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The Expected Impact of Autonomous Vehicles on Road Transportation Infrastructure Supply

An analysis of Gothenburgs road network when forecasting autonomous vehicle scenarios using PTV Visum along with a Mobility-as-a-Service study.

Master's thesis in infrastructure and environmental engineering

OLIVERA PULJIC

Department of Architecture and Civil Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2019

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Supervisor: Ivana Tasic, Department of Architecture and Civil Engineering
Examiner: Ivana Tasic, Department of Architecture and Civil Engineering

Master's Thesis 2019:ACEX30-19-28
Department of Architecture and Civil Engineering
Division of Geology and Geotechnics
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

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Abstract

The obtained master thesis shows how autonomous vehicles (AV) can impact the City of Gothenburg in terms of vehicle miles travelled and congestion. It analyses two different AV fleets, a shared autonomous fleet (SAV) and a private autonomous fleet (PAV).

For the analysis six scenarios was established and simulated in the software program PTV Visum 2018. From Trafikkontoret a Visum model over Gothenburg's road network for car transport was provided. The six scenarios were divided into two years, 2019 and 2040. With 2019 the current traffic demand was used where the PAV and SAV scenarios were tested on. For 2040 a forecast was performed with a population growth factor set to 1% that was applied onto both AV fleets. The calculations used assumptions from two literature studies. For the PAV scenario, literature study from Zhang et al. (2018) was used and for the SAV scenario, Fagnant et al. (2014) report was being used. All the scenarios were simulated in the Visum program and in Gothenburg's road network. Both literature assume an increment in vehicle miles travelled (VMT) which is consistent with the calculations for Gothenburg. From the congestion level analysis, the result was that it will affect the minor and smaller roads the most. The result can be seen in the Visum model, and in the analysis some higher congested areas and their reason for the exceeded congestion levels in these particular areas are discussed around.

Alongside this calculation a brief literature study is performed on the Mobility-as-a-Service (MaaS) where it analyses three different projects to see how this tool can work as a complement towards autonomous vehicles. The outcome from this study was that the mobility solution has great possibilities to give a perfect integration where all transport modes will be included which can lead to even smarter traffic in the future.

Keywords: autonomous vehicles, Visum, mobility as a service,
vehicle miles travelled, V/C ratio

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Sammanfattning

Det erhållna examensarbetet undersöker hur självkörande bilar kan påverka Göteborgs trängsel och fordonskilometer. Arbetet kommer att jämföra två olika typer av självkörande flottor, där den ena är privatägda självkörande bilar och den andra är delade självkörande bilar.

I den här undersökningen har sex scenarios simulerats i trafiksumuleringsprogrammet PTV Visum 2018. Trafikkontoret har försett den här studien med deras trafikmodell över Göteborg vilket fungerade som ett underlag till alla scenarierna. De olika scenarierna var uppdelade i två olika år, 2019 och 2040. Det första året motsvarar dagens trafik och både två flottorna var testade med den här trafikdata. År 2040 är en framtidsprognos som är uppbyggd på en populationsfaktor satt till 1% och även på det här året testades de två olika självkörande flottorna. Beräkningarna använder antaganden från två olika litteraturstudier. För de privatägda självkörande bilarna används Zhang (2018) medan i det andra scenario med delade självkörande bilar användes antaganden från Fagnant (2014). Alla scenarierna är simulerade i Visum och i Göteborgs nätverk. Både litteraturernas resultat antar en ökning av fordonskilometer och trängsel när självkörande bilar implementeras vilket också är konsekvent med beräkningarna gjorda på Göteborg. När analyser görs på trängselnivån blir resultatet att de mest drabbade vägarna som får uppleva mest trängsel är de mindre vägarna i nätverket. Det här syns även i Visummodellen och de mer trafikerade områdena som uppstår i scenarierna har diskuterats i analysdelen om vad orsaken till en ökad trängsel kan vara i de här områdena.

Bredvid beräkningarna har också en kortare litteraturstudie gjorts på Mobility-as-a-Service (MaaS) som analyserar tre olika projekt för att se hur det här verktyget kan fungera som ett komplement mot självkörande bilar. Resultatet av den här studier var att MaaS visar en stor potential till att ge perfekta integrationer där alla olika transportsätt kommer att vara inkluderande vilket i framtiden kommer att leda till ännu smartare trafiklösningar.

Nyckelord: självkörande bilar, Visum, mobilitet som en tjänst, fordonskilometer, V/C förhållande

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Finally, I would like to express my warmest gratitude towards the hospitality from co-workers at Cowi during my study.

Olivera Puljic, Gothenburg, June 2019

Nomenclature

AV - Autonomous vehicles. Self driving car without the need for a human driver. This reports definition of AVs are that the humans are just passengers in the car and cannot maneuver the vehicle in any way.

SAV - Shared autonomous vehicles. Autonomous vehicles that are not privately owned and are shared by different passengers. Works like an extension to the public transport.

PAV - Private autonomous vehicles. Autonomous vehicles that is privately-owned where no ridesharing is included.

VMT - Vehicle miles travelled. A metric that is used in transport planning. It measures the amount of vehicular travel in a geographic region over a given time period.

Unoccupied VMT - Vehicle miles travelled used when AVs relocate themselves without any passengers.

PTV Visum - A software program for traffic simulations that gives static results in form of: queues, queues length and flows.

LOS - Level of Service. It is a measurement that is used to analyze roadways and intersections to determine the quality levels of traffic. The quality is based on speed, density and congestion. It measures how well the travellers can get from point A to point B without interruptions.

Agent based model - Is a sort of calculation model, used for simulations and are build upon macro characteristics in which several minor objects and information are gathered into one model to make it look like a real scenario, that conforms with reality.

Traffic assignment model- Built upon O/D matrices (Origin/Destination) that are estimating the traffic flows and volume in a road network. In the model more data on link characteristics and performance functions can be found. All the O/D trips are based on a travel time of the alternative roads that have the capacity to meet the traffic demand.

Activity-based model - These models are based on people's daily activity patterns. It analyses when different activities are conducted and then try to align the travel patters according to these activities.

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1 Introduction

One of the most severe problems in urban areas today that adversely affects the environment is the traffic. Cities are often forced to face problems like congestion and overloaded roads which are big issues for people living in the exposed regions due to the restricted accessibility. Expanding the infrastructure is not always the solution to the congestion problem since it usually ends up attracting more traffic. People are going to use the the new infrastructure since the new supply will lower the time for people to travel, leading to more people utilizing the new system which may not be the wanted effect of the expansion claims several researches [29]. For the congestion problems to improve, new mobility solutions, technology and the human behaviour needs to change. A new perspective on travel and mobility is required in order to reach the wanted improvements for the congestion in traffic.

These congestion issues have been some of the causes for the fast progress of autonomous vehicles (AV). The new intelligent cars have the potential to reduce crashes and create a safer environment for surrounding people, they will be utilized more effective which leads to a decrease in congestion and pollution and energy consumption will also be a result of smoother driving. These factors plays a big part when planning for future cities. AVs are beneficial for the capacity of roads since they will be able to utilize platooning, a system that allows AVs to drive closer to each other. Where there is no human errors on the roads, groups of vehicles will be able to decrease the distances between each other using the electronics functions that comes with the platooning technology along with other smart solutions which allows them to accelerate and brake at the same time [10]. The communication between the cars also contributes to more efficient trips with smoother transitions. If the technology develops in a direction that will use cars as a sharing system instead of privately-owned vehicles, it will contribute to an increase in capacity of the roads because of the vehicle reduction. A high vehicle reduction is expected from the implementation of shared AVs since people will share the cars between each other. Due to these benefits mentioned in this paragraph, the vision of how AVs could be the solution to the congestion problems and contribute to a more sustainable future, quickly became coveted by many cities. The research about AVs quickly increased contributing to a more widely discussed subject around the world [1]. The technology brings an aspiration to countries to be the first one to implement a driver-less fleet. The new technology has the potential to be the solution to a new way of travel that opens up for new market and economic opportunities that will affect a lot of stakeholders. Being first in utilizing the technology can be a great beneficial for the country's economy.

Alongside the development of AVs, research about other intelligent mobility solutions have increased. One of the most discussed when it comes to incorporate smart mobility solutions into the city is Mobility-as-a-Service (MaaS). This technology has great potential to provide optimal assortment of as many modes of transports that are available to be used based on every person's individual needs. MaaS can be incorporated with current traffic but it is also one of many methods that works as a good complement to AV systems since it will function as an extension of the AV technology in the potential future. Only applying new technologies like AVs into society may not be enough to get the wanted impact on the congestion as the problem will most likely require new travel patters with a more sustainable view of travel. MaaS enables travel patterns to change easier than with just AVs, since the subscription of a MaaS package will include all possible transport modes, which decreases the need of owning a car.

The utilization of AVs and MaaS will target a broad group of people (for example: the elderly, the ones with disabilities to drive, and the minor), not only the once driving cars today since AVs will not require a driving licence. The cost will too get effected depending on which type of AV fleet that is being implemented, in some cases the cost will be less expensive since there will not be any need for a chauffeur or owning a vehicle. It is significant that every human has the same rights when it comes to travel and public transit but at the same time it is important to consider the disadvantages that a wider utilization of the fleet will bring. The shared pool introduces more people into the traffic, the result could be an increase of vehicle miles travelled (VMT), resulting in a negative affect on the congestion [1]. The rebound effect on the VMT is one of the most crucial factors when planning for an implementation of AVs and other smart solutions. If the congestion will increase, the use of AVs will not be as relevant anymore. This report will investigate how AVs will impact the VMT in Gothenburg and what kind of infrastructure supply will be needed. The optimal solution may not be to build more roads that leads to congestion, this report investigates other viable solutions for the problem.

The introduction of AVs will happen gradually but exactly how the integration phase would look like is still unknown. This study process three different concepts of autonomous vehicle implementation in urban environments. One concept being the implementation of the private autonomous vehicle that is shared within the household and can later evolve to the second concept which is a larger shared fleet. The second concept with a shared fleet begins with some families or neighbourhood shares the cars between each other and can then expand the sharing to include the whole city. The third and most advanced concept is the implementation when everything becomes integrated together (for example when public transit and bicyclists are cooperating with AVs). When the cars start to communicate between each other it will enable for the MaaS system to work as optimized as possible due to the information exchange that the cars offer. AV calculations is only made for two of the concepts in this report, a privately-owned fleet (PAV) where people own their own AVs and a shared fleet (SAV) where people are sharing vehicles between each other in Gothenburg and where the cars are consumed as a service. Calculations for different scenarios have been conducted on both fleet types to see how they will affect the congestion in different scenarios. These scenarios involves calculations on year 2019 and then on a forecast for year 2040, to see how the cars will adopt due to a population growth in the city. The third concept involving MaaS integration was excluded from the calculations due to short time limit. An overview on three projects involving MaaS was researched and summarized to get a deeper understanding on the topic and can be helpful for future traffic planning.

1.1 Purpose and aim

The purpose of the thesis is to forecast the impact that a private and a shared driver-less fleet could have on the congestion level of Gothenburg's traffic through calculations on the network. Alongside the calculations a literature study about MaaS was conducted in order to give a broader understanding on how the infrastructure demands will look like in the future with new mobility changes.

1.2 Research questions

Research questions (RQ) were formulated based on the purpose of the study.

RQ1: Based on the reports by Zhang's et al, (2018) and Fagnant's et al, (2014), how will the capacity of the roads behave due to more efficient vehicle technology leading to mobility improvements?

RQ2: How will the driving population change due to driver less car adoption?

RQ3: What impact will the changes in current and future road network structure due to autonomous vehicles have for each scenario below?

- Scenario 1: Present traffic volumes
- Scenario 1.1: Present traffic volumes, population adopts private AVs
- Scenario 1.2: Present traffic volumes, shared AVs
- Scenario 2: 2040 traffic volumes
- Scenario 2.1: 2040 traffic volumes, population adopts private AVs
- Scenario 2.1: 2040 traffic volumes, shared AVs

RQ4: How will the infrastructure be affected due to AVs? Will there have to be more or less roads to construct? Based on the reports, what kind of infrastructure supply is needed to keep the traffic manageable?

RQ5: Is there a chance to impact traffic by using MaaS and what indication gives other projects results regarding MaaS and AVs? Have Gothenburg worked with this tool yet?

2 Theory

In this chapter the knowledge is presented for existing theories about AV research and theory relevant to the calculations that has been made in the result. An interview with Trafikverket has been summerized in this chapter.

2.1 Autonomous vehicles, background

There are many definitions of what an autonomous vehicle (AV) is and when a vehicle is considered being autonomous. The National Highway Traffic Safety Administration (NHTSA)[21] have constructed a definition divided into a six-level list, where a higher level have a more developed automation.

Level 0 At this level there are no automation at all and the driver is in total control over the vehicle.

Level 1 The cars have some automated functions in level 1 but it still requires a driver to control the vehicle.

Level 2 To achieve level two, the vehicle most have combined autonomous functions, namely that at least two automated functions work at the same time. The driver still must remain active during the whole driving period.

Level 3 The driving functions are automated enough to allow the driver to engage in other activities, but the driver must be ready to take back control at any time.

Level 4 The car can perform all driving and monitoring in the driving environment. Mainly, do all the driving in certain circumstances. The human is not required to be active at this level.

Level 5 The car can do all the driving in all circumstances. The travelers are just passengers that never need to be involved in the driving.

The focus of this study is level 5, where the car is completely automated without the need of a driver. The definition shows a clear indication that the technology have the potential to fundamentally change the travel and patterns in a given region [1]. The magnitude for change and benefits that AVs brings depends on the level of achievement. In the discussions about introducing a self-driving fleet onto a road network, are usually two fleet types that are on the agenda:

1. **SAV**: Self-driving cars that can be shared simultaneously by several passengers (a shared driver-less fleet). SAV works like a taxi system or extended public transport that picks up passengers who are located nearby and have similar destinations. Strangers travels together from door-to-door, hence this can be a service that include detours when serving all passengers because of the passengers destinations or pick up places. After the car has dropped of the passengers, the car reposition itself to a location where there is a high need for AVs.
2. **PAV:** here the definition of the private AVs are that they work in the same way as conventional cars, where people have ownership for their cars. Not much have changed in the vehicle business compared to the current situation, except that the cars now are self-driving. [38].

In this study both scenarios are evaluated to understand what difference they make and how an implementation of the two can affect Gothenburg's road network. A third concept will be discussed in the report for the implementation of AVs, that can be seen as the final result of AVs and it is a total connected fleet. In the third concept the AVs are now well established in the network and is cooperating well with public transit, pedestrians, bicyclists etc. The final integrated concept works together with other intelligent mobility solutions that functions as an extension of the fleet and optimizing the integration of the modes and trips in the network. The first two fleets mentioned (SAV and PAV) are used in calculations and comparison is made between the two, the third concept is not included in the calculations. A literature study for MaaS, a potential mobility solution that will integrate well with AVs and contribute to a more connected network, is carried out in Chapter 2.5. This section gives a deeper explanation on some challenges and possibilities with AVs.

One of more severe obstacles when trying to implement an entire new transportation system with intelligent technology is the cost. Today the cost for AVs is too high and therefore other more manageable solutions needs to be found. The new technology is a barrier in the way of it being too expensive and can therefore not be implemented onto an entire fleet. When incorporating an AV system, the entire business model for vehicles would have to change in order to keep up with new solutions. Another obstacle to consider is the managing of creating a consistent certification framework that needs to be the same for everyone in the world. Standardization contributes for everyone to have the same presumptions of safety acceptance everywhere in the world. The disagreement between countries and stakeholders on how this framework would have to be established is a barrier.

One of the largest benefits that developers hope will arise when the transition of AVs is made and only a driver-less fleet exists, are the deficiency of human errors in traffic. AVs contribute to a more well distributed spread of vehicles in urban areas, preventing the number of accidents and save costs both in human life and financial damages which are currently too high [6]. The way the AVs' distribute themselves on the roads is important for the safety and congestion in an area but how the AVs' chooses its routs may not necessary be the most optimal solution for the residence living in there. If the cars end up distributing themselves to minor roads near residential areas it will contribute to an increased congestion in the housing regions, causing an unsafe environment for the residents. For AVs to be implemented it is crucial that the technology is safe which means they have to be able to recognize different types of objects on the roads. If an accident is inevitable it is important for the system to know how to handle the situation or avert to other routes. If something sudden would have happened on the road it is important for the vehicle to make the right decision during the short amount of time that the accident emerge. Developing a program that has the ability to foresee all the possible factors that can lead up to a crash is still harder for AVs than it is for the humans. For the potential high safety level that can come with AVs, it is assumed that the manufacturing around the AVs are performed in the right way and that they work perfectly on the roads. Today the liability for these issues are still a concern and the safety technology of vehicles are not fully developed and can be an impediment when trying to realize the system and enhance safety to a great extent.

A lot of factors around AVs needs to be solved before the implementation can be realized. Scenarios when AVs work in the most optimal way imagined, they will have a great potential to increase safety on the roads. The increase of safety and capacity is because there will not be any human activities in traffic as mentioned before which today is known for the most common reason for accidents. When taking away the human errors on the roads the cars will be able to drive closer to each other. When the AV technology is fully developed it can contribute to increasing the capacity on the roads. A platooning system can be incorporated to facilitate smoother driving like cars moving at high speeds with small spacing in between. Platooning has earlier been tested with trucks on highways where there are no as many interruptions in flow, with AVs the vision is to implement platooning in urban areas too. [10]. The technology behind AVs are expected to emend the traffic flow since it will manage intersections without the amount of interruption as conventional cars does today, getting a smoother way of avoiding the interrupted flow incidents [4]. AVs are also expected to have functions that can plan a route in the smoothest way possible were the braking and accelerating of driving would be well planned and lead to an increased efficiency [2]. Alongside, the AV technology can work with other smart technology like mobile internet, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technologies, where the last two technologies are intelligent transport systems [22]. V2V communication can exchanges information about speed and position of surrounding vehicles and V2I can gather global or local information on traffic and road conditions. The intelligent technology provides a lot of information that can enable new ways of smarter transport planning [11].

To realize this optimization of the road network, sharing of AV data is nearly compulsory since the information can help transportation network managers and designers to develop the most optimal road network based on people's demands that in terms leads to better investments and policies. It is important to understand that sharing information can intrude on the traveller's privacy and it can be seen as controversial when storing information like route information, destinations and times of day etc. The information gathered can be misused by the government if no proper policies are set to this. When digitizing an intelligent transportation system like AVs, safety risks concerning overrides or disabling of the system makes it important for the society to be prepared for e.g. computer hackers, terrorist groups or hostile nations that can target the system. The system is fragile and by only taking control over the technology, great damage and destruction of infrastructure can happen in short amount of time.

The optimal achievement with AVs is to be able to create a system that requires lower infrastructure supply than the demand is today. Researches argues that if more roads are built into a road network it would most likely attract more traffic, it will lower the time and cost which enables more people to drive. AVs can be the potential solution to the problem to the congestion since the usage of the road network will be more efficient and the potential to diminish road supply and lowering the congestion at the same time are high. There are still some important factors to consider with the new system that contributes to difficulties when introducing the AVs onto the society. AVs will open for new travel patterns and give the opportunity for more people to utilize the mobility, such as: those too young to drive, the elderly and disabled people, thus new higher road capacity demands will occur and the increase in capacity from only AVs may not be high enough to suffice for all new travelers [3]. It is important to know how to use the demand strategies around AVs and to implement it thoughtfully.

This report will focus on the VMT and the congestion level which today is one of the largest disadvantages when talking about AVs. Without solving the congestion problem the effect that AVs will have on the road network will be worse than today's situation.

