an opportunity for MaaS would be for other types of congestion than the regular ones studied in this research. For example, in case of roadworks or car crashes, people could be more open to using MaaS platforms to plan alternative trips and receive up-to-date traffic information. This could also work the other way, in case of changes in regular public transport service, or availability of shared vehicles.

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10. Appendices

Appendix A: Average travel times South & West

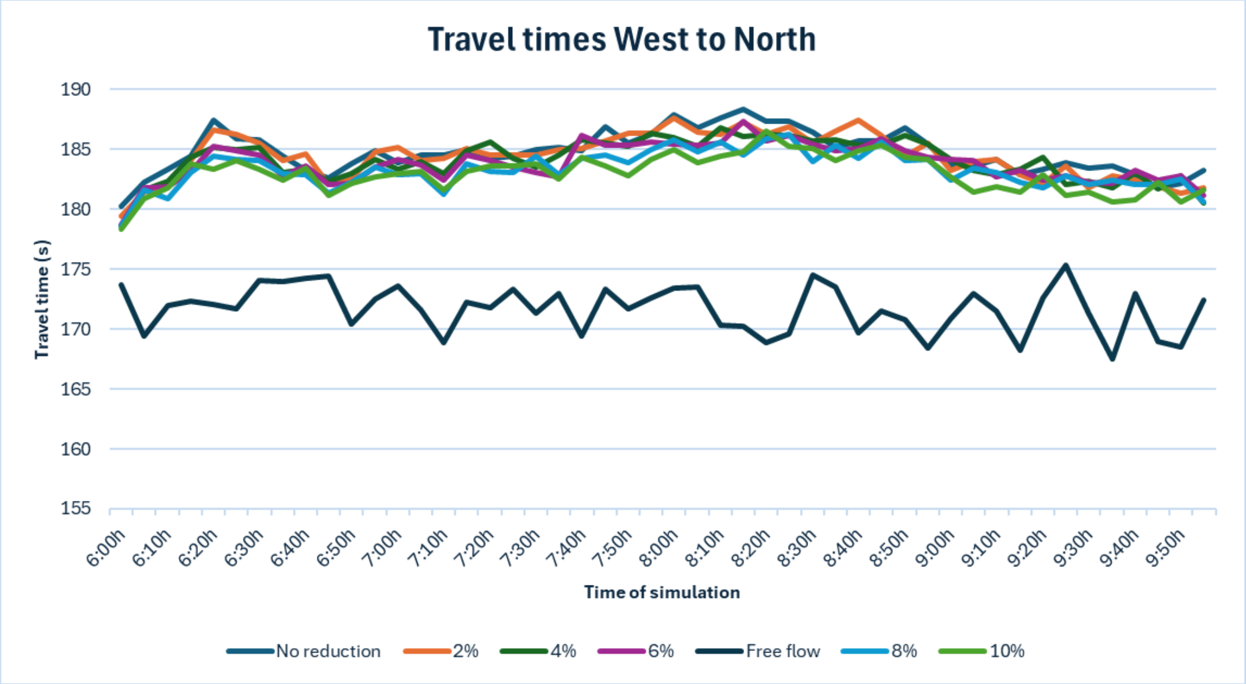

Figure 10.1: Average travel times West to North

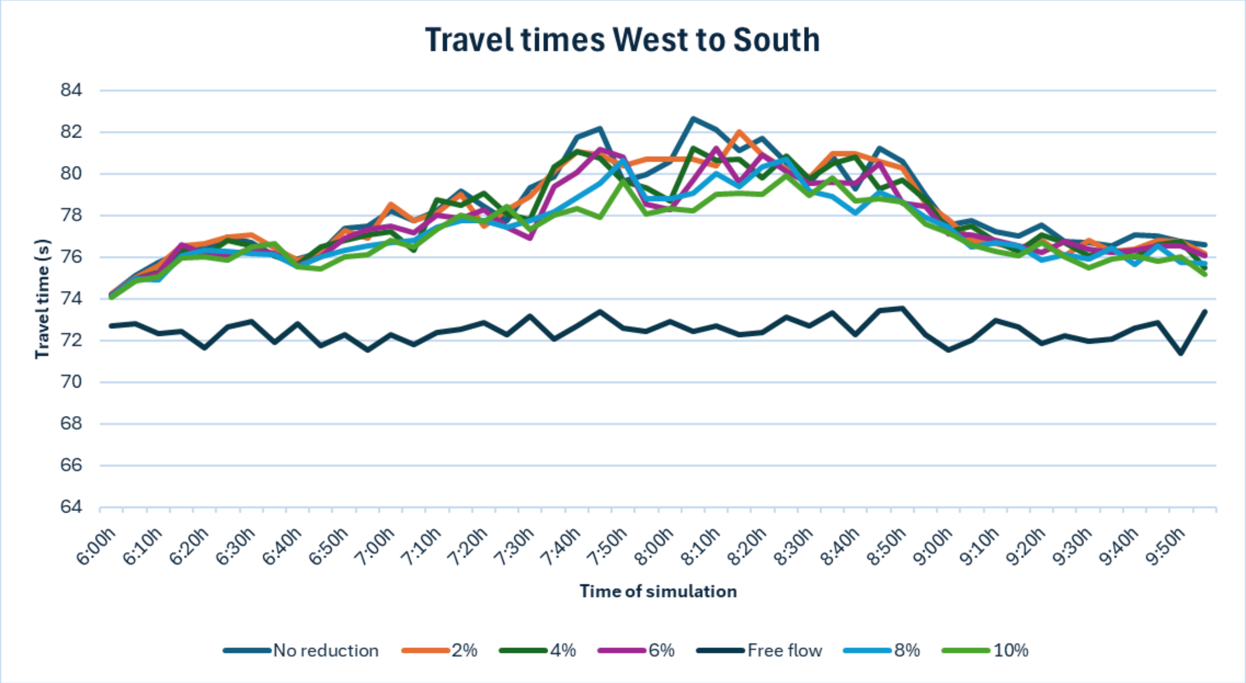