2.2 The relation between vehicle miles travelled (VMT) and autonomous vehicles (AV)

In this report, vehicle miles travelled (VMT) is a metric that is often referred to. The metric is common in transport planning since it measures the amount of vehicle travel in a geographic region over a given time period (e.g. hours, days, annual basis). VMT is usually used for transport planning and when estimating forecast for both current and future years. The values of VMT gives an overview on how the congestion can develop in a certain region since it indicates how the demand or travel behavior are performing at the analyzed area. Values on the demand is significant for transport planning since it simplifies the allocating of resources needed[32]. As mentioned VMT can also define the travel patterns in the region and through that be able to comprehend how the traffic is going to behave in different scenarios. The metric enables the appraisal of emissions, fuel consumption and can also contribute to appreciate the traffic impacts [14]. Travel demand forecasts can be adjusted by knowing the VMT value which is an advantage when planning for new infrastructure, and how new policy decisions is going to be implemented on that area.

Due to these advantages mentioned in the first paragraph, this metric is also significant when planning for AVs. Most literature studies that is about the introduction of AVs, uses the VMT as an important indication in how the congestion will look like in theirs scenarios. For future planning it is essential to understand how the outcome of AVs can impact the congestion and also the environment around. By doing different forecasts the result will be more realistic and closer to the actual result.

With the introduction of AVs, decisions on where to live and how long the trips takes can be revalued since it today are restricted to time. If AVs opens up for doing activities in the cars and not focus on driving it will save time, and facilitate for people living further away from the city centre. In addition, if the usage of a sharing system are less expensive than car ownership it can too be a contributory factor when deciding where to live [15]. This modernization of traffic could contribute to an wider spread of where people live since it will not be as time efficient as it is today to live in the city centre. With AVs, people will be more open to live in rural areas, they will not see commuting as time consuming anymore. It will relieve the urban areas, but at the same time it encourages for more travels which gives more excessive VMT [1].

The excessive VMT can usually be found between commercial and residential areas due to the relocation of AVs. In addition to these relocation trips, for SAVs the relocation also arises between the distances that AVs need to take between picking up and dropping off passengers and when it is parking itself in a chosen location. For PAVs the relocation process can be from driving to work and then driving to find a cheap parking, back home again to park or to drive the next family member to a new destination [20]. The excessive VMT can be seen as a downward spiral because a higher usage of AVs will contribute to a less expensive fleet due to more stakeholders involved coherently to a well established technology in the region, which leads to more vehicles on the roads.

On the transportation engineering side today, there is only small changes that can be done to improve the vehicle design technology, but we can explore how to use it in order to make it truly beneficial for transport systems and communities in general.

2.3 PTV Visum

PTV Visum is a software program developed by PTV group, a group that specialize in traffic analysis programs. The program performs on traffic analyses on a macro level, meaning that it is more of a general analysis that analyses entirety of a larger area or entire cities. Using the program, a more comprehensive perspective is obtained since the analysis interaction is on a broader level and can analyze large scale of flows or queues. Visum is built upon several parameters like residential areas, traffic measurements, income, volume, capacity etc. where the outcome from the simulations are static. In the traffic industry in Sweden Visum is a well established program that is mainly being used by consumers for traffic analysis, forecasts and also includes a GIS-based data management. For transport planning the program can be used to model interactions, transport networks, analysis of traffic demands for all the road users and for planning public transport. The traffic simulations are built on OD-matrices (origin-destination) meaning that all the trips are dependent on their start and final destination [25]. These origin and destination spots also represents the working places and residential areas. From the matrices, information can be extracted and data inputs can be gathered and inserted into the program to get more accurate values. Due to the amount of information, the software is able to describe the areas that will generate and attract the trips but also the space between them. With the knowledge within the program it can iterate forward the choice of route that optimizes the total travel time for everyone in the network system.

A weakness for the software is that the algorithm within the program presume that all the passengers are well known with the road network and aware of how the traffic flows are changing but also assumes that the passengers have knowledge about other peoples destination and how they act and plan their route. The weakness of the program is not coherent with the reality since in practice the parameters on how people are choosing its routes are unknown by the passengers.

When developing the traffic in a city, a part of the planning is to create efficient vehicle, bicyclists and pedestrian entry. It is important to have information from forecasts and expected traffic volume in order to make the traffic planning as successful as possible. More data inputs in a model contributes to more accurate result since more factors have been considered which gives a detailed overview when connecting the new area onto the existing transport model. The program can be of value when establishing an economic analysis and forecasts on supply and demand. The economic analyses gives an indication on the cost savings since Visum provides several evaluation parameter's that simplifies the economic analysis. [23].
The economic part is important since e.g. companies that are providing public transport needs to now the cost-effectiveness of its services. Visum is also able to manage sharing systems that enables an optimization between the amount of vehicles, the user demand but also the exertion it is required for the vehicles to relocate. the optimization will minimize the investment in supply for infrastructure of such systems [24].

In this report, Visum is used to simulate all the scenarios calculated for AVs. By inserting new estimated values on capacity (see section 2.4 for calculations) onto the existing road network on Gothenburg, new scenarios will occur and the traffic situation will differ from the original model. The flow that shows in Visum represents how much vehicles that passes in each link under the actual time period where in this case was set to 24 hours. A flow that shows 3400 vehicles in one direction means that there is 3400 vehicle/ day passing this link.

2.4 Literature for Visum case studies

For the calculations in the result part of this study, two reports was used for data on increased V/C ratio that was applied onto Gothenburgs network:

1. The impact of private autonomous vehicles on vehicle ownership and unoccupied VMT generation written by Zhang et al. (2018)
2. The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios written by Fagnant et al. (2014)

From the first report, Zhang et al, (2018) the focus was on PAVs and their impact on excessive VMT but also on vehicle reduction. The study is based on Atlanta's travel survey together with Atlanta's activity based model which is important to clarify since the type of outcome from the result depends on which region the study is evaluated on. The study is based on the metropolitan area of Atlanta which is a mono-centric city that have 420 003 citizens distributed over a region of 347 km^2. The utilization of public transport in Atlanta is around 11 % and the car use is 66 % [36]. The researches began with estimating an algorithm that was used to determine the minimum number of PAVs needed for households to be able to maintain their current travel schedule. Then a mixed integer program was used, where some values are constrained to be integer values which makes it feasible for more complicated optimization problems to be solved. In this case an optimization was composed in order to get an answer on residence that had the potential to reduce their vehicle ownership. To obtain the optimal vehicle route that will minimize the excessive VMT a software program called IBM CPLEX was used to determine the origins and destinations of unoccupied paths. These two model components were later inserted to the travel survey that had the ability to study vehicle reduction and unoccupied VMT. The components were also applied onto the activity based model to generate new origin and destination matrices. As the final step of the methodology, CUBE were used to locate unoccupied AV trips to the transportation model. CUBE is an American software program similar to Visum as mentioned in Chapter 2.3 that works with transport planning on a macro level.

The result from Zhang's et al. (2018) report indicates the most significant increase in traffic is during peak hours. 18,3 % of the households in the survey was able to reduce vehicle ownership even when maintaining their current schedule making it a total decrease of vehicle reduction by 9,5% for all citizens in the region. Even if the vehicle number decreases the system will still generate unoccupied VMT due to the relocation process and the results from the report points to an increase for household where they will on average produce 28,9 more VMT per day per reduced vehicle as shown in fig. 2.1.

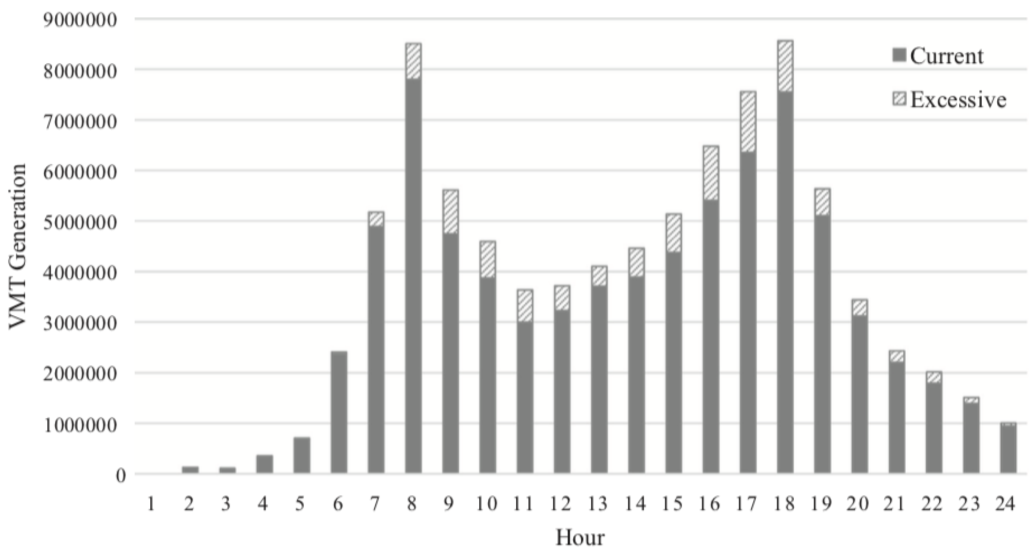


Figure 2.1: The figure shows the distribution of unoccupied VMT during one day (Zhang et Al, 2018).

Additionally, analyzing the Volume/Capacity ratio (V/C-ratio) also called the congestion level sorted by road type in Table 2.1, the largest increment is in the morning and evening peak hours. This relation gives an indication on the congestion, where relations >1 have higher demand that they have capacity which is critical to the traffic flow. This report is reusing these V/C ratio for the AM peak results when calculating on scenarios for Gothenburg to get an appreciation on how a PAV fleet can impact the road network (the calculations are presented in Chapter 3). As seen from the Table 2.1 the V/C ratio will increase by 3,02-7,53 % for the road types presented during AM peak. The highest impact on the congestion level on the roads is the minor arterial roads.

Table 2.1: Change of V/C ratio before and after AVs based on road types (Zhang et al, 2018).

Time period	Scenarios	Interstate/Freeway	Expressway	Parkway	Principal arterial	Minor arterial
EA	BAU	0.297	0.171	0.169	0.124	0.098
	AV	0.298	0.172	0.169	0.125	0.099
	Changes	0.31%	0.68%	0.29%	0.50%	1.00%
AM	BAU	0.650	0.514	0.549	0.468	0.375
	AV	0.669	0.539	0.564	0.486	0.403
	Changes	3.02%	4.99%	2.76%	3.73%	7.53%
MD	BAU	0.503	0.404	0.367	0.353	0.280
	AV	0.516	0.421	0.383	0.37	0.305
	Changes	2.65%	4.13%	4.15%	4.93%	9.16%
PM	BAU	0.692	0.557	0.554	0.547	0.440
	AV	0.709	0.581	0.576	0.573	0.479
	Changes	2.40%	4.39%	4.05%	4.71%	8.68%
EV	BAU	0.441	0.298	0.321	0.239	0.197
	AV	0.449	0.306	0.33	0.249	0.21
	Changes	1.86%	2.66%	2.83%	4.00%	6.83%

BAU: Business as Usual.

The second report written by Fagnant et al. (2014) is about SAVs and their potential to provide solutions onto today's existing car-sharing problems. To obtain the best solution for the match requirements, this project is introducing a way of repositioning the vehicles. The report mentions that since SAV is a new way of travel it could transform the transportation for many when going from a privately owned fleet to a more service oriented business model, which is sought in cities with a high population density because it is more economically viable there and the congestion is usually a more vital problem in cities.

To obtain the results an agent based model for SAVs was established that generates daily trips throughout a grid-based urban area. All the trips in the model are served by SAVs and have an origin, destination and departure time to attain as accurate results of travels as possible. The model generates individual trips on a 5 minute interval that goes over one-hundred days. As a first step, the system will be simulating the artificial city where it will go through the vehicle assignment model 20 times. The performance of this step determines how many SAVs will be required in the area to be able to serve everyone there. The program determines where the cars should be located in the beginning of the day to minimize travel times. The final amount of SAVs will then be used as a fixed number for the fleet size to be used in later investigations. In step two, the model will re-run itself but this time to see how the system will behave and how it can optimize the travels in the gridded area. The model will simulate over one hundred days with a constraint on a 5 minute interval for the vehicles in service to relocate themselves and to reduce waiting time for the next travelers. Here the congestion factor is also taken into consideration, where during peak hours the SAVs will have lowered speed.

When all the simulations was finished, the model was applied onto 25 case studies were different factors will vary, for example: trip generation rates, the distribution of travel patterns and behaviour, information about relocation that the cars have to take and fleet size were factors that changed. The case studies was performed to see how SAV will behave in different scenarios and what kind of restriction that arises with it. The model shows several important factors, two of them being the impact of VMT and vehicle reduction. The findings regarding vehicle reduction is that a SAV fleet will lower the vehicle ownership, one SAV will replace eleven conventional cars. The model estimates a VMT increment on 11% which shows that the travel will be induced negative, making this a conclusion similar to Zhangs et al. (2018). The results on VMT increment has later been used for calculations on SAVs in this report and these calculations are presented in Section 2.4.

Different reports have different results on the VMT and vehicle reduction. In general, SAV does produce more excessive VMT but they also do have a larger decrements in vehicles. It is important to consider this when using assumptions from literature studies because the result is fully dependent on which study is being used.

2.5 Mobility-as-a-Service (MaaS)

Digitization has grown rapidly over the past few years and is today essential to communities and cities. Intelligent solutions are preferable since they save time, giving people the opportunity to prioritize more valuable activities than transportation. Hence, it also becomes vital for the traffic sector to keep up with this trend in order to provide the city with smart tools that helps with planning a trip from point A to point B, while at the same time building a smart infrastructure where the surface space is used in the most optimal way [33].

Mobility-as-a-Service (MaaS) is a technique with the potential to change travel behaviour. Its main focus is to provide mobility as packages that are based on needs instead of the means of transport [12]. Namely, different types of transport means are going to be used as services where the need for owning a vehicle can be decreased. Today, there is a broad diversity of transportation that exists in an urban area which is a great benefit for the residents. Although, planning a trip often leads to confusion since it can be complicated and the benefits that comes with more options does not appear as effective as it could be. When planning a route the tickets for different transport modes are mainly found on diverse platforms making it hard to get a smooth integration between different transport modes, which in turn often leads to delays or extra waiting time. The unstructured part of this system favours the private car since it becomes the more convenient choice, unfortunately that choice contributes to an increase of traffic.

The purpose with using MaaS is to give people the optimal solution for getting from point A to point B that suits every person on an individual level, so that people would start seeing public transport as the most adaptable way of transportation instead of the private car. It can be done by gathering all the planning into one platform, that is using door-to-door services. The platform is now able to provide tickets that include: a train ride, a bus ride and a bike ride instead of it being three tickets which could facilitate the trip planning. The travel option could later be chosen based for example on how much time the route would take, the healthiest route or the safest together with other constraints. MaaS gives an overview on the travel modes and the different kind of routes available. When people are choosing their way of travel it could vary more than before, leading to new traffic distributions where traffic could be spread out more evenly. The potential distribution of the cars can unload the highly congested areas and contribute to a more continuous traffic flow around the city. The most optimal result from MaaS would be to provide the city with intelligent tools and space efficient infrastructure while at the same time create an advantageous system that works the same in all cities. This will help the travellers arriving to the city, which could ease the understanding in how the mobility works since it will be a consistent platform in different cities [18].

Even if the car today is the most convenient choice, it is a high cost for many households which can make it more unfavourable than it is auspicious. MaaS is supposed to be an option for household with high mobility demands to optimize their travel patterns where they do not need to own a car, Fig 2.2 shows a simplified picture between car ownership and MaaS. When the system is fully incorporated into society it would be an easier way of living with more convenient ways of planning transportation. The vision is to enable the same application for travel to be used worldwide in order to provide the same services everywhere, that it does not matter where in the world the citizens are located, the mobility services will still look the same and be consistent. With Maas, the orientation have the potential to be even easier around the world, and this simplifies for all consumers using it. The taxi-service Uber is a great example of this. With Uber's app it is possible to order a taxi anywhere without having to worry about currency differences, since the procedure around it is the same worldwide [16]. The simplicity of it may also be one of the reasons why Uber have had such great success in the world.

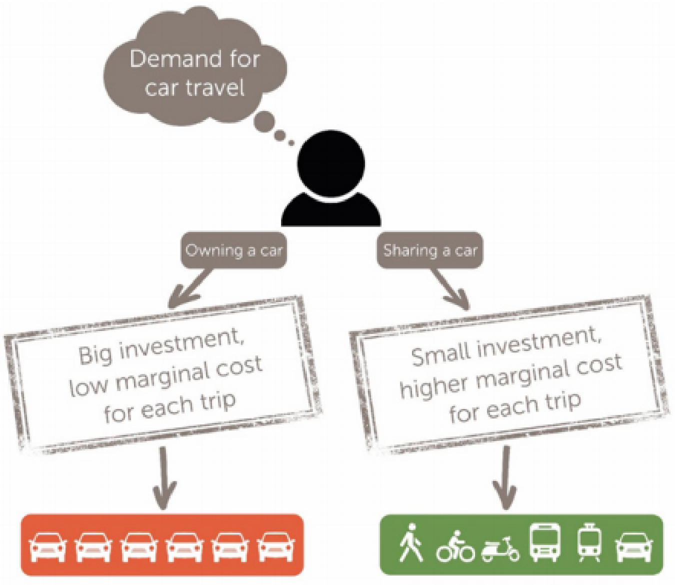


Figure 2.2: The figure simplifies the relationship between the usual business model where cars are privately owned and how a solution with MaaS will look like (Trivector, n.d.).

With MaaS implementation, new challenges will arise where one of the more discussed challenge is the adapting phase. People will need to accept the change and start using MaaS as their first choice. For the technology to work in the most optimal way, the majority of people have to use the system in order for more stakeholders to invest into the technology. A well invested system will contribute to a more functioning integration to the infrastructure and when the system is well functioning, more people will end up using it since it will be the convenient choice. If the demand for MaaS increases it will bring new stakeholders to the market who has to adapt to the technology which will contribute to the development of the MaaS concept [28].

When using MaaS it becomes important to understand the sensibility that comes with a system where the payment is based on credit cards. A large amount of information can be gathered from the credit cards, which later is used for planning and understanding travel patterns and how to reach unmet demands. This kind of data are necessary for intelligent solutions like MaaS in order for the system to serve passengers in the most optimal way. New methods and policies needs to be established to process the information gathered from the cards in a way that does not intrude on peoples privacy [19].

To use MaaS and get access to the packages that it is offering, a subscription of the system would be required. The configuration of the subscription is influenced by mobile phone companies where they offer packages to their customers that are including a number of calls, text and usage of internet. MaaS is doing the same thing, only they have translated it to the transportation market e.g. access to public transport, fixed number of taxi rides, car sharing and a certain number of days using car rental. How large subscription that is needed is determined by several factors, but the main factor is the size of the household, since the volume is coherent with the total travel demand.

Designing a system like this have its difficulties that arises when trying to find a method that suits everyone. The standard package can be seen as unfairly distributed in relation to the cost (e.g. the number of taxi trips and car rentals can be seen as low compared to the unlimited public transport in relation to the cost value of the both modes). It would still be possible to add more car rentals and taxi trips into the subscription, but it would make the subscription more expensive, therefore people who already see the standard package as too expensive would most likely not end up using this service.

The impact of MaaS on travel behaviour is dependent on how it is being implemented into society and how the stakeholders are promoting it. If the stakeholders are encouraging cheaper and more convenient mobility for households, the people who has not previously owned a car would probably try using this system too as it is less expensive. If the system is implemented without constraints to keep it sustainable and with the main focus of only making a profit, having more people using it could backfire and increase vehicle miles travelled (VMT) and add up to more congestion. A downside of MaaS is that it can strike hard towards the public operators because it will be hard for them to get the same amount of market share as before since they cannot keep up to the way that MaaS is working, which can end up in system cuts for transport services. Namely, all the services would instead be within the MaaS package, which can bring a negative impact on people that will not be able to use MaaS for different reasons (e.g. to poor, people that do not own a smartphone etc.) and this system will hurt these groups the most [5]. For the result of MaaS to come close to the wanted vision, it is important to think about the new business model that follows with this system and also on the demands that has to be set in order for it to work. The municipality have a great possibility to control the development around MaaS since they are the ones that make demands on operators and people in how to handle the technology in the most advantageous way for all parts involved. MaaS would change the entire market for mobility, and it is vital for different stakeholders to be up to date when MaaS is being implemented and to understand the new role various stakeholders need to take for the changed market [17].

Maas is already applicable on today's traffic, but to optimize the system even more, an autonomous fleet is of big advantage. Using MaaS together with AVs would create new integration opportunities between modes that are more sufficient than the ones on the market today, making the travel in urban areas even more convenient and hopefully efficient in lowering the vehicle miles travelled, increasing vehicle reduction and lowering the number of privately-owned vehicles. MaaS can contribute to decrease the amount of relocation trips for the cars due to the information exchange, that the cars provide. The mobility service works as an extension of the intelligent technology which in best case will result in more capacity on the roads than when just using AVs.

2.6 Conducted projects involving Mobility-as-a-Service

This section will present how Gothenburg, Lisbon and Oslo have worked with MaaS during recent year and how they interpret MaaS. Also an interview have been conducted with Trafikverket regarding new mobility solutions. Today the definition of MaaS can vary between different cities depending on their own starting point, which is important to consider in order to understand different researches and their approaches. The investigation is made to gather knowledge for Cowi that can be useful in future transport planning when it comes to new techniques on how to keep the VMT down in urban areas. In this report, the general definition of Maas comes from the network Maas-Alliance:

> "Mobility as a Service (MaaS) puts users, both travellers and goods, at the core of transport services, offering them tailor-made mobility solutions based on their individual needs. This means that, for the first time, easy access to the most appropriate transport mode or service will be included in a bundle of flexible travel service options for end users."

In following sub-chapters, an introduction of 3 ongoing projects about MaaS and autonomous vehicles are conducted together with an interview with Trafikverket about MaaS.

2.6.1 Urban mobility upgrade: How shared self-driving cars could change city traffic.

This study was carried out by the international transport forum at the OCED which is an intergovernmental organisation with 54 member countries. The work behind this research was funded by the International Transport Forum's Corporate Partnership Board (CPB) a board that specializes in areas where there are issues regarding transport policies or innovation challenges regarding the transport system. This study also referred as the 'Lisbon report' examines the changes that comes from transitioning to a shared and self-driving fleet of vehicles. In the report two different methodologies of self-driving concepts were studied. The first fleet of self-driving cars can be shared at the same time (TaxiBot) by different passengers and the second fleet was cars that pick up and drop off single passenger periodically (Autovot). The analysis is based on Lisbon, Portugal and since the city is similar towards other cities in Europe it could easily be used for comparison towards the other cities in Europe.

The aim with this report is to comprehend how different AV fleets will behave in different scenarios and how they will affect the congestion and policies in Lisbon. The report mainly investigates the impacts on the car fleet size, volume of travel and parking requirements over two different time scales: an entire day (24h) where an average is estimated and then for peak hours only. The methodology was carried out with a literature study in the beginning, where earlier studies about mobility solutions regarding AVs were analyzed. The study was important to investigate in order to understand previous methodologies and approaches to comprehend what kind of direction this new report had to take. The result from the literature studies give an indication on the potential AVs have to reduce number of vehicles and parking spaces but at the same time retain the level of mobility and service.

The next part of the methodology was a case study, where data was collected with different parameters that all contributed to a more specific and detailed model of the city.

An agent-based model was developed that runs the daily performance of a shared mobility fleet. The agent based model is a calculation model that is used for computer simulations which is build upon several easier objects, integration and agents to simulate more realistic result of the reality onto a macro level [9]. From the information about Lisbon's road network given from the travel survey, real trips based on citizens activities was enabled to be inserted into a assembled grid of cells. The only interest for the model is the relation between the consumers and vehicles and at which degree the service needs to be operated in. It does not take into consideration bicycles, pedestrians and other public transport except the metro.

To be able to obtain information about some economic parts of the SAV system in this model, an established algorithm for this project was conducted. The algorithm could calculate which trip would have the lowest cost between the nodes that exists in the network.

Some constraints from the results and the traffic assignment model is that it only examines scenarios where AVs are fully phased in and there are no more conventional cars to choose. The demand in the model is still based on the conventional cars demand, which may not be totally aligned with how the demand for traveling will look like in the future. In the result there were no deeper investigation of any costs, when in reality the travel demand is dependent on the cost, which gives more uncertainties to the demand. Some scenarios assume that the people using the subway in Lisbon will continue doing that, while in reality the usage of the public transport will be different and vary between individuals. The model also assumes high level of service, meaning that the model is calibrated where the waiting time is set as short as possible and that there will not be too long detours for the passengers. If these values would ease their limitations, AVs would probably manage to handle more passengers.

The result from the simulations shows that the Taxibots has the ability to retain the same amount of service even if they lower their vehicle reduction by 90% and keep the public transport. The worst scenario produced in this research in terms of vehicle reduction was the AutoVot without any public transport, and even in that scenario, 8 out of 10 cars could be diminished. Analysing the VMT, for TaxiVot it will increase by 6% due to several factors but where the main factor of increase is its increased number of costumers. Meanwhile in the worst scenario with AutoVots there will be a major increment in VMT by almost the doubled than today's situation. However, the worst scenario with Autovots does not have any public transport so more added relocation and servicing trips are found in this scenario which is a contributing factor to an increase in VMT. During peak hours there will be an increase in both scenarios.

From the results, it is clear that AVs will save more space in urban areas. How this space is managed is important to decide so that the city develops in the most sustainable way possible. Also, business models for a lot of stakeholders will have to change due to vehicle reduction that comes with AVs. The vehicle reduction will increase safety but the life span of cars will be shorter since there will be less cars always in use, driven more intensely with more kilometres per day. The shorter life expectancy of the cars opens up for development of new improved technology.

During the past few years, ITF have released more studies based on Lisbon, which can be of importance too. These studies are:

- Shared mobility - Innovation for livable cities
  (Focus on ridesharing within an autonomous vehicle fleet)

- Transistion to shared mobility - How large cities can deliver inclusive transport services.
  (Focus on the consequences for the Lisbon region)

- The shared-use-City - Managing the curb
  (How the city will change and how to manage the curb)

Cowi Denmark have recently done a research about the possibilities to implement a shared driver-less fleet in Oslo (see Chapter 2.6.2) where they have been influenced by this Lisbon study.

2.6.2 The Oslo study - How autonomous cars may change transport in cities

The Oslo report is a collaboration between Cowi, PTV and Ruter that has been performed for Oslo. Ruter is a private Norwegian public transport company in Oslo, that manages the transport means in the city. At their request, this report was performed since Ruter wanted to comprehend how the technology could change the mobility in Oslo. Based on Ruters request, the aim for this study is to examine how Oslo's infrastructure would manage new mobility solutions like autonomous vehicles and Mobility-as-a-Service (MaaS). To obtain the result a literature study was conducted as the first step to get some more knowledge about Oslo but also what factors were needed to be considered when creating a traffic model. The next step for the project was designing a traffic model that consisted of autonomous vehicles, which could give an estimation on how different mobility patterns in the city would look like. The report was influenced by the Lisbon report summarized in Chapter 2.6.1. Calculations were based on today's traffic demand and by knowing the demand in the entire region, a full implementation of autonomous vehicles both in a shared fleet and a private fleet was investigated. Meaning that the report only investigates the scenarios when AV fleets have fully replaced conventional cars. The scenarios distinguish the type of group that will adapt to new mobility solutions and how it will affect the capacity on roads for each case. The following presents the tested scenarios in the Oslo study and how they have been composited:

1. **Car users:** Shared cars without ridesharing.
   Public transport: Commuters continues to ride public transport
2. **Car users:** Change to shared cars without ridesharing
   Public transport: Train and metro riders stays the same, all other public transport modes are switched to shared car.
3. **Car users:** Change to shared taxi with ridesharing.
   Public transport: Continues to ride public transport.
4. **Car users:** Shared taxi with ridesharing.
   Public transport: Train and metro riders stays the same, all other public transport modes are switched to shared taxis with ridesharing.

Some of the model constraints are that it only examines scenarios that have fully replaced the conventional cars, and therefore does not take into consideration the transition period where AVs is going to be combined with conventional cars. The scenarios assume that people travelling with metro or train will continue doing it in the scenarios as well, but in reality groups will not behave coherently when choosing transportation mode because it will be an individual choice.Furthermore, the model does not take into consideration bicyclists or pedestrians and it only looks at trips with origin and destination between Akerhus and Oslo. Calculations are based on transportation demand forecast for year 2020 where the demand is estimated for peak hours. The demand gives uncertainties since the future demand will differ from today's. The capacity challenges are investigated but it does not highlight the changes in travel due to the traffic level transformation. Finally, in the model assumptions there only is one car fleet that is used to meet all transportation demand. In reality there will probably be several mobility companies competing to be leading in MaaS solutions, making the assumption used in this report the most credible. In addition, the different mobility companies can contribute to the emergence of a scenario with an increase in traffic compared to the results in the Oslo report.

In the report's result the effect of AVs are investigated in terms of vehicle miles, fleet size and level of service (LOS). The scenarios are all put in relation towards the base case were the calculations are performed with a standard transport model. The best case was able to reduce 14% of the vehicle miles driven and it was scenario 3, where the car users changes to shared taxis and the public transport works as before. 14% is a higher value than the Lisbon report but authors explains that the higher percentage can be connected to the lower population in Oslo. Long waiting times or detours are not allowed in the calibration because this study consider a high level of service since these factors are definitive for people when accepting a to transition AV technology. The outcome of high level of service is that the system cannot be as effective as when longer detours would have been allowed because then it would be possible for the system to serve more passengers.

In all scenarios tested, the vehicle reduction was major. Between the worst and best case the vehicle reduction of private vehicles on the roads were between 84-93% in morning peak hours. A result that clearly present that reducing the amount of vehicles in traffic is feasible.

Even if parts of the results indicates to a positive development of the congestion, it will still be required for Oslo to add new infrastructure supply such as pick up and drop of places around the city which can contribute to some congestion because these pick up and drop offs also needs to be located in the most busy areas near city centre, where they take up space. At the same time, Maas also have the potential to re-use other larger areas such as parking to something else non traffic related which can benefit the city's development to a more sustainable transformation.

2.6.3 The Ubigo project

Ubigo is an ongoing MaaS project in Sweden where trial periods for MaaS have been implemented into reality. The Ubigo was developed within Go:smart which is a project with goals to develop and test innovative services and system and the aim to develop sustainable transports [37]. This trial is one of few MaaS projects that has been realized in the world. The first pilot trial was performed in Gothenburg during year 2014 for 70 households under a six month period [27]. Now the project is relaunching in Stockholm and is tested by the citizens of Hammarby Sjöstad, Finnboda and Minneberg. In the Ubigo project different companies are collaborating to give the customers individual packages based on their needs. It offers costumers a subscription on different transportation modes e.g. public transport, car rental, taxi and bikes which decreases the need of owning a car. Every transport mode is accessible through one singular platform where all the bookings of trips are made and the subscription includes the entire household. The project is dependent on its collaboration and is now cooperating with a few other transport providers, e.g. Hertz, Move about, Västtrafik and SL. It is also provided support by the EU H2020 project and Civitas along with Stockholm as site owner [35]. EU H2020 stands for a research and innovation programme financed by EU that will be available to use until 2020 [7].

Chalmers University of Technology have made an evaluation of Ubigo's first pilot project in Gothenburg where they pointed out positive and negative aspects of this implementation based on the participants experience of the trial. Researches came to conclusion that the outcome overall was positive and that all the participants made more sustainable choices of transportation when utilizing this method during the six month test period. The largest change was among participants that have previously owned a car but did not use it under the trial period.

The downside of this project that was expressed by the customers was mainly that the project did not have enough flexibility. For it to work smoother, more transport providers are required, in order to serve full demand. Also modes that covers long distance travels were not included, and was pointed out as a negative part. The flexibility part and cooperation between providers are some of Ubigo's largest issues, since the project is built upon collaboration between different companies. The boundaries between the different transport modes, public and private operators is still indistinct. The evaluation indicates that setting regulations may be the largest barrier to the growth of MaaS [13].

2.6.4 Interview with Trafikverket regarding new mobility solutions.

The conducted interview was with 2 employees at Trafikverket. The first one was an investigator that worked with digitizing and social sustainability. The second interviewer was also an investigator that works with digitizing although with a focus towards the transport system within planning in region west. The interview mainly consisted of questions about MaaS (see Appendix 1), but there were also some questions about AVs. Definition of MaaS within Trafikverket in Sweden is following:

> "MaaS is a concept where travelers buys or subscribes to a combination of possibilities for mobility instead of or as a complement to own or buy your own means of transport."

The interviewers discussed about the congestion question and how Trafikverket works with this problem. In general Trafikverket are mainly focusing on investments that will contribute to sustainability and on transport that does not take up to much land use e.g. railway, public transport lanes, bicyclists and pedestrian lanes like the ongoing project Västlänken. Furthermore, they have seen improvements in congestion after applying congestion charges around the city. Questions regarding innovation like MaaS and autonomous vehicles are not widely discussed yet at Trafikverket since they are estimated to be too far into the future but there are still some projects involving this anyway and the topic around innovation is growing within Trafikverket. The interviewers are certain that these new systems will be realized onto reality, it is only a question of time. The implementation of AVs may not be first in private cars but rather in freight transport and public transport, the interviewer claims.

The discussion about new mobility solutions is mostly on national level and in cooperation with EU/industry and academy. In the Gothenburg region, discussions about approval of experimentation on the national road network is also discussed. Trafikverket today have got an assignation of the government within mobility as a service which will promote demonstrations and pilots. Earlier, Trafikverket was also involved in the MaaS project performed in Gothenburg called Ubigo, but they had limited possibilities to work further with this project since it is considered to be a matter of commercialization of service. Trafikverket still works on how to handle data information that also is an important factor when it comes to developing MaaS. For MaaS to be implemented it requires a major cooperativeness between a lot of different stakeholders for it to work in reality which takes time to establish. The interviewers are more certain that the implementation of AVs is closer to be realized. The AVs have the right kind of prerequisites in Gothenburg for this to work since the representation of academy, industry and authorities is high and the research behind AVs can be out in good time.

Regarding people's travel behaviour, MaaS will have a great potential to change it eventually but the most efficient way of changing peoples behaviour is through political instruments, where the technology can open up for possibilities and will require political decisions argues the interviewers.

Some constraints regarding MaaS is the unwillingness to change transport means several times during the route which is a problem that can contribute to MaaS only working with one travel mode. The infrastructure when implementing MaaS will probably change. In what way is hard to predict since there are no answers on how the distribution of the shared ownership will be organised the interviewers claims.

2.6.5 Outputs from MaaS-literature

Before the implementation of MaaS will be realized in Sweden, many challenges needs to examined and solved for the integration to work correctly. In Sweden there are research going on regarding MaaS where one of the greater projects is the Ubigo project mentioned in Chapter 2.6.3. The trial was working good in Gothenburg and therefore it is now going to be implemented and tested in Stockholm as well for a trial period. The participants gave the Ubigo project a lot of positive feedback, although the largest disadvantages regarding the implementation for Ubigo was to get many stakeholders to cooperate with this system, and therefore it was not as flexible as it could be where the participants sometimes felt constrained by the deficiency of travel modes. The cooperation between stakeholders is a problem mentioned in the interview as well and may be one of the toughest challenges when it comes to the integration. To develop a MaaS system that will work well on Gothenburgs infrastructure, more research needs to be conducted. The expansion of MaaS onto Gothenburgs road network will require more investigations and planning for this system, where the conditions need to be totally based on Gothenburg. By establishing similar reports like the two mentioned in Chapter 2.6.1 and Chapter 2.6.2 is a good way to comprehend how well the system will be integrated on Gothenburg's own transport system but also with AVs.

Interviewing Trafikverket, they stated that the discussion around new mobility solutions have moved slowly in the past but that they have seen an interest in these topics during the past few years, and that the subject is becoming more relevant to talk about. On the behalf of the Swedish government, Trafikverket did get a mission regarding conducting more research involving a fossil-free fuels and MaaS [26]. The government have instructed Trafikverket to do a demonstration project together with other companies that will support mobility as a service. The aim behind the demonstration is to clarify which demands needs to be set on the physical and digital infrastructure to enable MaaS. Based on the knowledge about MaaS from this report, there are a lot of people working on research around the mobility service and how it can be incorporated with AVs, both in Sweden but also in Europe, which is positive for enabling the implementation in the future.

3 Methods

The conduction of this report focuses on what impact AVs have in terms of congestion level and vehicle-miles travelled (VMT) using assumptions and calculations from literature studies in section 2.4 and then simulating it in PTV Visum 2018. To the simulation part, Trafikkontoret assisted with a Visum-model of current traffic situation (2019) in Gothenburg that could be applied onto the calculations for the case studies. In addition to the calculations, a brief interview with Trafikverket about autonomous vehicles and MaaS was conducted and presented in Chapter 2.6.4.

3.1 Data description

Gothenburg is the second largest city in Sweden with 599 011 citizens in the urban center where the area is 215,13 km^2. It is a mono-centric city where several suburbs are situated around the city. Therefore, in the entire Gothenburg region, the population is 1 025 355 inhabitants with an area of 3 694,45 km^2 formed by 4 other municipalities. The car ownership in Gothenburg is 285 cars per 1000 inhabitants. In the city a well established public transport system exists, and the 28% of the inhabitants are using that system daily and 45% are utilizing the car as transport mode instead. The city have several actions planned to solve the congestion issues at the worst affected areas in Gothenburg. The municipality are planning extension of the infrastructure at several of the affected spots. The planned expansion is discussed in the analysis chapter and incorporated with the answers that this report's results of the simulation for current network gives.

The traffic simulations in Visum are based on Trafikkontorets latest model over Gothenburg's road network. The model used is a normal traffic assignment model based on matrices from Trafikverkets traffic model Sampers from year 2014. Sampers is a software program that is owned and managed by Trafikverket, and they also have future responsibilities for further developments of the program. Sampers is a national model system for general traffic analysis focused on private transport where the main services is to provide future forecasts, flows and different types analyzes [34].

The model is used in this report as a base to the calculations and for different scenarios are applied on the network. Gothenburg's road network model consists of 2824 links and for each link there are information about: type of roads, length of links, permitted transport on each roads, capacity, volume, traffic measurements over the past years etc.

The Visum model shows an general road network on Gothenburg's infrastructure system where it mainly focuses on the larger roads that has been extracted from Sampers. The model is not fully detailed and does not contain information about any public transport, pedestrians or bicyclists which can be a constraint. Matrices from Sampers are also constraint since they are fixed and not fully up to date because they are built upon flows from 2014. There are also many minor roads in the network that does not have any information at all and can cause decisive results when trying to simulate the model which can result in large aberrations on link level. Since the model only contains car traffic it loses the connection between different transport modes which entails that actions made on the road network does not give any effect on the entire car traffic, but only on the car transportation's route choice. Trafikverket are currently working on new more detailed traffic model, and due to that the frequency of updating this model are not contiguous anymore and instead is only updated when defects are found.

The literature study for the AVs is based on two reports:

1. The impact of private autonomous vehicles on vehicle ownership and unoccupied VMT generation written by Zhang et al. (2018)
2. The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios conducted by Fagnant et al. (2014)

Respective report is used onto calculations for this study. The first report focus on PAVs and therefore assumptions about this transport mode is reused for the calculations. The second report focuses on SAVs and the findings from this report are applied into this study when doing assumptions for SAVs.