Figure 10.2: Average travel times West to South

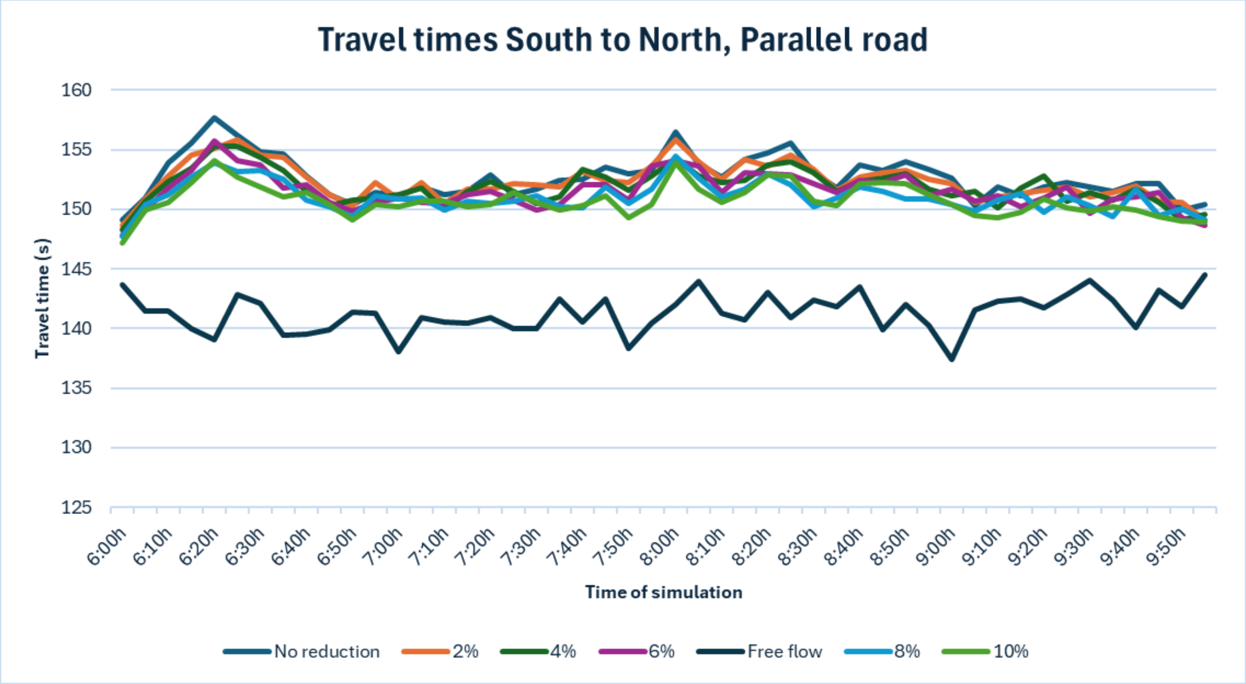

Figure 10.3: Average travel times South to North, through parallel road

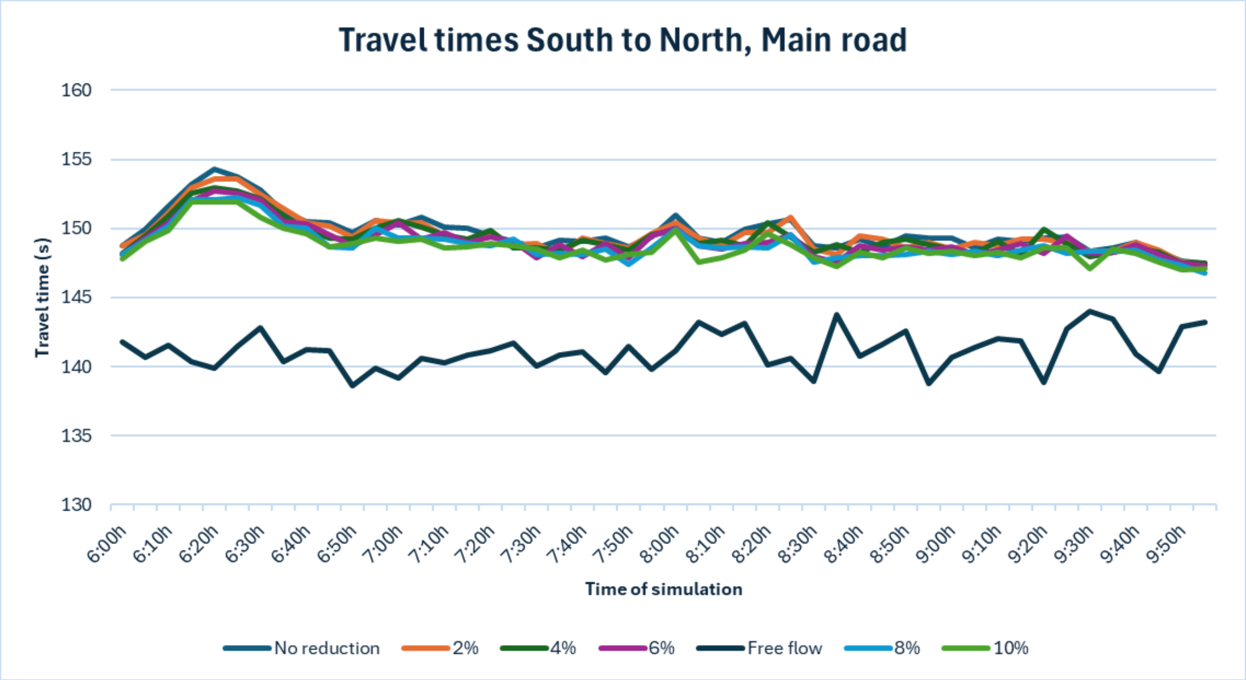