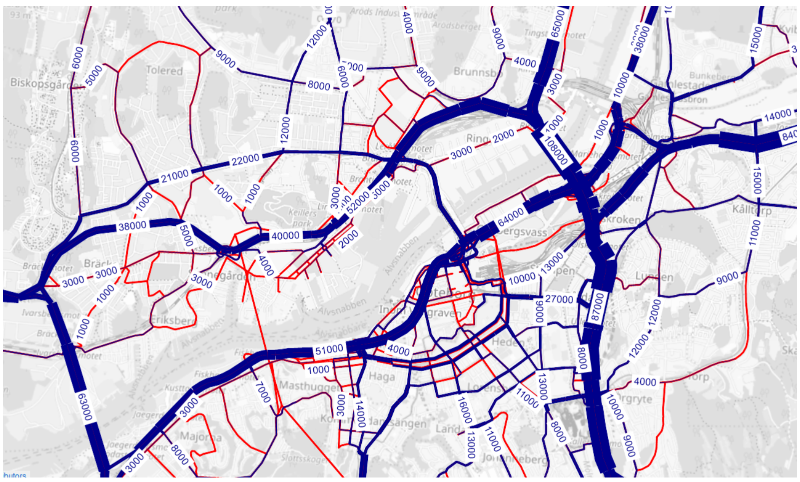


Figure 3.1: Part of Gothenburgs road network in PTV Visum, provided by Trafikkontoret.

3.2 Case studies for autonomous vehicles

The methodology of the first part begins with a literature study to obtain a broader understanding about the impact that autonomous cars have on VMT. Thereafter, literature about transport models, theory behind the calculations and the Visum program is collected to give an introduction to the result part. By reading different studies about AVs an examination on how these theories could be applied onto Gothenburg is possible to conduct.

For the result part the PTV Visum software was used as a tool where Trafikverket generously provided this project with their Visum model. The model was used for simulations to different AV scenarios where Trafikkontoret's model was used as a base. The data on Gothenburg's road network was extracted and inserted to excel, where it was recalculated based on assumptions from literature studies. Then, new values from the calculations were inserted and simulated again in the Visum program. Six scenarios was conducted to see how different AV fleets will impact the infrastructure in year 2019 and 2040 (see Table. 3.1). All the scenarios and part of their calculations are presented below and the first links in the excel file is found in Appendix 2.

Table 3.1: Overview on the six calculated scenarios in the report based on literature studies and Gothenburg's Visum model.

Literature assumptions for scenarios 1-6			
	Conventional cars	Private AVs (Zhang et al. (2018))	Shared AVs (Fagnant et al. (2014))
2019	Original model provided from Trafikkontoret without any changes.	Increase in V/C ratio for all road types based on AM peak hour. (See Table 2.2)	unoccupied VMT increase on 11%
2040	Forecast on year 2040 with a population growth factor set to 1%.	Increase in V/C ratio for all road types based on AM peak hour combined with the population growth of 1%. (See Table 2.2)	Unoccupied VMT increase of 11% combined with the population growth set to 1%.

1. **Traffic in year 2019**
   The first scenario is the original values from Trafikkontoret where no change has been made. The scenario represent today's traffic situation with conventional cars and is utilized as a base when comparing it towards other scenarios. The only calculations added to this scenario is the V/C ratio that will be used as the base value when calculating the congestion level on different links.

$$\textit{V/C ratio based on 2019: } (V/C)_{base} = \frac{Volume}{Capacity} \tag{3.1}$$

2. **Traffic in year 2040**
Scenario 2 is a forecast on year 2040 where a growth factor of 1% has been applied using the equation 3.2. The forecast shows the lowest amount of required change for the infrastructure demand during the 21 years since no more factors have been taken into consideration in this forecast. In this scenario, only the volume increases due to the population growth but the capacity on the roads stays the same since no infrastructure supply has been taken into account. The roads will be the same as for 2019, only with an added population. This forecast has also been used as basis when trying scenarios for PAVs and SAVs for year 2040.

$$Volume_{2040} = Volume_{2019} \times (1+i)^{2040-2019} \tag{3.2}$$

$i = 0,01$ Growth factor set to 1%

By using the volume estimated for year 2040, a new V/C ratio could be produced.

$$(V/C)_{40} = \frac{Volume_{40}}{Capacity_{19}} \tag{3.3}$$

3. **Traffic in year 2019 when using PAVs**
This scenario is based on assumptions from Zhang et al.(2018) report in Section 2.4. All conventional cars have in this scenario been replaced by a PAV fleet with scenario 1 as basis to the calculations. The information from Table 2.1 on how the V/C ratio would change for different road types was applied onto this scenario where the AM peak values were used. In excel the roads where sorted by road types and then different percentage of increase from Zhang's report were applied onto the different road types. From the calculations a rough estimation on how PAV could affect Gothenburg's road network, when these assumptions was applied.

To estimate the year 2019 with PAVs, the increment in V/C ratio needed to be multiplied into the equation and therefore Equation 3.1 was multiplied with the increase ratio from the literature.

$$(V/C)_{PAV_{19}} = \frac{Volume}{Capacity} \times i_{AMpeak} \tag{3.4}$$

i_{AMpeak} = Increment in V/C ratio based on road type according to Zhang et al. (2018) study (See Table 2.1).

$$Capacity_{PAV_{19}} = \frac{Volume}{\left(\frac{V}{C}\right)_{PAV_{19}}} \tag{3.5}$$

These equations was applied to every link in the road network. The new capacity for year 2019 with the PAV assumptions was then inserted into the Visum model and replaced the old capacity. When the model was run, the volume changed. With the new volume, new V/C ratio calculation were made to get both new capacity and volume in the equation in order to make the V/C relation correct.

$$(V/C)_{PAV,estimated_{19}} = \frac{Volume_{19new,PAV}}{Capacity_{19new,PAV}} \tag{3.6}$$

This new estimated V/C relation was later subtracted with the original V/C ratio (Equation 3.1) for every link and the result from this was the increase in the congestion level on each link in the network (Equation 3.7).

$$congestion\ level = \frac{V_{19new,PAV}}{C_{19new,PAV}} - \frac{V_{19}}{C_{19}} \tag{3.7}$$

When obtaining the increase in V/C ratio, Visum was used to see where the largest increment was found on different links in the network. The final step was to explain why the increase did appear at the particularly roads and then to suggest what kind of infrastructure supply and solutions could be performed on these roads.

4. **Traffic in year 2040 when using PAVs**
Here the scenario 2 was used as a basis to these calculations. The volume that was estimated for year 2040 is being used when calculating on the scenario with PAVs. It is still the same assumptions as for scenario 3 from Zhang et al. (2018) report.

$$(V/C)_{PAV_{40}} = \left(\frac{V}{C}\right)_{40} \times i_{AMpeak} \tag{3.8}$$

i_{AMpeak} = Increment in V/C ratio based on road type according to Zhang et al. (2018) study (See Table 2.1).

$$Capacity_{PAV_{40}} = \frac{Volume_{40}}{\left(\frac{V}{C}\right)_{PAV_{40}}} \tag{3.9}$$

The performance of this is done in the same way as in scenario 3 where the equations were applied to all links in the road network and the new capacity was inserted to the Visum model and then simulated again. New volume was then estimated and used for the congestion level results, where the new estimated V/C ratio was subtracted with the old original base scenario in 2019

$$(V/C)_{PAV,estimated_{40}} = \frac{Volume_{40new,PAV}}{Capacity_{40new,PAV}} \tag{3.10}$$

$$congestion\ level = \frac{V_{40new,PAV}}{C_{40new,PAV}} - \frac{V_{19}}{C_{19}} \tag{3.11}$$

5. **Traffic in year 2019 when using SAVs**
Scenario 5 is based on Fagnant and al. (2014) report where the result points to 11% of VMT increase when changing to SAVs from conventional cars. The result differs from Zhang et al (2018) report because this number is applied to all type of roads and is a general number of increase. The calculation for increment is presented in Equation 3.12. The result will get a rough indication on how an SAV fleet could affect Gothenburg.

$$(V/C)_{SAV_{19}} = \frac{Volume}{Capacity} \times i_{VMT} \tag{3.12}$$

i = 11% increase in VMT based on literature in section 2.4.

$$Capacity_{SAV_{19}} = \frac{Volume}{\left(\frac{V}{C}\right)_{SAV_{19}}} \tag{3.13}$$

The next step is to estimate a new V/C ratio followed by the congestion level to get out the most affected roads in the network.

$$(V/C)_{SAV,estimated_{19}} = \frac{Volume_{19new,SAV}}{Capacity_{19new,SAV}} \tag{3.14}$$

$$congestion\ level = \frac{V_{19new,SAV}}{C_{19new,SAV}} - \frac{V_{19}}{C_{19}} \tag{3.15}$$

6. **Traffic in year 2040 when using SAV**
The last scenario is based on year 2040 with the assumptions for an implementation of SAVs from Fagnant et al. (2014) report. The growth factor are taken into consideration and then an 11 % increase in VMT is added to the equations.

$$(V/C)_{SAV_{40}} = \left(\frac{V}{C}\right)_{40} \times i_{VMT} \tag{3.16}$$

i = 11% increase in VMT based on literature in section 2.4.

$$Capacity_{SAV_{40}} = \frac{Volume_{40}}{\left(\frac{V}{C}\right)_{SAV_{40}}} \tag{3.17}$$

New estimated V/C ratio were calculated following by the congestion level to get out the most affected roads in the network.

$$(V/C)_{SAV,estimated_{40}} = \frac{Volume_{40new,SAV}}{Capacity_{40new,SAV}} \tag{3.18}$$

$$congestion\ level\ for\ SAVs = \frac{V_{40new,SAV}}{C_{40new,SAV}} - \frac{V_{19}}{C_{19}} \tag{3.19}$$

Using these scenarios a rough indication on how AVs will impact the network can be obtained. The Visum program is used to define the links that will be overloaded to see where infrastructure supply will be needed. The results will bring a forecast overview on how to handle the demand and capacity that comes with AVs.

3.3 Analysis and scenario outputs

The method to the results was conducted by extracting information from literature studies and applying those assumptions onto data from the Visum model over Gothenburg's road network provided by Trafikkontoret. The given increase on congestion level was on PAV and SAV scenarios that was calculated and used in the traffic assignment models. The increase was applied onto every link in the entire network, to get a more accurate result and through the calculations a new capacity result was obtained. The new calculated capacity on the roads was inserted back to the model, and with the new values in the program, it was simulated again. New values came up and was once again extracted and used when calculating the change in V/C ratio (congestion level) for all the links in the network. The new values measures where the major congestion on every road type is expected in the network. The final step was to discuss the reason behind it and give future recommendations for that area.

A limit to the method is that the better way of doing this would be to estimate the increase in capacity due to AV introduction as well as the increase in volume and then run the assignment. Although the time limit was a constraint and it took time to get the data at this point (read more about limits in Section 3.4.

3.4 Limitations

The limitations of this study are as follows:

1. The assumptions made for the calculations are based on two studies Zhang et al. (2018) and Fagnant et al.(2014) where both studies are based on U.S. cities and systems. The result may not be entirely accurate since the conditions can differ based on which town the study is performed. This report's result are totally dependent on what kind of data that have been accessible, hence a simplified forecast.
2. The analysis would have been more realistic if more studies and factors where taken into consideration to give some more insights but due to the short time limit several things was neglected in the calculations. For example:
   - Ongoing or planned infrastructure is not taken into consideration in the results which can give deceptive results of the reality since it does have a large impact on the road network and congestion in Gothenburg.
   - The Visum model and calculations only consider car traffic, all other transport modes are overlooked.
   - The forecast for year 2040 is very simplified where only a growth factor is counted on. The forecast gives the minimal amount of infrastructure supply needed for the network. More factors considered would give a more relevant traffic forecast.
   - The Visum model have several uncertainties and is not entirely reliable but for this report that also is being neglected. To read about the uncertainties see Chapter 3.1.
   - The report only takes in consideration the V/C relation to the scenarios. In the literature studies there are more facts about vehicle reduction that follows with AVs but for this report that factor is overlooked.
3. For the report the most interesting factor was the V/C relation. No interests has been shown for the volume or capacity separately. There was not enough time to go into the model and make adjustments on every link for both the capacity and volume. In order to achieve the recommended relationship, we did decrease the capacity and kept the volume. In reality the volume will be increased too since more people will utilize the new system.

4 Results

In following chapter the results from the calculations for the two base scenarios are presented. The first scenario is based on year 2019 and represent the current traffic situation. The second scenario is a forecast on year 2040 with a growth percentage set to 1% according to Equation 3.2. Both scenarios are then tested with two different AV fleets:

- private AVs: Conventionally cars are fully replaced with PAVs, where V/C ratio assumptions are based on Zhang et al. (2018) report in Section 2.4.
- shared AVs: Fleet have replaced conventional cars. The assumption on the VMT is based on Fagnant et al (2014) report mentioned in section 2.4.

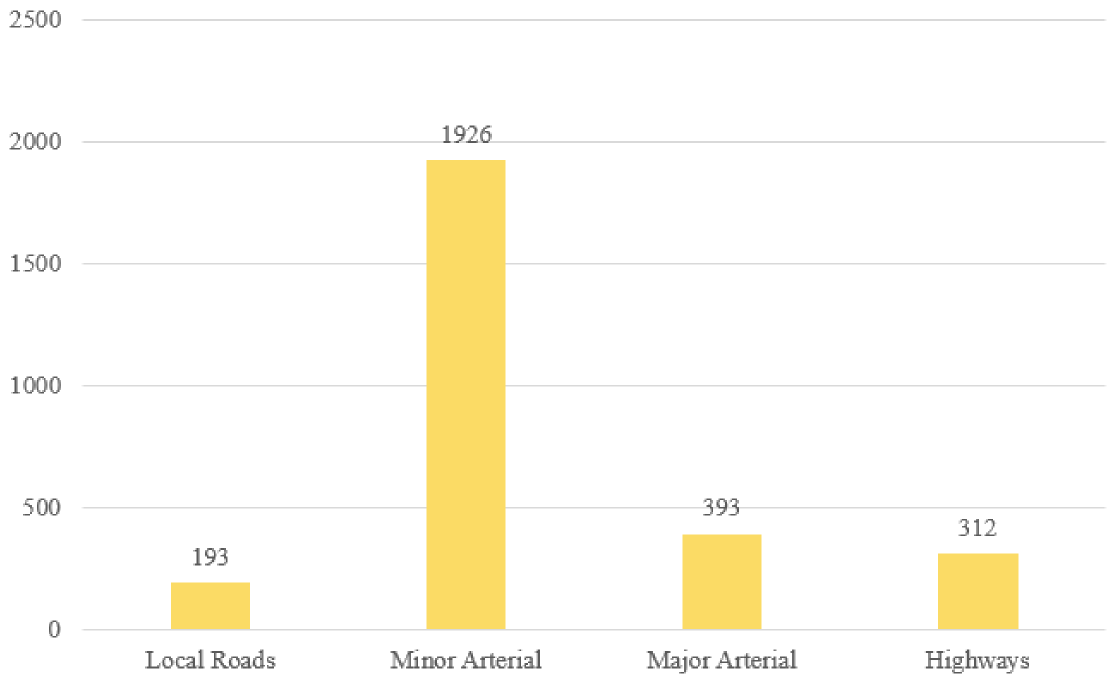


Figure 4.1: Road distribution on Gothenburgs network divided into four road types.

The Chart 4.1 represent the road distribution in Gothenburg city divided into four subcategories: local roads, minor arterial, major arterial and highways. The highest represented road in the chart is the minor arterial roads where it is almost 6 times higher than the rest of the roads among the subcategories. Information on some local roads are missing from the Visum file since this model mainly represents the main roads in the network.

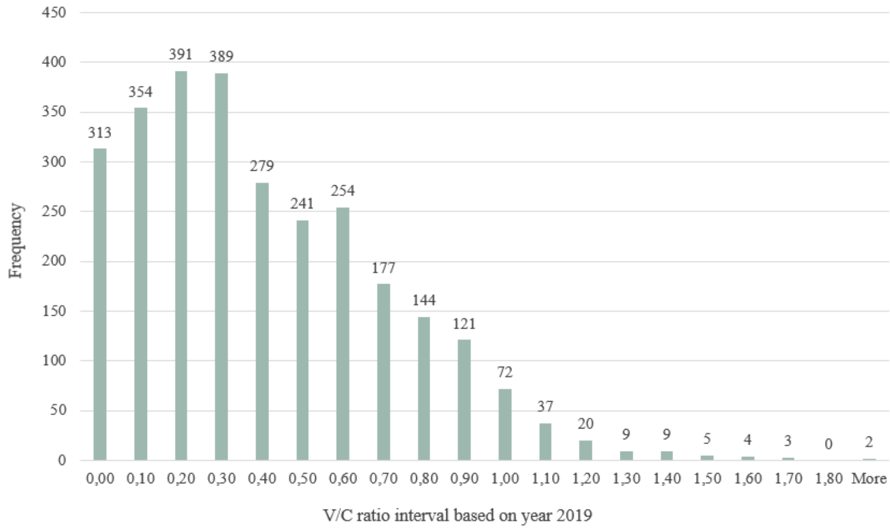


Figure 4.2: V/C ratio (congestion level) distribution based on year 2019.

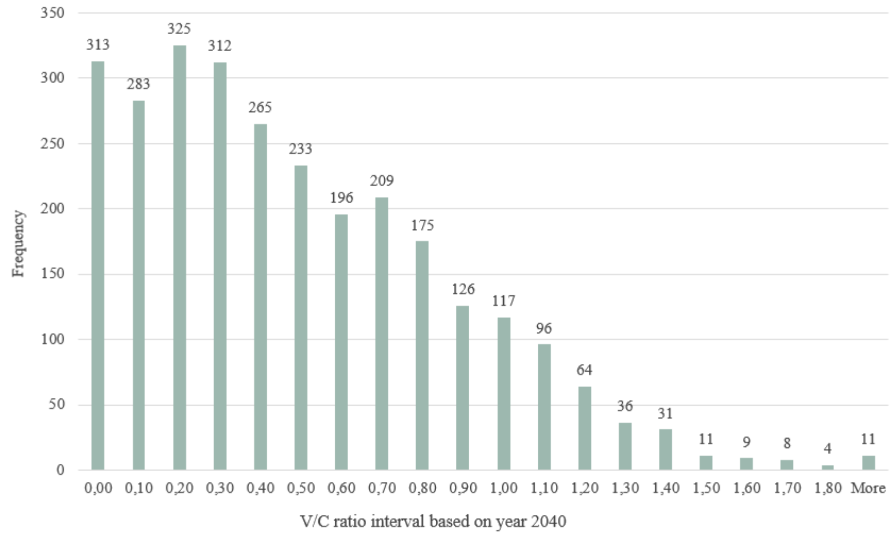


Figure 4.3: V/C ratio (congestion level) distribution based on year 2040.

Fig. 4.2 and Fig. 4.3 shows the V/C distribution for the road network in Gothenburg without any AVs. It shows a V/C ratio interval on a scale from 0-1,8 on the x-axis and the frequency on the y-axis that explains how many roads is within a certain interval. Comparing Fig.4.2 to Fig.4.3 it shows that within the V/C ratio interval 0-0,6 the frequency is higher for year 2019 and for interval 0,7-1,8 year 2040 have a higher frequency. The results shows that more roads are now within the interval with higher V/C ratio which indicates that it will be more congested in the future if no change in infrastructure is made or new mobility solutions are applied until this year.

4.1 Traffic distribution when using AVs

In this section, the previous base scenarios for year 2019 and 2040 have been used when applying assumptions for PAVs and SAVs. Under Chapter 3 the calculation method is presented for following scenarios and in this chapter, the outcome from the calculations are presented.

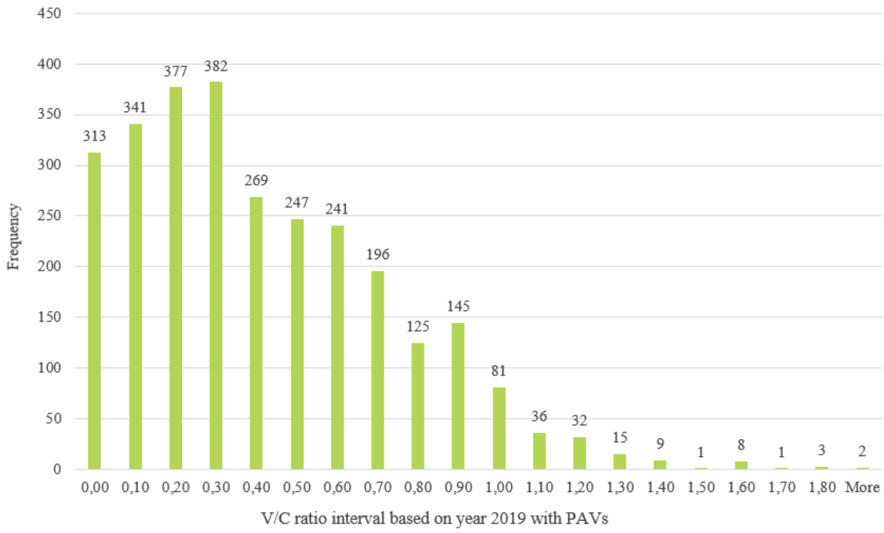


Figure 4.4: V/C ratio (congestion level) distribution based on year 2019 when the fleet is fully replaced with PAVs.

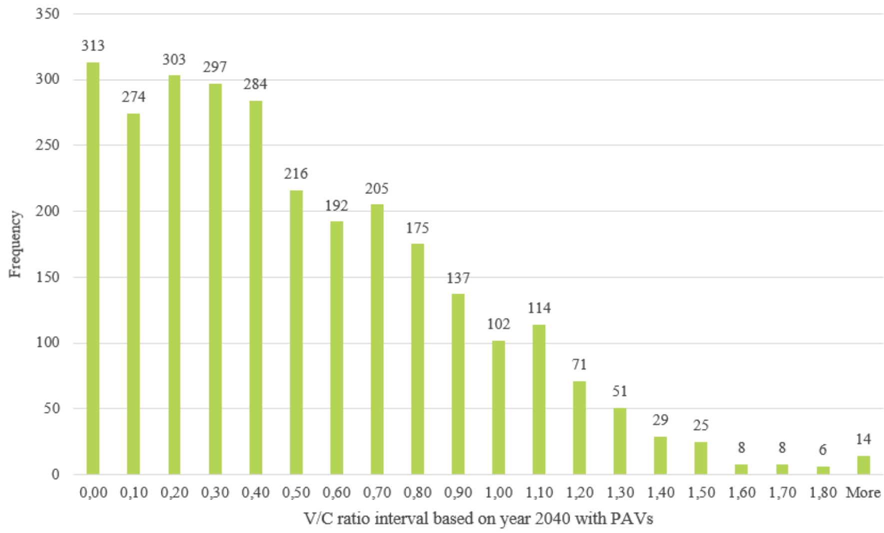


Figure 4.5: V/C ratio (congestion level) distribution based on year 2040 when the fleet is fully replaced with PAVs.

Fig.4.4 and Fig.4.5 represent Gothenburg's road network when it is fully replaced with PAVs for year 2019 and 2040. The pattern for PAVs is almost the same as the base scenarios since it follows the pattern from the base scenarios (Fig.4.2 and

Fig.4.3) where the year 2019 have a higher frequency of roads within the interval 0-0,6 than for year 2040. Assumptions made from Zhangs et al. (2014) theory (Table 2.1) the increase of V/C ratio is set to 3-8% and therefore PAV scenarios will have some higher frequency of roads within interval >0,7. Comparing the two PAV scenarios towards each other, the scenario based in year 2040 will have a higher congestion level due to the increment in population over the past years. Comparing these two PAV scenarios towards the base scenario, there will be a higher congestion level when applying AVs. This can be seen by looking at the histograms for PAV scenarios, a higher frequency on the higher V/C ratio values are estimated in comparison to the base scenario.

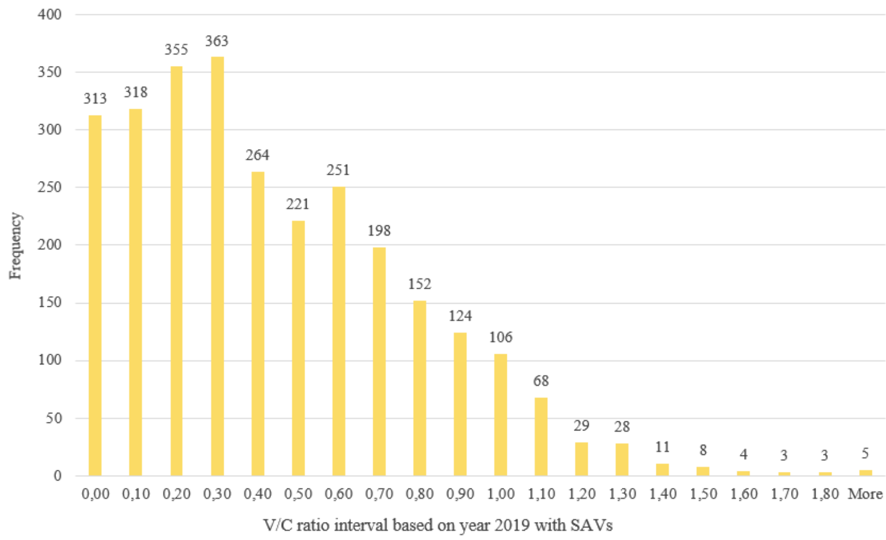


Figure 4.6: V/C ration distribution based on year 2019 when the fleet is fully replaced with SAVs.

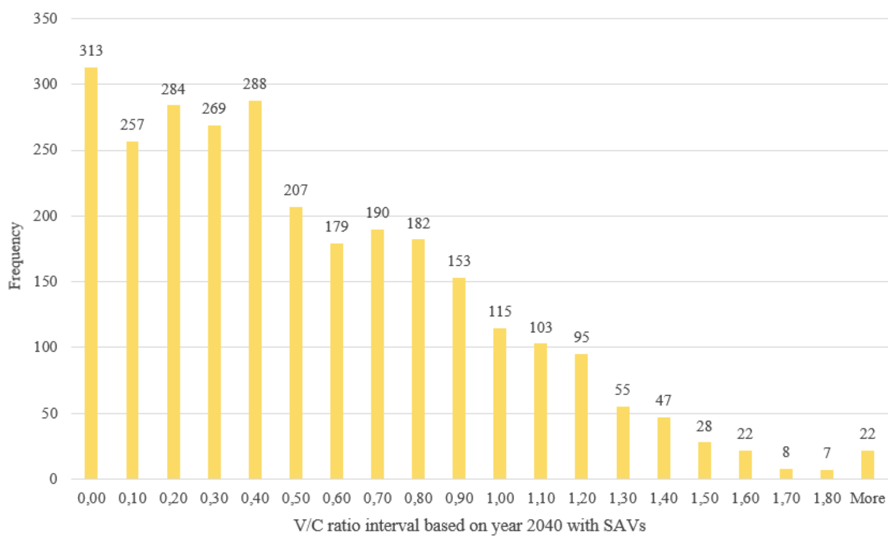


Figure 4.7: V/C ration distribution based on year 2040 when the fleet is fully replaced with SAVs.

Fig.4.6 and Fig.4.6 represent Gothenburg's road network when it is fully replaced with SAVs instead of privately owned cars. The difference with SAVs is an 11 % increment in VMT according to Fagnant et al. (2014) for all road types in the network. The increment will contribute to a higher frequency of roads in the interval 0,6-1,8 in comparison to scenarios without any AVs (Fig.4.2 and Fig.4.3). Comparing the two SAV scenarios towards each other, the scenario based in 2040 will have a higher congestion level due to the increment in population over the past years. SAV scenarios in relation to PAV indicates that there will be a higher increase in the V/C ratio, which is consistent with literature and calculations, since the assumptions for SAVs have a higher increment in VMT. Comparing the AV scenarios towards the base scenario without any AVs, it shows that it will be a higher V/C ratio when applying the vehicles. The increase in V/C ratio is seen in the histograms since AV scenarios have a higher frequency on the higher V/C ratio is estimated than from the base scenarios.

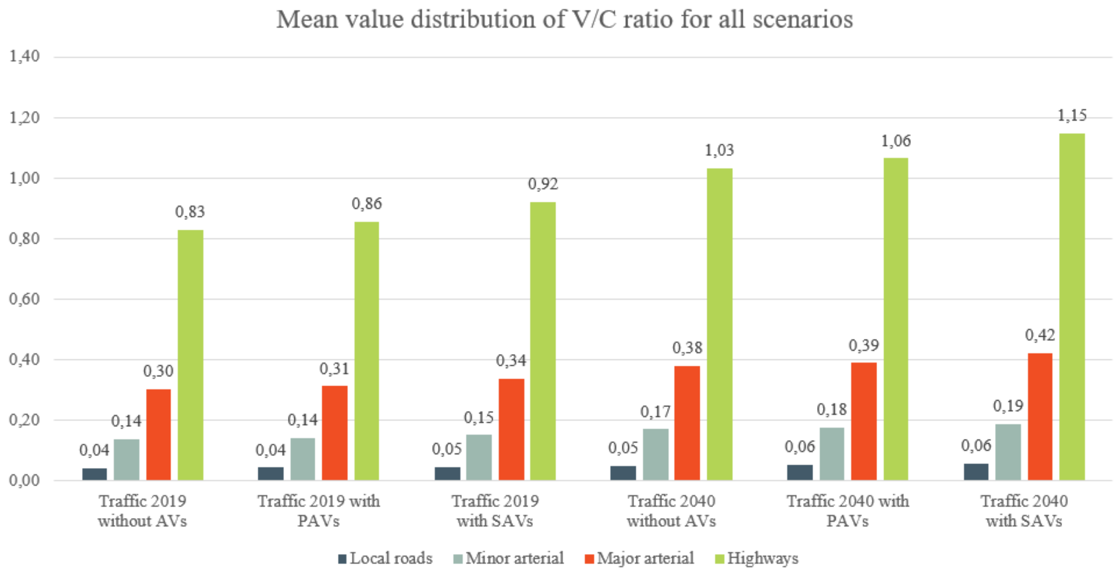


Figure 4.8: Mean value distribution on V/C ratio for all scenarios.

Fig. 4.1 is presenting the mean value distribution of V/C ratio between the four road types: Local roads, minor arterial, major arterial and highways. The columns are then divided into six scenarios: Traffic 2019 without AVs, traffic 2019 with PAVs, traffic 2019 with SAVs, traffic 2040 without AVs, traffic 2040 with PAVs and traffic 2040 with SAVs. From the chart it shows that there will be more congestion using PAVs and SAVs which is consistent to the assumptions made. There will also be more congestion in year 2040 if the infrastructure looks the same which is reasonable due to the population growth factor and deficiency on infrastructure supply made until this year. The patterns will look the same when applying AVs, where the most congested roads will continue be the highways. As mentioned before in the data description in Chapter 3.1, there are some deficiency of data for smaller roads, making the result not entirely consistent with the literature. From literature studies in Chapter 2.4 it indicates that the most radical impact on the congestion level will be on the smaller roads, which does not show in this result. The highest increment in congestion level compared to the base scenarios lies between 15-23 % for some particular links in the network when applying AVs.

The figures below are extracted from the model in Visum and are representing different scenarios for year 2019 and 2040. The four different road types behaves approximately the same in respective scenario throughout the model and therefore places have been selected to roughly represent these four road types in the network. The roads presented in the result parts have a higher congestion level than other roads in their category, since this is of interest to understand why this increase have appeared at these particular areas. Fig.4.9 to Fig.4.20 represent scenarios in 2019. The first picture in every figure represents the base scenario without any AVs in 2019 followed by two pictures below that represents PAV and SAV scenarios. From Fig. 4.21 to Fig.4.28 the scenarios from 2040 are shown. The scenarios for 2040 are presented in the same way, with the base scenario for 2019 followed by PAV and SAV scenarios from year 2040.

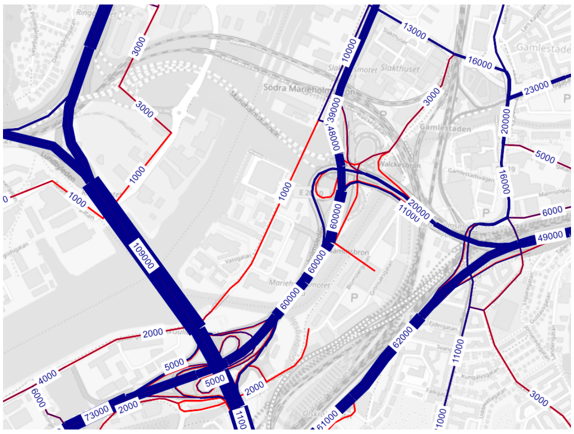
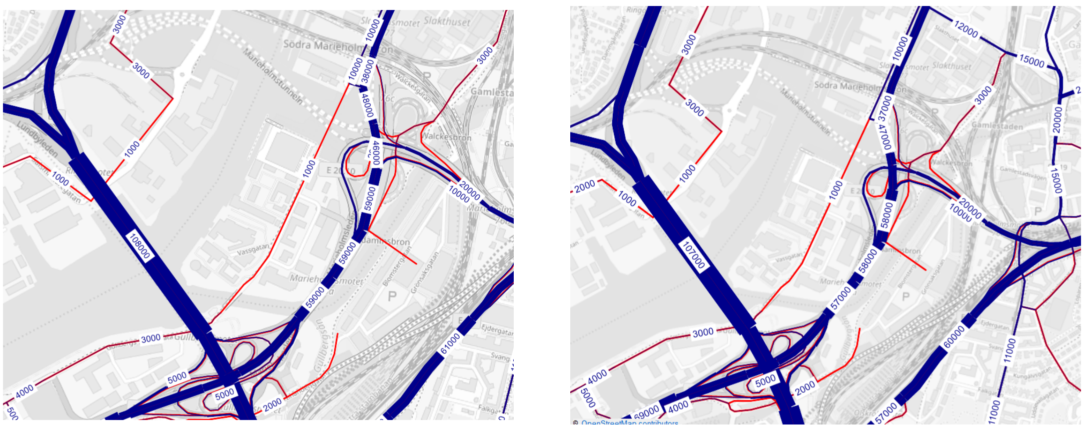


Figure 4.9: The amount of traffic at Marieholmsförbindelsen without AVs in year 2019.



(a) With PAVs

(b) With SAVs

Figure 4.10: The amount of traffic at Marieholmförbindelsen when using AVs in year 2019.

From Fig.4.9 and Fig. 4.10 the flows are presented. The figures presented shows how the volume will change and looking at SAVs there are lowered amount of flows at some links. The flows in scenarios with AVs will decrease which is a contradict towards the literature which happens because of the limitations in the report. In calculations the capacity is changed and the volume does stay the same. In reality when implementing AVs the volume will go up, causing more flows than it does for this result which is described in Chapter 3. These values on flow rate in the following scenarios are inconsistent towards the literature study. From the V/C ratio calculations in Appendix 2 we can see an increase in congestion level by 9 % when switching from conventional cars to PAVs and for the SAV the ratio will increase by 19 % in this area. Comparing it towards the literature studies it is consistent since they also find increment in congestion level when switching to AVs. From the excel file, the highest congestion level is shown and through that file, the link where the high level is situated can be analysed and shown in Visum. In Visum, conclusions on why this increase in congestion level appears at that particular place can be answered by looking at location and nearby roads.

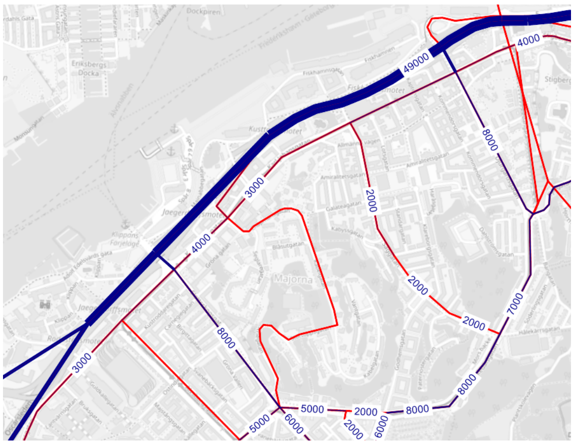


Figure 4.11: The amount of traffic at Oscarsleden without AVs in year 2019.

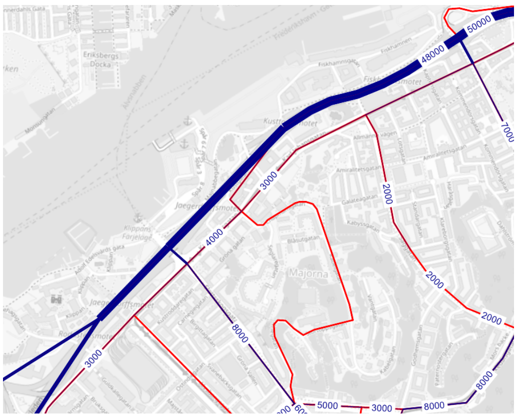


Figure 4.12: With PAVs

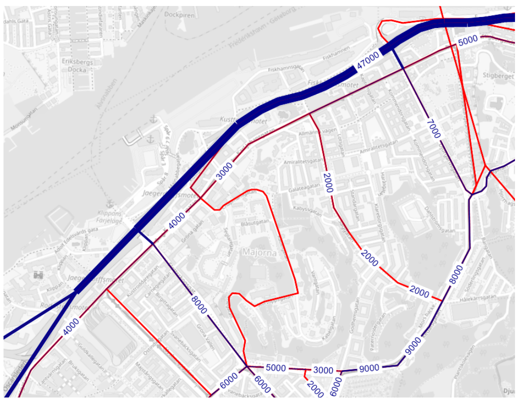


Figure 4.13: With SAVs

Figure 4.14: The amount of traffic at Oscarsleden when using AVs in year 2019.

From Fig. 4.11 and Fig. 4.13 the flows at Oscarsleden are presented. Figures shows approximately the same results as in previous scenario, but looking into Appendix 2 and the congestion level it will increase by 5 % when switching from conventional cars to PAVs and for the SAV the ratio will increase by 16 % in this area. Comparing the PAV and SAV scenarios towards the literature studies and their assumptions on increment it is consistent.

Figure 4.15: The amount of traffic at Mölndalsvägen without AVs year 2019.

(a) With PAVs **(b)** With SAVs

Figure 4.16: The amount of traffic in Mölndalsvägen with AVs year 2019.

Mölndalsvägen is presented in Fig. 4.15 and Fig. 4.16. The flows in this area will vary where the largest road will have the lowest flow in the SAV scenario meanwhile the roads around it will differ in how they change. Mölndalsvägen separately will decrease when implementing AVs which is a contradict towards the literature study that has been explained earlier in paragraph one in this chapter, where the time limit is a constraint. From the V/C ratio calculations there will be an increase in congestion level by 7 % when switching from conventional cars to PAVs and for the SAV the ratio will increase by 15 % in this area. Comparing it towards the literature studies it is consistent since they also find increment in congestion level when switching to AVs.