Figure 10.4: Average travel times South to North, through main road

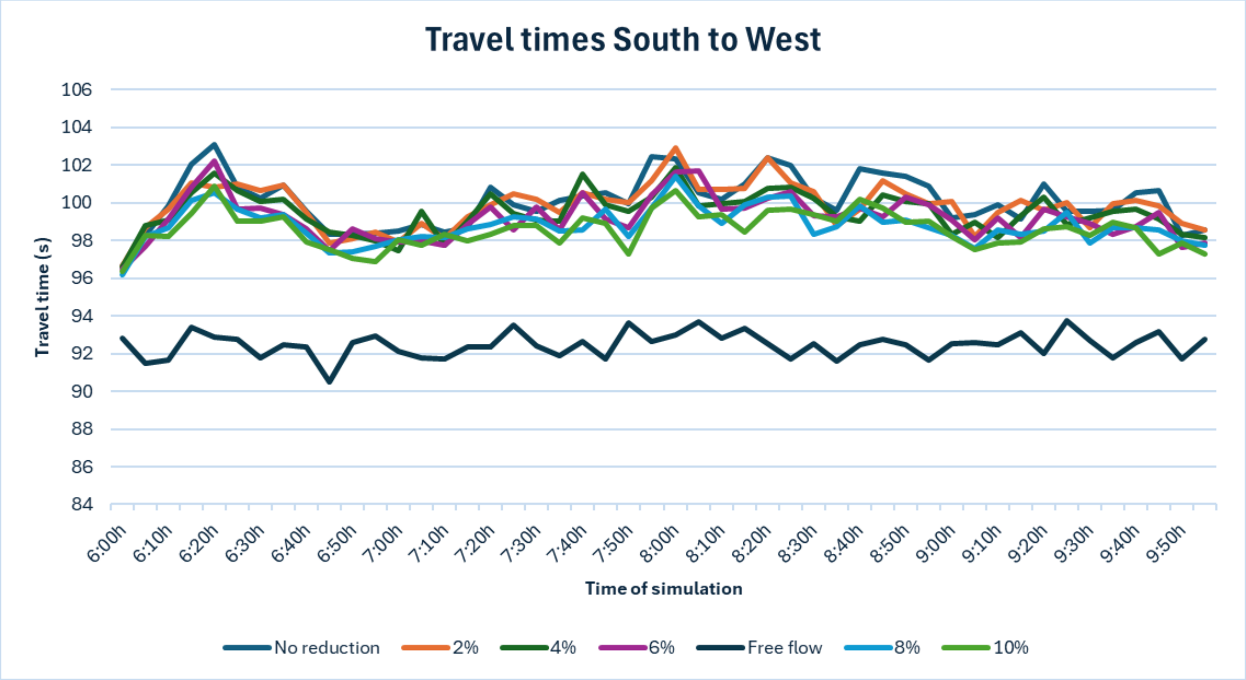

Figure 10.5: Average travel times South to West

Appendix B: Standard deviations South & West

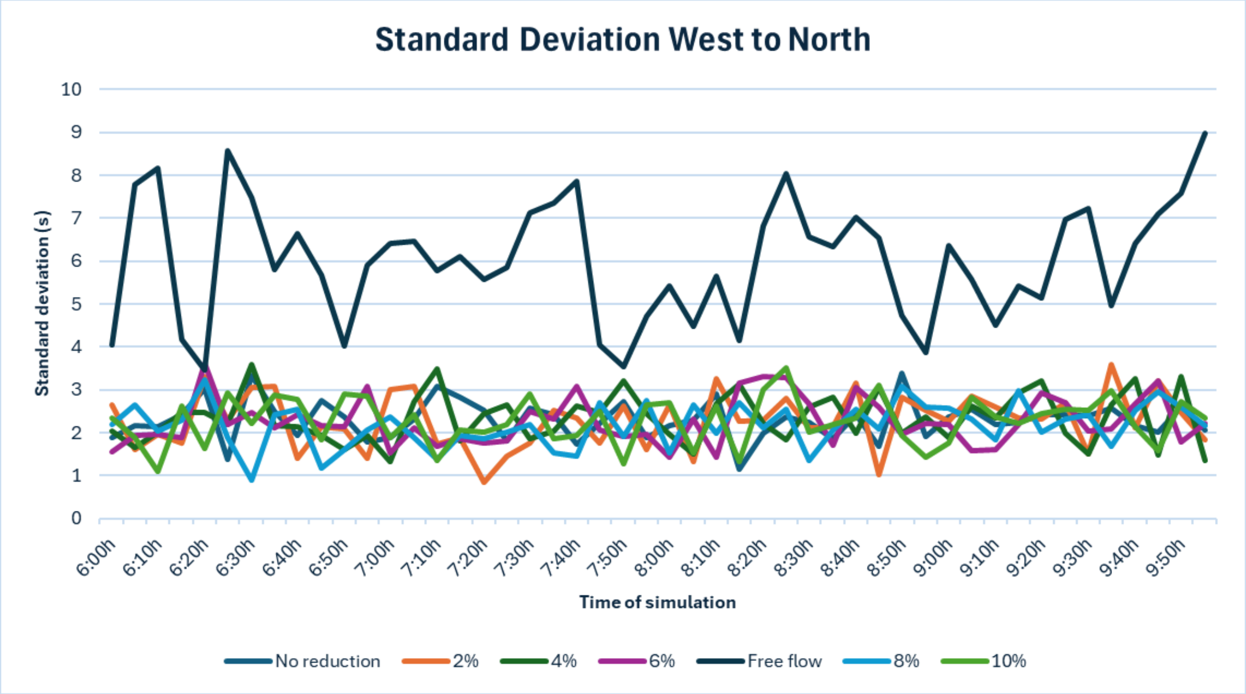