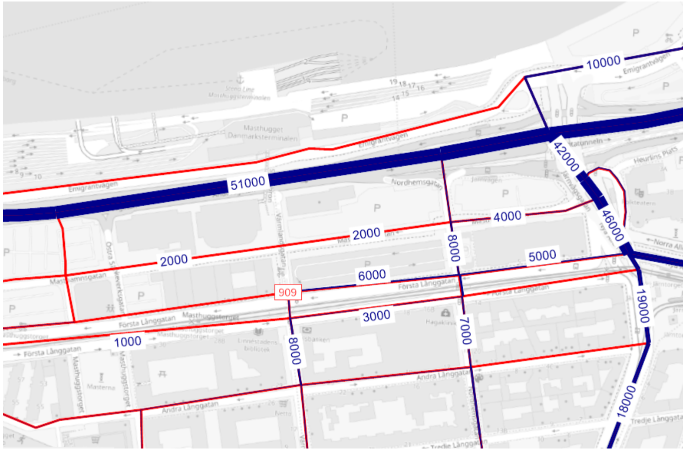


Figure 4.17: The amount of traffic at Emirentgatan without AVs year 2019.

(a) With PAVs

(b) With SAVs

Figure 4.18: The amount of traffic at road Emirentgatan with AVs year 2019.

From Fig. 4.17 and Fig. 4.18 the flows at Emirentgatan near Järntorget are presented. Here it shows how the volume will change and looking at AVs there are going to be increased amount of flows at some links. From the V/C ratio calculations in Appendix 2 we can see an increase in congestion level by 9 % when switching from conventional cars to PAVs and for the SAV the ratio will increase by 14 % in this area. Comparing it towards the literature studies it is consistent since they also find increment in congestion level when switching to AVs.

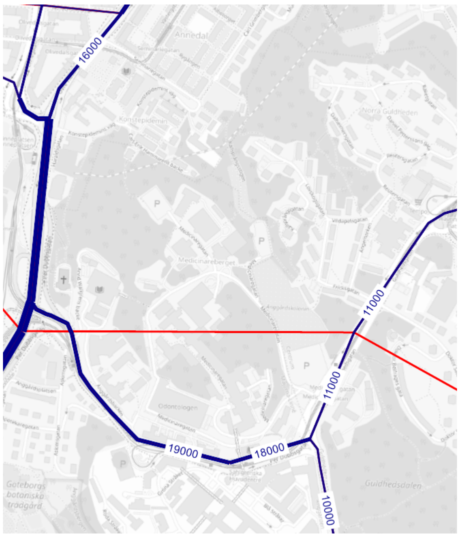
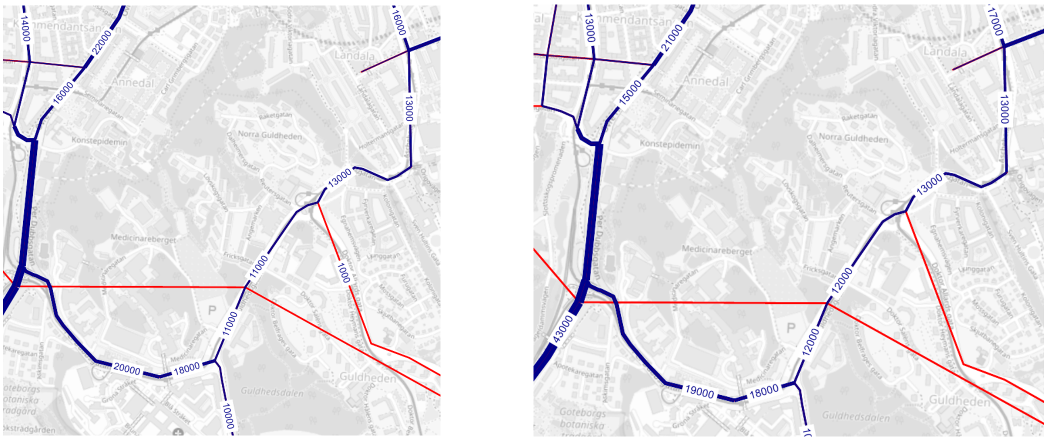


Figure 4.19: The amount of traffic in Guldheden without AVs year 2019.



(a) With PAVs

(b) With SAVs

Figure 4.20: The amount of traffic in Guldheden with AVs year 2019.

From Fig. 4.19 and Fig. 4.20 the flows at Guldhedsgatan in Guldheden are presented. The area around Guldheden is also consistent with the literature studies since the congestion level shows an increase when adapting to AVs a slightly lower increase when adapting to PAV by 6 % and a higher increase by 10 % for SAVs which agrees with literature assumptions and at the same time the flows from Visum agrees with these assumptions.

In the results below, the road network for year 2040 are presented and the execution is done in the same way as above. The scenarios are on four different road types and the chosen roads are the ones with a higher congestion level than rest of the roads within their group. The results shows where the V/C ratio will have the largest affect and where the congestion level can become a problem. The first picture presents the base scenario in 2019 and the pictures below are PAV and SAV scenarios from 2040.

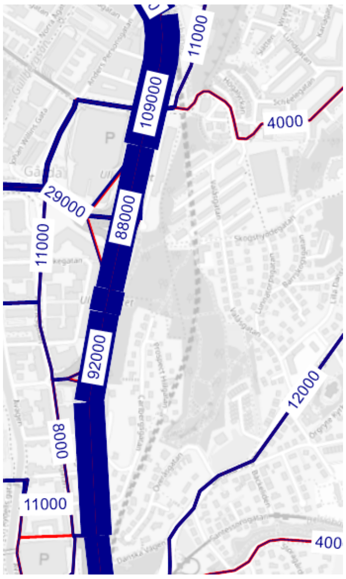
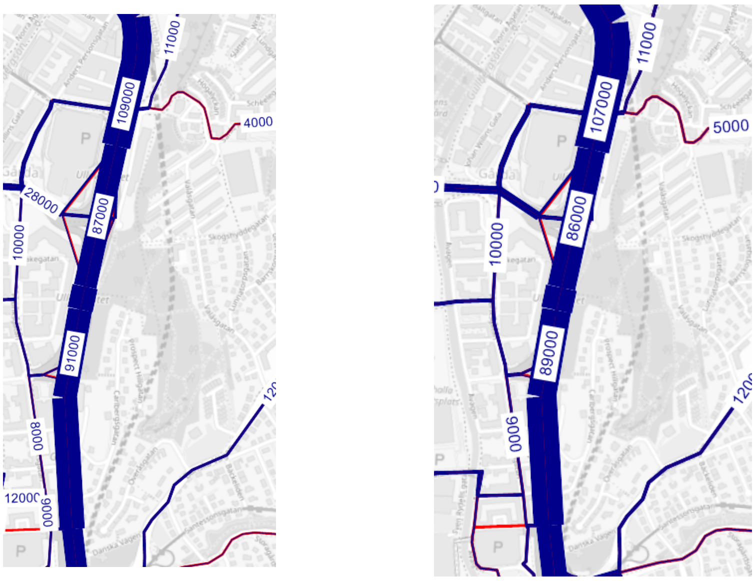


Figure 4.21: The amount of traffic in E6 south without AVs in year 2019.



(a) With PAVs

(b) With SAVs

Figure 4.22: The amount of traffic at E6 south with AVs in year 2040.

Fig. 4.21 and Fig. 4.22 shows how the the flow looks like on highway E6. In Appendix 2 it shows that the congestion level does not increase to much in percent when converting to AVs. For PAVs the increase will be 2 % and for the SAVs it will be 6%. These low increments in highways are consistent throughout the model. Even if the increment seems low when comparing it towards other examples in the result part, it is still a large amount of traffic on the highways since the capacity on these roads are higher comparing to other roads in the network.

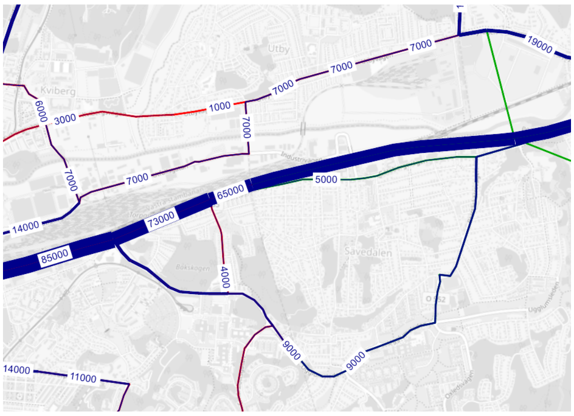


Figure 4.23: The amount of traffic in Alingsåsleden without AVs in year 2019.

(a) With PAVs **(b)** With SAVs

Figure 4.24: The amount of traffic at Alingsåsleden with AVs in year 2040.

For this arterial road the increment in congestion level will be 6% with the PAV scenario and 21% with the SAV scenario. The calculations are presented in Appendix 2. The large increment in SAV in this scenario is discussed in the analysis part.

Figure 4.25: The amount of traffic in Masthamnsgatan without AVs in year 2019.

(a) With PAVs **(b)** With SAVs

Figure 4.26: The amount of traffic at Masthamnsgatan with AVs in year 2040.

In this scenario the figures present minor roads. Overlooking at the congestion level here it shows an increment of 7% for PAVs and an increment of 13 % for SAVs. These percentages are slightly higher than for the larger roads which usually lies between 1-5% for their increment. It is consistent with the literature studies were the authors claims that the most radical impact on the congestion will be on the minor and local roads.

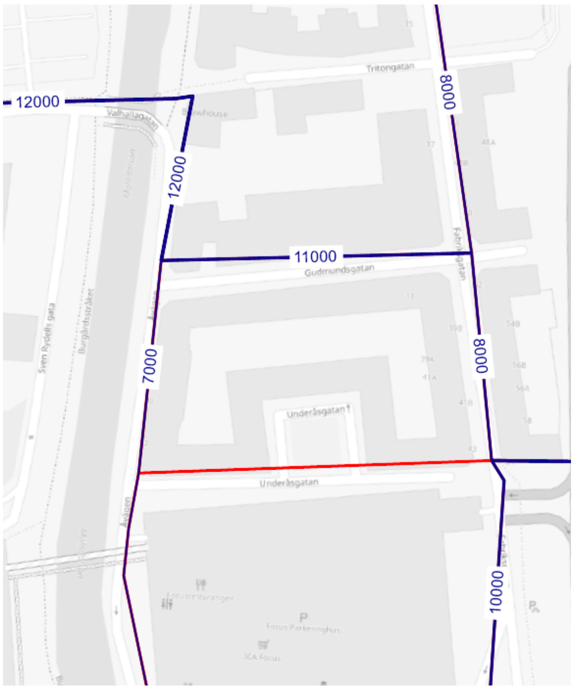
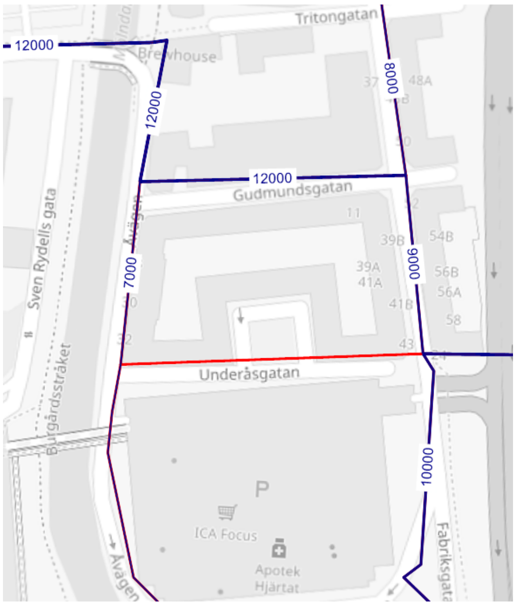
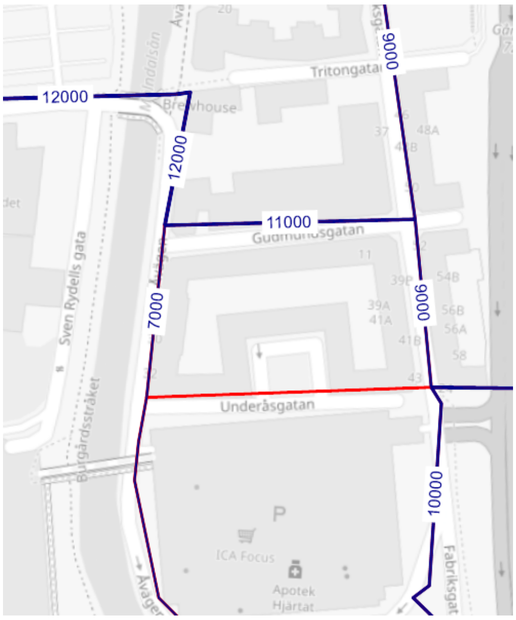


Figure 4.27: The amount of traffic at Fabriksgatan without AVs in year 2019.



(a) With PAVs



(b) With SAVs

Figure 4.28: The amount of traffic at Fabriksgatan with AVs in year 2040.

For this local road the increment in congestion level will be 11% with the PAV scenario and 6% with the SAV scenario which is consistent with literature studies were the authors claims that there will be a higher impact on the congestion will be on the minor and local roads.

5 Analysis

Researches agrees that there will be an introduction of AVs in the future but how and in which order the implementation is going to be realized in is harder to predict. In terms of the suitable solution, it may begin with a simple replacement of AVs, where households adapt it as a private car, shared within the family. The technology can later expand to a sharing system where it begins with sharing AV cars between families within a neighborhood and in the and in the end evolve to entire cities. The final and most complex solution when implementing an AV system will be when every transport modes are integrated together alongside other intelligent mobility concepts like MaaS.

The order for implementation for the different concepts is just a theory and it does not necessarily mean that it will happen this way. MaaS and other solutions can work on current traffic as well and may be integrated before the AVs. The procedure of implementation will depend on several factors, for instance: What system will be the most affordable, what type of mobility are people in the city interested in and what are the demands on different places around the world? AV systems may not be realized in the same way worldwide since all countries are characterized by their own politic and it is most likely that the implementation will reflect that (e.g. some countries may begin with a private fleet while other countries prefer a shared etc.).

To give a recommendation of which fleet may be the most optimal for Gothenburg's network can be difficult based on only this report's result in Chapter 4. In the result, both AV scenarios indicates to an increase in congestion level, which is a crucial factor when transition to a new transport mode. However, several factors have been excluded from this report due to the time limit along with uncertainties from the Visum model and calculations mentioned in limitations in Chapter 3.4 which could have a large impact on the congestion level. In Chapter 5.1, the deceptiveness of the result and deficiency of some factors are discussed.

5.1 Analysis of method

From the literature studies used for the calculations it is important to understand the insecurities that follows when applying these values onto Gothenburg's road network and different scenarios. Zhangs's et al. (2018) report's main deviation is that the report is based on Atlanta's road network as mentioned in section 2.4, a town with different conditions than Gothenburg. Atlanta is slightly smaller with a smaller area than Gothenburg and it is more car oriented with a less developed public transport where only 11% of the citizens utilize it. In Gothenburg the amount of people using the public transport is 28 %. The usage for public transit in Sweden is more than the double of Atlanta's usage which indicates that the assumptions made on V/C ratio may not agree with Gothenburg's data. The results from the report indicates to larger increase in V/C ratio in residential areas which can depend on less developed public transit, a value that can differ in Sweden due to higher usage of the public system. One similarity between Gothenburg and Atlanta is that they both have a mono-centric design's on the town, where many are living in the suburban areas outside the city centre. When more people are living in the suburbs, it will indicate to a higher relocation between home and residential regions. To keep down the excessive VMT it is important to not have a high mismatch between these two destinations because of the daily trips needed for errands and work/school.

The main insecurities from Fagnant et al. (2014), is that their results are based on a discrete trip-vehicle distribution model, with a theoretical grid network on an artificial city. It is not based on a real city, and the demand applied onto the gridded network are based on national statistics for the U.S. which means that this report's demand also varies from Swedish data. The result shows an increase in the VMT by 11 % for the synthesized city, a value that has been re-used for this report in the calculations. This report's calculations implies that there will be an increase of 11% on every road in the entire network of Gothenburg which can be misleading since in reality, various roads will be affected differently. Adding the increased VMT value from Fagnant et al's. (2014) report, onto the calculations can bring incorrectly results for the simulations in Visum and can be an indicator on the general high increase of VMT in all SAV scenarios, for this report.

The Visum model provided by Trafikkontoret comes with abnormalities in comparison to how the reality looks like which affects the results. The network focuses on the main roads and because of that, input data is missing on some of the smaller roads in the network which brings incorrect results on link level. The deficiency of information, contributes to results that differs from the literature studies results in Chapter 2.4. The insecurities of the model affects the result part negatively, since the conclusions are dependent on how the links will behave and where the highest changes will be in the network (e.g. The links with the highest congested level in the model may not be the most congested in reality). The Visum model is built upon flows from 2014 and is not entirely up to date which gives incorrect flow rates in some areas where there have been an expansion of infrastructure made over the past 5 years.

5.2 Analysis of result

When inquire into the result, there will be a clear increase in congestion level throughout all AV scenarios which is important to consider since it can have a large negative impact on the road network and its capacity. The extent of the increment in congestion comes from that AVs do target a wider population, is a more convenient travel mode and use better cars with a more reliable time scheme. In addition, if there would not be any privately-owned cars in the system, the price for using the shared ones will be less expensive which opens up the accessibility for more people utilizing these cars. The increase in utilization of the cars will enhance the excessive routing between different origins and destinations. Due to the potential increase it becomes important to set right kind of demands and policies to the operators and stakeholders so that AV technology develops in the most sustainable way possible. How the cars are being marketed together with policies, have a big impact on the congestion. Added VMT due to these aspects is a big disadvantage that weighs heavier than many other benefits that AVs bring.

Investigating the scenarios in the result it is clear that the worst scenario that contributes to the highest increase in V/C ratio is when adapting to SAV in year 2040 since this forecast includes a growth factor. From the result the most congested areas will still be the highways but when adjusting the simulations, the most radical impact on congestion level that comes with AVs will be found on smaller and minor roads. Calculations from the result is consistent with Zhang's et al (2018) and Fagnant's et al. (2014) results' where both reports assumes an increase in VMT when using AVs. Even if this report's result is consistent with these two literature studies, there is still a higher increment in congestion levels at some particular areas. The peak hours will be the most congested in all scenarios performed in the result and since the AVs have the potential to choose routes the distribution of roads will differ from today where the use for minor roads will increase since AVs will choose less congested routes. The downside of choosing these roads is that they do not have the same capacity and are often located in residential and quieter areas which can bring an unsafe and unpleasant environment amongst people living there.

Analyzing the simulations in Visum it shows that when applying the PAV and SAV scenarios in the model there will be a lowered flow rate. A lowered flow rate is a contradiction towards literature studies in Chapter 2.4 that assumes an increase in traffic. The results depends on the uncertainties that comes with calculations and model but has been constrained as a limit in Chapter 3 and due to that is showing a reverse result in the model. The calculations are adjusted so that they correspond to the increase in traffic from literature studies in Chapter 2.4, where the V/C ration (congestion level) have been analyzed. When doing these calculations, only the capacity is taken into consideration and has been recalculated on with the values of V/C ratio increase. In order to match the literature studies entirely, the volume also needs to be changed since this value goes up as well in reality. To change the volume, a detailed calibration in the Visum model needs to be performed but due to the short time limit this part was neglected and put in the limits in Chapter 3.4.

The calculations is still accurate since the report's main focus is the V/C relation and how it changes when applying it onto scenarios.

In Chapter 5.2.1 below, a discussion on where the increment in congestion level will strike the hardest in Gothenburg's road network model based on the four road types (local road, minor roads, arterial roads and highways).

5.2.1 The affect on Gothenburgs infrastructure using AVs

Analyzing the V/C ratio in the result from the calculations it shows a clear indication that the most affected roads will be the minor and local roads. These road types will experience the highest change since they do not have as high capacity as the larger roads have. In general, the majority of the smaller and minor roads can be found in the suburban and rural housing areas where the neighborhood is more car oriented according to data from the city of Atlanta.

Overall, the highways and arterial roads do not increase more than 1-8% in congestion level for both fleet scenarios. These increment in congestion is consistent with literature studies that has been used for the calculations and can depend on a higher road capacity. For the PAV, values are taken from Zhang's et al. (2018) results where it assumes that the V/C ratio will differ depending on road type. For SAV scenarios, values from Fagnant et al (2014) presents an increment on 11% which have been applied onto every road type, contributing to more congested scenarios. The certainty of these values can not be seen as equivalent and therefore it can be unjust when comparing these two scenarios towards each other. The forecast calculated for year 2040 only considers a growth factor and for more accurate forecasts, more factors needs to be applied onto the calculations. For this report the growth factor is enough since this it indicates the least amount of actions that needs to be taken to the infrastructure improvements.

The cases presented in this chapter are some of the roads that have had some deviation, where a higher congestion level can be analyzed in comparison to other roads in their road type group (local road, minor road, arterial road and highways). A discussion on what potential reasons causes the larger increment in these particular areas is summarized.

Marieholmförbindelsen is an important connection for cars and other transport modes, situated in Gamlestan in Gothenburg. Today there are a lot of traffic in this area, making the connection congested. The surrounding roads that intersects this area consists of mainly highways and arterial roads. Marieholmförbindelsen is a direct link that connects people from the suburbs north-east of Gothenburg to the other side of the city or the centre. Due to connection, many commuters are utilizing these roads, which can be an impelling reason for the congestion that gathers at this connection. Implementing AVs scenarios from 2019 onto Marieholmförbindelsen will contribute to an increase in congestion level with 9% for the PAV scenario which is consistent with Zhang et al. (2018) result in increment of V/C ratio that for arterial roads and highways are between 3-5%. The percentage value is calculated by subtracting the current scenario of PAV 2019 with the original base scenario. 9 % is a high number of increase when comparing it towards the other results for the same type of road but the reason for that can be the restricted amount of connections in this area. For the SAV scenario the congestion level will rise to 19 % which is a high number of increase, but still is relevant since the assumptions from Fagnant et al. (2014) are higher than for the PAV scenarios and assumes that there will be a 11 % increase. The 11 % increase in VMT applies onto every road type as mentioned before which also induces the high increase at this location. The result gives a clear indication on the congestion where the capacity on the roads will not add up to the demand if future scenarios are added. Gothenburg city are right now expanding the Marieholm connection and the infrastructure around this area that today almost is done. The flows in Visum does not show new infrastructure supply entirely since the model is build upon traffic measurements from 2014 and the latest updates on flows may not be accurate because of the unfinished construction.

Oscarsleden is an arterial road located in city centre that extends from approximately Götatunneln to Kungstensmotet/Älvsborgsbron. Since it is located in the city centre it will have a large amount of congestion in the base scenario as well. The road connects commuters from Majorna and Frölunda to the city centre but also people that comes from Hisingen and are crossing over the Älvsborg bridge. The road is trafficked today and causes queues in the worst peak hours because people need to go home or to work. Adding AV scenarios onto this area there will to be an increase in the congestion level. When applying 2019 scenarios, the PAV will have an increase of 6 % and applying the SAV scenario it will increase by 16 % on Oscarsleden. The Göta tunnel that is connected to this road is a relative new infrastructure supply that has increased the capacity in this area but when investigating the calculations in this report, the capacity from the tunnel may not be enough for future mobility applications. Adding more infrastructure supply as future work will be complicated since the road is isolated by Göta Älv on one side and the city centre on the other side, making the region hard to expand in the required amount. Due to this constraints, future recommendations for the area can be to raise the capacity on nearby roads and intersections that opens for more route choices. An example on an ongoing project that contributes to a higher efficiency in traffic is the construction around Nordstan. The current situation around Nordstan is congested, and this area is situated near Oscarsleden making it to a potential contributory factor to the increased congestion level. Today the area is under construction with building the new bridge, Hisingsbron and reconstructing the surrounding area.

Mölndalsvägen is an arterial road that connects Mölndal to Gothenburg, but also other travelers coming from the south, for example: Kungsbacka, Kållered, Lindome and the rest of nearby suburbs. To Mölndalsvägen there are a lot of entrances coming in from larger road types like E20 and E6 that are located next to the road. The added traffic when cars from highways are being incorporated with the cars on Mölndalsvägen can lead to queues and interrupted driving due to traffic signals and in the peak hours creating congestion. Public transport also uses this road in forms of buses and trams and next to the stops there are more traffic signals that contributes to cause interruptions in the traffic flow. The area today have more potential to increase its sustainability but when adding this report's calculations of AVs in 2019 the scenarios will contribute to more congestion. For PAVs it will increase the congestion level by 7% and for the SAV it will increase by 15%. More infrastructure in this area is a potential solution to increase the capacity on the roads. One more potential solution that often contributes to an increase in capacity is expanding the public transit and make it more accessible, for commuters to travel. Expanding the public transport, for example the connections between trains that goes from the suburbs to Gothenburg may be a possible solution along with a higher frequency of trains. Today one of the fastest transport mode in the suburbs to Gothenburg is by train, and to optimize this mode by taking down the waiting times, it will be utilized more by the commuters.

Emirentgatan is a minor/local road that becomes adversely affected by the congestion level. The road is located near Masthugget and Järntorget. It begins near Skeppsbron, passes the Stena line terminal all the way to Fiskhamnsmotet. Near Skeppsbron the congestion level will be the highest since there are a lot of traffic in this particular area. In addition there are a lot of public transport nearby that is designed to take passengers with buses, trams and ferries which will contribute to interrupted flow in traffic. It takes up space in an area that already is narrow, making the capacity for cars low. Applying the PAV scenario for year 2019 there will be an increase of congestion by approximately 9% and for the SAV it will be around 14% which is consistent with the two literature studies in Chapter 2.4. That the minor roads get affected agrees with the study as well since the roads have a decreased capacity in comparison to larger roads but also when AVs chooses these routes it will quickly become more congested. In this area the applied AVs will lead to an increment in traffic because the area is too narrow and crowded by public transport which will not handle the increase in an optimal way. Gothenburg city are planning to expand around Skeppsbron and build a new region with both residence and commercial houses which may contribute to a lower increase of congestion in the future. The city is also planning an aerial way from Hisingen to Järntorget that have the potential to lower the congestion to this area since people will not be forced to take the ferry over to Stenpiren, but instead can choose the aerial way. The aerial transport have the possibility to lower the amount of cars on Oscarsleden as well since it will be a new way for people on one side of the river to commute to the other side.

Guldhedsgatan is a minor road situated near a residential region and Sahlgrenska Hospital. The street is trafficked and narrow with a connection area between public transport means near Sahlgrenska hospital where there is some traffic signals contributing to interrupted flow. The surrounding area consists of a residential area, parking places and large buildings. When applying AVs, they will be able to choose routes, and for this scenario they might choose the local roads that surrounds the minor roads which will contribute to more congestion on the local roads near the housing areas. When applying the PAV scenario for 2019 it shows from the results that the congestion level will have a 6% increment and a 15% for the SAV scenario which adds up to the literature studies. Adding more cars to residential areas can make people feel unsafe and therefore the recommendation for this particular road is to increase the capacity here which can be possible solution since there are enough space. Alongside Guldhedsgatan, there is a large parking area that can be reduced when the implementation of AVs happen an re-used for capacity improvements.

E6 is a highly congested highway that is utilized by many residents in Gothenburg but also commuters to or from the city. The highway connects the north of Gothenburg to the south and since there are a lot of commuters from both regions the road gets congested in current traffic as well. In the Gothenburg region, E6 extends from approximately Mölndal and continues past the Tingstads tunnel. The highway goes by the city centre and is utilized by many which contributes to a large demand but not enough capacity. Tingstads tunnel is too a contributory factor for the congestion since the tunnel is old and does not have enough capacity for the traffic which leads to queues in the AM and PM peaks. Applying scenarios from year 2040 for PAV there will be an increment in congestion level on 2% and for the SAV with 6%, which is consistent to the literature study. The increase that follows will not have as high effect on the largest roads in the because those roads also have the highest capacity. Highways can take more cars than the local roads, but since that road type in current traffic situation already is almost too congested, it still is a problem to add more traffic onto it since it will decrease the level of service even more and the capacity on the roads will not be able to meet the demand.

Alingsåsleden is an arterial road that goes from Olskroksmotet and is connected to E6 and E20. The road connects the suburbs to the North-West and is one of the main roads when arriving from Stockholm. Applying the scenarios from 2040 with the PAVs there will be an increment in congestion level by 6% and for SAV the increment will be around 21% which is consistent but for the SAV, the number is high. This can depend on that there are several highly congested large roads in the area and when adding 11% of increment onto all those roads together with a growth factor of 1% the result will be high. It can also depend on the uncertainties that the calculations and model brings which may not be entirely correct. If the result did agree with reality, to reduce the congestion more infrastructure supply needs to be added and an expansion of the arterial road is required to be able to manage the increase in future demand.

Masthamnsgatan is located in Masthugget between Järntorget and Oscarsgatan. The road is considered being minor and is affected by the congestion level since the road has a low capacity and is more sensitive towards the amount of cars. When AVs are choosing its routes they may end up choosing Masthamnsgatan since it is located between two more congested roads: Andrégatan that is an arterial road and Stigbersliden that usually gets congested from the public transport making the area to narrow for the cars. Applying scenarios from 2040 there will be an increase in traffic. For the PAV scenario the increase will be 7% and for the SAV the increase will be around 13%. To keep a sustainable saturation on the road it would have to be expanded or the capacity on nearby roads needs to be increased so that the AVs does not choose this minor road. The same applies to Fabriksgatan that is a local road situated near E6 and E20 that will suffer from an increased congestion level of increment of 11% for the PAV scenario and 6% increment for the SAV scenario in year 2040.

All these scenarios and recommendations in this report does not take into consideration that when applying an AV system onto the road network there will be lowered number of vehicles on the roads due to more efficient driving and sharing systems. PAVs can increase the capacity by driving closer to each other and households does not need to own more than one car in most of the scenarios. For SAV the cars could also drive closer and since the SAVs will be shared between passengers it will lead to a higher vehicle reduction because there will be more than one passenger in the car. In Zhang's et al. (2018) result, the vehicle reduction percentage is 9,5% in the region where the majority of the households could not achieve vehicle reduction due to their overlapping schedules. The few households in the report that had the possibility to lower their vehicle ownership had an average on 1.1 cars reduction per household. Fagnant et al. (2014) results indicates that one SAV can replace 11 cars which is a higher value of vehicle reduction than for the PAV fleet.

From the Lisbon and Oslo report presented in Chapter 2.5 their result differs from this report's result because of the vehicle reduction factor. If this report would have taken vehicle reduction into consideration, the most congested scenarios would most likely not be the AV scenarios. PAV will most credible lower the congestion, if used in a proper way where most households will only need one PAV to meet their demands. The SAV are expected to lower the highest number of vehicles in traffic due to its sharing potential. If these factors would have been taken into account then the result would be more of value since it will be more consistent to other researches and give a more indication on how the congestion will behave. The vehicle reduction will also affect the infrastructure supply recommendations in this report, where in some areas the supply will differ from the recommendations and in some cases not be needed at all. In the third AV concept where the technology is integrated with public transit and MaaS, the theoretical result will be the highest reduction of congestion. How implementable these AV systems are and the willingness for people to share cars between each other and change transport modes several times in one route which will be required when using MaaS integration can be reluctant from the citizens. PAV has been an interesting scenario to investigate since the vehicles will be privately owned and have the potential to be faster adapted by the citizens. The main obstacle for PAVs is that the vehicle reduction will not be as low as it is for SAVs because the travel pattern would stay the same. The business model of PAV will almost look the same as for conventional cars and PAVs will contribute to the same amount of trips or more. These factors are important to change if an improvement in traffic is going to happen the PAVs may not have the same possibility to solve the congestion problem.

To sum up, AVs can still have great potential to reduce the cars in traffic and decrease the congestion. In some cases there will be a need for other solutions than applying more infrastructure supply in the city because some areas are too narrow for expansion. More roads will not lead to a better environment for people to live in. Which type of AV-fleet that works best with the road network in Gothenburg is hard to predict. When considering all factors, the SAV scenario combined with a public transit is theoretically the most optimal in all studies according to literature reports in chapter 2.5. The positive result in the congestion depends on the high vehicle reduction for SAV. The PAV scenario does not have the same potential to decrease the amount of vehicles but it is a scenario considered to be easier adopted by the citizens due to the high comfort it will have. However, this is a question of demand and in what direction the people wants Gothenburg to develop in. Regulations in how new technology should be implemented are the key to more sustainable travels since it will force people to change their travel patterns which is needed if wanting to obtain the necessary results of lowering the congestion.

6 Conclusion

Based on the report's result, there will be an increment of VMT when introducing AVs, which will be consistent throughout all the AV scenarios. The reason behind the increase can be that AVs do open up for more of the population to utilize the technology since it will be less expensive and will be a more convenient travel mode. The broader population utilizing the AV technology can result into more relocation trips contributing to an increase in VMT.

In both literature studies used for the calculations, the impact on the vehicle reduction factor is discussed and how it changes when adopting to AVs. Vehicle reduction is an important factor to consider when analyzing the congestion since AVs have the potential to reduce a great amount of vehicles in traffic and lower the congestion overall. In this report, the vehicle reduction factor has been neglected in the calculations due to the short time limit but is still important to consider and discuss about since its potential impact on the congestion. Even if the VMT increases due to all the relocation trips that the AVs needs to take, in some cases there will still be less traffic since the total number of cars has been reduced.

The result of this study clearly indicates that AVs can have a negative impact on the mobility and congestion level and the system will require more infrastructure supply since the capacity of the roads will not meet the needed demand from the wide population that will use the cars. The most affected areas on excessive VMT will be in residential regions with smaller roads. The highways are today already congested and more actions there regarding the infrastructure supply needs to be taken into consideration.

From Zhangs et al. (2018) report, the results shows an increase in the V/C ratio where the increase lies between 4-9% depending on road type for a PAV fleet. Fagnant et al. (2014) results shows an increment in VMT with 11% on every road type when transitioning to a SAV fleet. Due to the higher increment on excessive VMT for the SAV scenario, the worst scenario in this thesis was the forecast for year 2040 when implementing SAVs. According to literature studies used for calculations, the relation between PAV and SAV are consistent, it is assumed that there will be more relocation trips when adapting to SAVs. Both Fagnant et al. (2014) and Zhang et al. (2018) results indicates a higher vehicle reduction when implementing the SAV scenario in comparison to the PAVs, since people will share the cars between each other. If the vehicle reduction is high for SAVs, then this scenario may be the most effective against congestion since the excessive VMT may not affect the traffic as much as the reduced amount of vehicles. Due to the neglected vehicle reduction factor in this report, the result can be deceptive. The outcome from the result is dependent on the limitations set for the calculations. The main uncertainties to this report's results are that the assumptions on the V/C ratio from the literature studies applied to the calculations are based on different cities with other conditions and that the Visum model for Gothenburg provided by Trafikkontoret is not fully detailed, which can give some inaccurate results.

MaaS's chance to impact mobility is described in the literature study in Section 2.5 where several reports where compared with each other. In order for MaaS to break through, it needs to offer a sufficient level of service compared to a regular car. The technology needs to be easy to use, have integrated payment systems, services needs to be individual and it is also important to be able to guarantee the realization of the trips. For the MaaS system to be sustainable it is important to know how to market the service and how to determine what policies are needed. This concept moves slowly forward, since the stakeholders wants a certainty in making a profit from investigating into the system. Since MaaS cannot guarantee a profit for every stakeholder based on today's knowledge, several parties acts repugnant to the implementation. From the MaaS projects presented in this study, increased in VMT but at the same time, their vehicle reduction was significant and had an adverse impact on the congestion. In order to acquire a deeper understanding about new technology and MaaS, reports with more factors taken into consideration are required for a more substantial comparison.

From the interview with Trafikverket, it is clear that MaaS together with shared autonomous vehicles is not a current topic in the city. Trafikverket is not focusing on MaaS as MaaS is considered to be a matter of commercialization of service. The only projects in Gothenburg regarding MaaS, was the Ubigo project that arose from the GO:smart project and was conducted with Drive Sweden at Lindholmen. Gothenburg city believes that MaaS will be hard to implement since it requires huge cooperativeness between different stakeholders in order to make the system work in practice and Gothenburg city assesses this to be further away in the future. Trafikverket also see greater potential with AVs since AVs will facilitate more stakeholders than MaaS for the current situation.

6.1 Recommendations for Future Studies

A few recommendations for future work on Mobility-as-a-Service and autonomous vehicles are:

- To comprehend how new mobility solutions will change a city, it requires designing an own transportation model based on the city's data in order for results to be correct. It is recommended to produce an entire new transport model based on Gothenburgs data, to obtain the right conditions for the city.

- A new Visum model more accurate than the one used in this program needs to be produced. More factors needs to be included (e.g. pedestrian, bicyclists and public transport) and new flows based on more recent years traffic measurements, in order to get the most accurate results.
- Research about the transition period, where AVs will have to share roads with conventional cars, needs to be conducted and the time for the transition period needs to be estimated.
- Before implementing AVs and MaaS, polices and technology needs to be fully developed in order to assure safety. More research regarding policies and how a standardized implementation of them can be conducted in order for the system to work in the same way in every part of the world and environments.