Figure 10.6: Standard deviations West to North

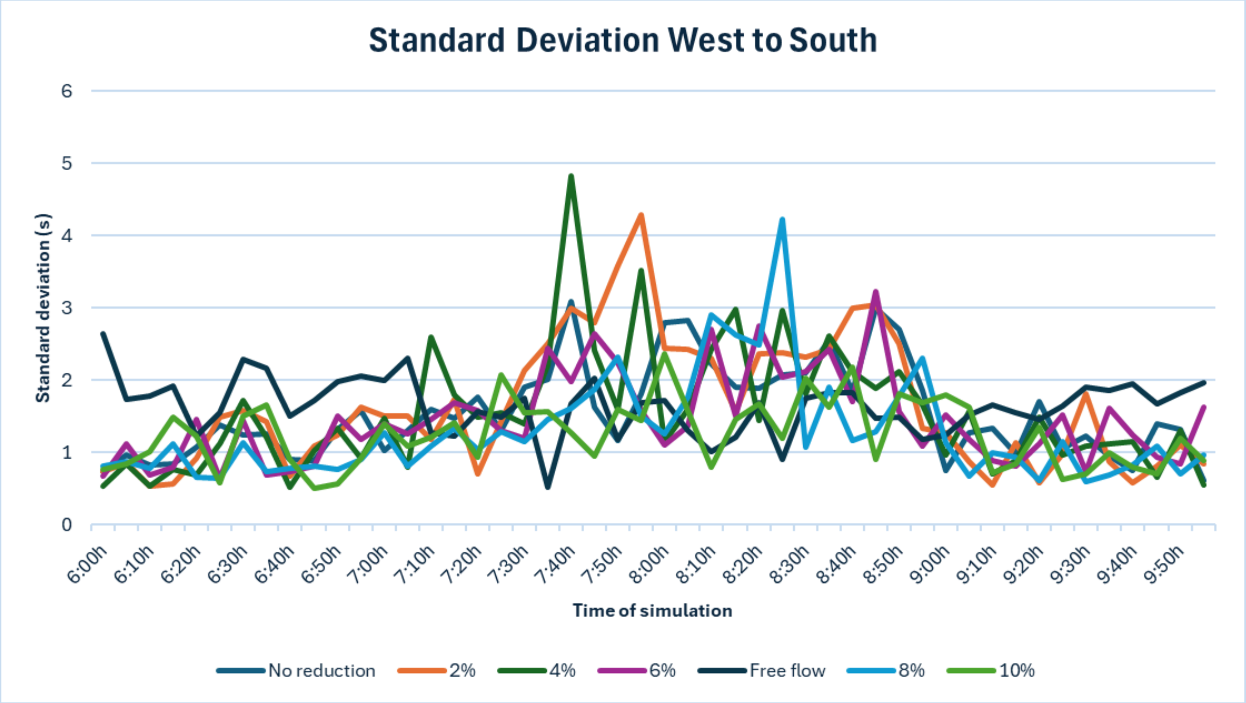

Figure 10.7: Standard deviations West to South

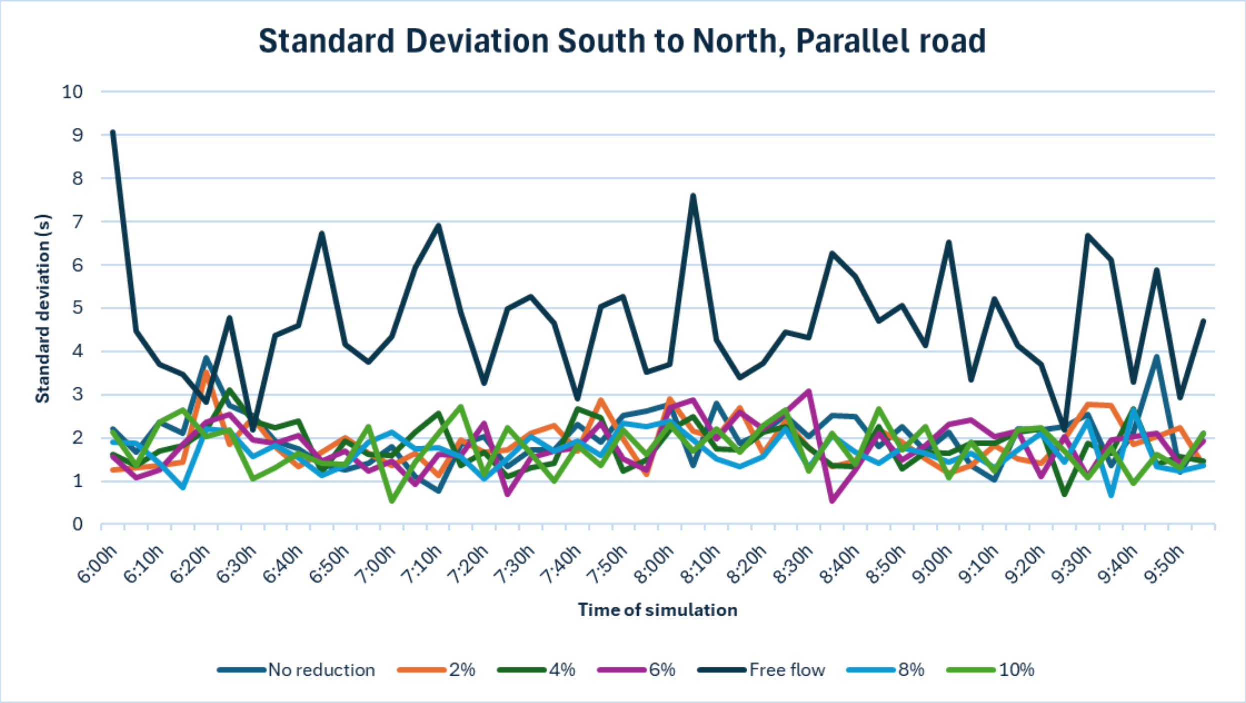

Figure 10.8: Standard deviations South to North, through parallel road

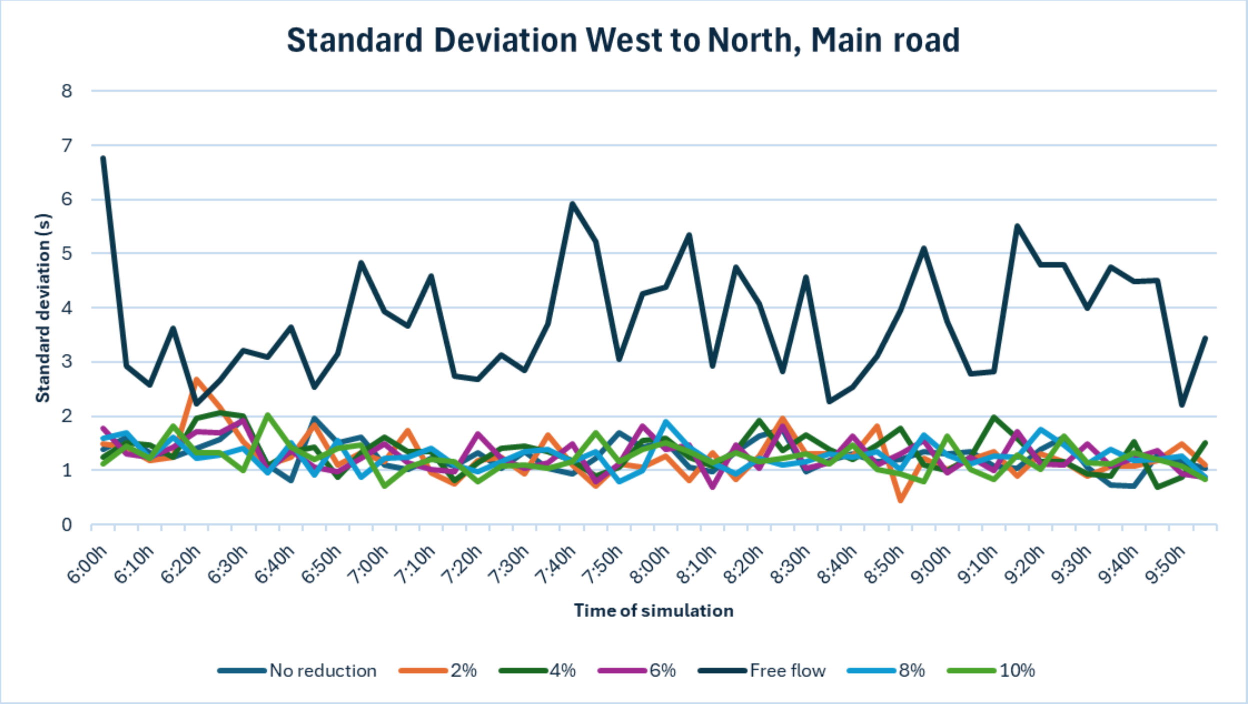

Figure 10.9: Standard deviations West to North, through main road

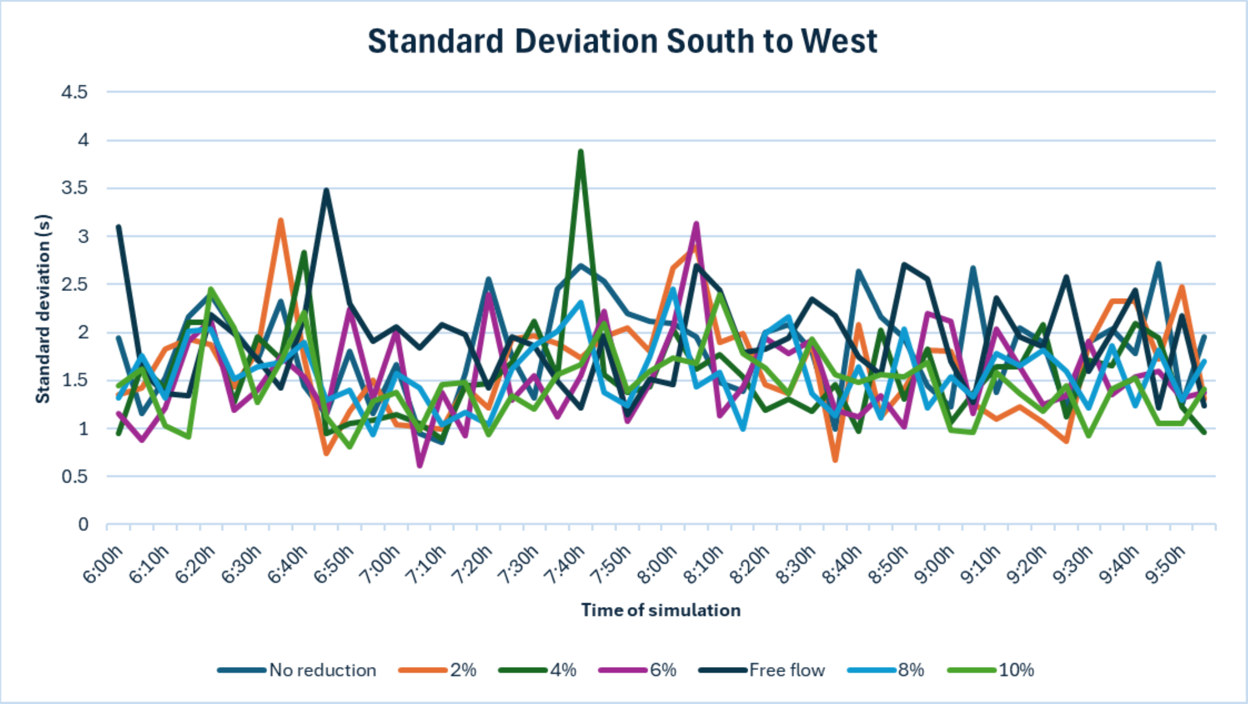

Figure 10.10: Standard deviations South to West