Bibliography

[1] Anderson, J. Kalra, N., Stanley, K. D., Sorensen, P., Samaras, C., Oluwatobi, A. O. (2016). Autonomous Vehicle Technology: A Guide for Policymakers. Retrieved from https://www.rand.org/pubs/research_reports/RR443-2.html

[2] Blue and green tomorrow (2018). How Self-Driving Cars Could Impact the Environment. Retrieved from https://blueandgreentomorrow.com/environment/self-driving-cars-could-impact-environment/

[3] Budget Direct (n.d). Driverless cars pros and cons. Retrieved from https://www.budgetdirect.com.au/blog/driverless-cars-pros-and-cons.html

[4] Center for urban transportation research (2013). Highway capacity impacts of autonomous vehicles: An assessment. Retrieved from https://pdfs.semanticscholar.org/713c/da5859535ca41986413e8c77c105f4898f2a.pdf

[5] Civitas prosperity (n.d.). Innovation brief on Mobility as a Service. Retrieved from http://sump-network.eu/fileadmin/user_upload/Innovation_Brief_Mobility_as_a_Service_22_08_2017_web.pdf

[6] DDS Wireless (n.d.). How Autonomous Vehicles Could Integrate with Fleet Management Systems. Retrieved from https://ddswireless.com/blog/how-autonomous-vehicles-could-integrate-with-fleet-management-systems/

[7] European Comission (n.d.). What is Horizon 2020? Retrieved from https://ec.europa.eu/programmes/horizon2020/what-horizon-2020

[8] Fagnant, D., Kockelman, K.(2014)The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios. Retrieved from https://www-sciencedirect-com.proxy.lib.chalmers.se/science/article/pii/S0968090X13002581

[9] Federal highway administration (n.d.). A primer for agent-based simulation and modeling in transportation applications. Retrieved from https://www.fhwa.dot.gov/publications/research/ear/13054/13054.pdf

[10] Fernandes, P., Nunes, U. (2010). Platooning of autonomous vehicles with intervehicle communications in SUMO traffic simulator. Retrieved from https://www.researchgate.net/publication/224190866_Platooning_of_auography

[11] Grand Challenges (n.d.). Vehicle-to-Vehicle/Vehicle-to-Infrastructure Control. Retrieved from http://ieeecss.org/sites/ieeecss.org/files/documents/IoCT-Part4-13VehicleToVehicle-HR.pdf

[12] Kamargianni, M., Li, W., Matyas, M., Schäfer, A. (2016). A critical review of new mobility services for urban transport. Transportation Research Procedia 14. Retrieved from https://www.sciencedirect.com/science/article/pii/S2352146516302836

[13] Karlsson, M. Sochor, J. Strömberg, H.(2016) Developing the 'Service' in Mobility as a Service: experiences from a field trial of an innovative travel brokerage. Retrieved from https://www.sciencedirect.com/science/article/pii/S2352146516302794

[14] Kumapley, K. R., Fricker, D. J. (1996). Review of Methods for Estimating Vehicle Miles Traveled.Transportation Research Record, No. 1551, 2007, pp. 59–66. Retrieved from https://journals.sagepub.com/doi/pdf/10.1177/0361198196155100108

[15] Lee, D., Klein, L., Camus, G. Induced Traffic and Induced Demand, Transportation Research Record. Retrieved from http://usa.streetsblog.org/wp-content/uploads/sites/5/2012/07/gentraf.pdf

[16] Li1, Y. Voege, T. (2018). Mobility as a Service (MaaS): Challenges of implementation and policy required. Retrieved from https://www.scirp.org/journal/PaperInformation.aspx?paperID=74675

[17] Lund, E. (n.d.). Mobility as a Service – What is it, and which problems could it solve? Retrieved from https://en.trivector.se/fileadmin/user_upload/Traffic/Whitepapers/Mobility_as_a_Service.pdf

[18] Maas alliance (n.d.). MaaS guidebook: Consistancy. Retrieved from https://maas-alliance.eu/library/

[19] Maas alliance (n.d.). What is MaaS? Retrieved from https://maas-alliance.eu/homepage/what-is-maas/

[20] Martin, W. E., Shaheen, A. S. (2010). Greenhouse gas emission impacts of carsharing in north America, Mineta Transportation Institute. Retrieved from http://innovativemobility.org/wp-content/uploads/2015/03/Greenhouse-Gas-Emission-Impacts-of-Carsharing-in-North-America-publication.pdf

[21] National Highway Traffic Saftey Administration (n.d). The road to full automation. Retrieved from https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety#topic-safety-timeline

[22] NHTSA (n.d.). Vehicle-to-Vehicle communication. Retrieved from https://www.nhtsa.gov/technology-innovation/vehicle-vehicle-communication

[23] PTV Group (n.d.). PTV Visum use cases. Retrieved from http://vision-traffic.ptvgroup.com/en-us/products/ptv-visum/use-cases/

[24] PTV Group (n.d.). PTV Visum 17 Highlights. Retrieved from http://vision-traffic.ptvgroup.com/en-us/products/ptv-visum/release-highlights/

[25] PTV Visum 14 Manual (2014). New features at a glance. Retrieved from http://vision-traffic.ptvgroup.com/fileadmin/files_ptvvision/Downloads_N/0_General/2_Products/1_PTV_Visum/Overview_Visum14.pdf

[26] Näringsdepartementet, Regeringen (2019). Uppdrag att genomföra informations- och kunskapshöjande insatser inom områdena Mobilitet som en tjänst respektive Medborgar- och trafikantinformation för ökad trafiksäkerhet i vägtrafiken Retrieved from http://vision-traffic.ptvgroup.com/fileadmin/files_ptvvision/Downloads_N/0_General/2_Products/1_PTV_Visum/Overview_Visum14.pdf

[27] RISE (n.d.). RISE ICT stories: Mobility as a Service. Retrieved from https://www.swedishict.se/mobility-as-a-service

[28] Rosqvist, K. J., Wendle, B., Kerttu, J. (2016). Konsekvenser av Mobility as a Service: Jämförelse av alternativa scenarier för implementering av nya mobilitetstjänster (förstudie). Retrived from https://www.trafa.se/globalassets/rapporter/underlagsrapporter/2016/trivector-rapport_2016_112-konsekvenser-av-mobility-as-a-service.pdf

[29] Speck, J. (n.d.). Induced traffic demand. Retrieved from https://www.ianfor4th.com/files/Induced-Traffic-Demand.pdf

[30] The International Transport Forum (2015). Urban mobility system upgrade: How shared self-driving cars could change city traffic. Retrieved from https://www.itf-oecd.org/sites/default/files/docs/15cpb_self-drivingcars.pdf

[31] Cowi (2019). The Oslo study- How autonomous cars may change transport in cities. Retrieved from file:///Users/oliverapuljic/Downloads/NO_Report_RUTER_Frokostmoede$%$20410$%$20(1).pdf

[32] Williams, T. A., Chigoy, B., Borowiec, J., Glover, B. (2016). Methodologies used to estimate and forecast vehicle miles traveled (VMT) Retrieved from https://static.tti.tamu.edu/tti.tamu.edu/documents/PRC-15-40-F.pdf

[33] SkedGo (n.d.). MaaS: The biggest transport revolution of the 21st century. Retrieved from https://skedgo.com/mobility-future/what-is-mobility-as-a-service-maas/

[34] Trafikverket (n.d.). Sampers. Retrieved from https://www.trafikverket.se/tjanster/system-och-verktyg/Prognos--och-analysverktyg/Sampers/

[35] Ubigo (2019). Via ID satsar på svenska mobilitetspionjären UbiGo. Retrieved from http://www.mynewsdesk.com/se/ubigo/pressreleases/via-id-satsar-paa-svenska-mobilitetspionjaeren-ubigo-2851336

[36] U.S. Census Bureau (2017). American Community Survey 5-year estimates. Retrieved from Census Reporter Profile page for Atlanta, GA https://censusreporter.org/profiles/16000US1304000-atlanta-ga/

[37] Vinnova (2012). Go:smart. Retrieved from https://www.vinnova.se/en/p/gosmart/

[38] Zhang, W., Guhathakurtab, S., Khalilc, E.B. (2018). The impact of private autonomous vehicles on vehicle ownership and unoccupied VMT generation (Transportation Research Part C, Volume 90) Retrieved from https://www.sciencedirect.com/science/article/pii/S0968090X18303188?via

A Appendix 1

Frågor angående Mobility as a Service (MaaS) och självkörande bilar.

1. Hur jobbar Göteborg/generellt med att få ner trängseln idag? Gör man något mer utöver att bygga ny infrastruktur som exempelvis västlänken eller att införa trängselskatt som kanske är de mest omnämnda åtgärderna i Göteborg idag?
2. Finns det en aktiv diskussion om MaaS/självkörande bilar på Trafikverket och om ja hur arbetar man med nya mobilitetsfrågor? Är det aktuella frågor idag?
3. Vad är Göteborgs definition på Mobility-as-a-service, hur tolkar man den nya teknologin och hur pratar man om att en implementering av det hade kunnat se ut i Göteborg?
4. Finns det något pågående projekt i Göteborg som arbetar med Mobility-as-a-Service (Har för mig att jag bara har läst om Chalmers projekt Ubigo). Eller projekt överlag i Sverige?
5. Hur troligt tror ni att ett MaaS koncept kommer att implementeras i Göteborg? Vad hade krävts för att få igenom det om vi förutsätter att teknologin för det redan är utvecklat? (Intressenter, politiker, pengar, krav etc.)
6. Hur troligt tror ni att självkörande bilar kommer att implementeras i Göteborg? Vad hade krävts för att få igenom det om vi förutsätter att teknologin för det redan är utvecklat? (Intressenter, politiker, pengar, krav etc.)
7. Man pratar ofta om att det inte räcker med att bara implementera ny teknologi på vägarna (självkörande bilar) utan för att man ska få mindre trafik så behöver människor resebeteende ändras också. Det jag undrar är hur ni ser på det här? Tror ni att MaaS kan vara grunden för ändrat resebeteende och kommer att fungera som ett bra komplement till självkörande bilar? Eller går det andra diskussioner om hur man ska ändra människors resesätt?
8. Låt oss säga att det skulle hända och att det blir en implementering av MaaS, hur tror ni att det hade sett ut just i Göteborg? Finns det något som hade stuckit ut här i jämförelse med andra städer?
9. Vilka restriktioner kommer med Mobility as a service? Vad är det nya systemets största brister och hur går diskussionerna kring det? (Nedan har jag tagit upp några som jag har läst om, du får gärna utveckla eller komma med annat också)

- Ovilja hos människor att byta transportmedel flera gånger under sin rutt.

- Hållbarhet: Svårt att få in ett hållbarhetstänk när man ska marknadsföra MaaS? Tänker att man kanske marknadsför den som billigare och mer bekväma än vanliga bilar vilket kanske leder till att ännu mer människor använder sig av dem. (Hur pratar man om det här problemet?)
- Mer infrastruktur, nya åtgärder på den gamla infrastrukturen? Hur kommer infrastrukturen att behöva förändras med hjälp av MaaS?

10. Hur förutspår man att infrastrukturen kommer att förändras med implementering av delade självkörande bilar?

B Appendix 2

The appendix shows calculations for the result for the first links in the excel link list.

Calculations with the introduction of AVs in current network (2018) and a forecast on 2040 with a population growth of 1%, Assumptions based on Zhangs theory about the V/C ratio (Ampeak), increament for PAVs, For SAVs the assumptions is from Fagnant based on VMT, The input in Visum is the capacity column for each scenario										
Scenario 1: Current traffic situation (2018) + input data without any Avs										
Link number	From which node the link starts at	To which node the link goes to	Type of road (federal, country,.)	Set of permitted transport systems which may use this link Car, E=Car not paying U=unused transport system, W= walk	Length of the link	number of lanes per link (körbana)	Private transport Capacity	Permitted speed private transport in the unloaded state (free flow speed)	Volume per hours (Analysis Period) [number of vehicles]	Ratio between VolVehPrT/CapPrT Volume capacity ratio
LINK:NO	FromNodeNo	ToNodeN	TypeNo	TSysSet	Length	NumLane	CapPrT	V0PrT (km/h)	VolVehPrT(AP	V/C ratio
1	291	365	51	C,E,U	0,062	1	1000	47	232	0,23
1	365	291	51	C,E,U	0,062	1	1000	47	232	0,23
3	293	547	83	C,E,U	0,467	3	6000	79	2896	0,48
3	547	293	83	C,E,U	0,467	3	6000	79	2795	0,47
4	293	548	83	C,E,U	0,251	3	6000	79	2669	0,44
4	548	293	83	C,E,U	0,251	3	6000	79	2896	0,48
5	293	992	72	C,E,U	0,302	2	3500	70	127	0,04
5	992	293	99		0,302	0	0	0	0	#DIV/0!
7	548	550	51	C,E,U	0,109	1	1000	47	199	0,20
7	550	548	51	C,E,U	0,109	1	1000	47	626	0,63
8	548	992	72	C,E,U	0,227	2	3500	70	644	0,18
8	992	548	72	C,E,U	0,227	2	3500	70	812	0,23
9	300	301	52	C,E,U	0,151	2	2000	47	1383	0,69
9	301	300	99		0,151	0	0	0	0	#DIV/0!
12	301	309	52	C,E,U	0,096	2	2000	47	1383	0,69
12	309	301	51	U	0,096	0	1000	47	0	0,00
15	303	304	51	C,E,U	0,104	1	1000	47	773	0,77
15	304	303	99		0,104	0	8000	30	0	0,00
16	303	311	99		0,076	0	8000	0	0	0,00
16	311	303	51	C,E,U	0,076	1	1000	47	569	0,57
17	303	321	99		0,115	0	0	0	0	#DIV/0!
17	321	303	20	C,E,U	0,115	1	100	10	94	0,94
18	304	305	51	C,E,U	0,106	1	1000	47	1363	1,36
18	305	304	51	C,E,U	0,106	1	1000	47	867	0,87
19	304	312	51	C,E,U	0,103	1	1000	47	773	0,77
19	312	304	51	C,E,U	0,103	1	1000	47	322	0,32
20	305	306	51	C,E,U	0,076	1	1000	47	1672	1,67
20	306	305	51	C,E,U	0,076	1	1000	47	867	0,87
22	306	308	51	C,E,U	0,085	1	1000	47	1266	1,27
22	308	306	51	C,E,U	0,085	1	1000	47	867	0,87
23	306	309	99		0,087	0	0	0	0	#DIV/0!
23	309	306	51	C,E,U	0,087	1	1000	47	1133	1,13
24	306	314	51	C,E,U	0,115	1	1000	47	1539	1,54
24	314	306	99		0,115	0	0	0	0	#DIV/0!
27	308	317	51	C,E,U	0,088	1	1000	47	1081	1,08
27	317	308	51	C,E,U	0,088	1	1000	47	815	0,81
29	309	922	99		0,184	0	0	0	0	#DIV/0!
29	922	309	51	C,E,U	0,184	1	1000	47	502	0,50
30	309	1116	51	C,E,U	0,099	1	1000	47	753	0,75
30	1116	309	99		0,099	0	0	0	0	#DIV/0!
33	311	336	99		0,167	0	0	0	0	#DIV/0!
33	336	311	51	C,E,U	0,167	1	1000	47	569	0,57
34	312	321	31	C,E,U	0,107	1	800	27	356	0,44
34	321	312	31	C,E,U	0,107	1	800	27	0	0,00

Scenario 2: Traffic situation in year 2040 where the growth population is set to 1% without any Avs			**Scenario 3: Traffic situation in year 2018 where conventional cars have been replaced with PAVS**					
New Scenario 2014, calculated volume growth for 1%	New ratio based on volume for 2040	Capacity based on new volume	Assumptions from Zhangs report increase in V/C ratio during AM	Estimated V/C ratio based on Zhangs AM assumption *(Using in Visum)*	New estimated Capacity based on assumptions from Zhang [AM] [Vold/(V/C)new] *Inserted in Visum*	Volume from new capactiy	NEW V/C ratio [Based on new capacity and new volume]	The increase in V/C ratio from Base [V/Cnewpav-V/Cold]
Volume 2040	V/C Ratio 2040	Cap(2040)	increment in V/C AM	V/C New AM	Cap2018PAV			
288	0,29		1,0373	0,240	964	232	0,24	0,01
288	0,29		1,0373	0,240	964	232	0,24	0,01
3604	0,60		1,0276	0,496	5839	2907	0,50	0,02
3479	0,58		1,0276	0,479	5839	2806	0,48	0,01
3322	0,55		1,0276	0,457	5839	2679	0,46	0,01
3604	0,60		1,0276	0,496	5839	2907	0,50	0,02
158	0,05		1,0753	0,039	3255	126	0,04	0,00
0	#DIV/0!		1,0276	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
248	0,25		1,0373	0,207	964	221	0,23	0,03
779	0,78		1,0373	0,650	964	642	0,67	0,04
802	0,23		1,0276	0,189	3406	648	0,19	0,01
1011	0,29		1,0276	0,238	3406	849	0,25	0,02
1722	0,86		1,0753	0,744	1860	1366	0,73	0,04
0	#DIV/0!		1,0373	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
1722	0,86		1,0373	0,717	1928	1366	0,71	0,02
0	0,00		1,0373	0,000	#DIV/0!	0	#DIV/0!	#DIV/0!
962	0,96		1,0753	0,831	930	764	0,82	0,05
0	0,00		1,0373	0,000	#DIV/0!	0	#DIV/0!	#DIV/0!
0	0,00		1,0753	0,000	#DIV/0!	0	#DIV/0!	#DIV/0!
708	0,71		1,0373	0,590	964	566	0,59	0,02
0	#DIV/0!		1,0753	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
117	1,17		1,0753	1,008	93	88	0,95	0,01
1697	1,70		1,0373	1,414	964	1336	1,39	0,02
1080	1,08		1,0373	0,900	964	865	0,90	0,03
962	0,96		1,0373	0,802	964	786	0,82	0,04
401	0,40		1,0373	0,334	964	323	0,33	0,01
2081	2,08		1,0373	1,735	964	1646	1,71	0,03
1080	1,08		1,0373	0,900	964	865	0,90	0,03
1576	1,58		1,0373	1,313	964	1253	1,30	0,03
1080	1,08		1,0373	0,900	964	865	0,90	0,03
0	#DIV/0!		1,0753	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
1410	1,41		1,0373	1,175	964	1094	1,14	0,00
1916	1,92		1,0753	1,655	930	1487	1,60	0,06
0	#DIV/0!		1,0373	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
1346	1,35		1,0373	1,122	964	1093	1,13	0,05
1014	1,01		1,0373	0,845	964	854	0,89	0,07
0	#DIV/0!		1,0753	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
625	0,63		1,0373	0,521	964	480	0,50	0,00
937	0,94		1,0753	0,809	930	752	0,81	0,06
0	#DIV/0!		1,0373	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
0	#DIV/0!		1,0753	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
708	0,71		1,0373	0,590	964	566	0,59	0,02
443	0,55		1,0753	0,478	744	354	0,48	0,03
0	0,00		1,0753	0,000	#DIV/0!	0	#DIV/0!	#DIV/0!
519	0,52		1,0373	0,433	964	432	0,45	0,03

Scenario 4: Year 2040 where conventional cars have been replaced with PAVS				
New estimated V/C ratio based on Zhangs assumption and the population growth for 2040	New capacity based on year 2040 and assumptions from Zhang [AM] [Vold/(V/C)new] *Inserted in Visum*	Volume from Visum with new calculated capactiy	NEW V/C ratio [Based on new capacity and new volume]	The increase in V/C ratio from Base [V/Cnewpav-V/Cold]
V/C Ratio AM 2040	Cap2040PAV			
0,299	964	232	0,24	0,01
0,299	964	232	0,24	0,01
0,617	5839	2907	0,50	0,02
0,596	5839	2806	0,48	0,01
0,569	5839	2679	0,46	0,01
0,617	5839	2907	0,50	0,02
0,048	3255	126	0,04	0,00
#DIV/0!	0	0	#DIV/0!	#DIV/0!
0,257	964	221	0,23	0,03
0,808	964	642	0,67	0,04
0,235	3406	658	0,19	0,01
0,297	3406	849	0,25	0,02
0,926	1860	1368	0,74	0,04
#DIV/0!	0	0	#DIV/0!	#DIV/0!
0,893	1928	1368	0,71	0,02
0,000	0	0	#DIV/0!	#DIV/0!
1,035	930	761	0,82	0,05
0,000	0	0	#DIV/0!	#DIV/0!
0,000	0	0	#DIV/0!	#DIV/0!
0,734	964	564	0,59	0,02
#DIV/0!	0	0	#DIV/0!	#DIV/0!
1,254	93	88	0,95	0,01
1,760	964	1336	1,39	0,02
1,120	964	867	0,90	0,03
0,998	964	787	0,82	0,04
0,416	964	323	0,33	0,01
2,159	964	1645	1,71	0,03
1,120	964	867	0,90	0,03
1,634	964	1252	1,30	0,03
1,120	964	867	0,90	0,03
#DIV/0!	0	0	#DIV/0!	#DIV/0!
1,462	964	1094	1,13	0,00
2,060	930	1487	1,60	0,06
#DIV/0!	0	0	#DIV/0!	#DIV/0!
1,396	964	1091	1,13	0,05
1,052	964	856	0,89	0,07
#DIV/0!	0	0	#DIV/0!	#DIV/0!
0,648	964	479	0,50	-0,01
1,008	930	754	0,81	0,06
#DIV/0!	0	0	#DIV/0!	#DIV/0!
#DIV/0!	0	0	#DIV/0!	#DIV/0!
0,734	964	564	0,59	0,02
0,595	744	354	0,48	0,03
0,000	0	0	#DIV/0!	#DIV/0!
0,539	964	433	0,45	0,03
0,150	964	117	0,12	0,01
0,000	0	0	#DIV/0!	#DIV/0!
0,266	964	206	0,21	0,01
0,000	0	0	#DIV/0!	#DIV/0!
0,665	964	515	0,53	0,02
#DIV/0!	0	0	#DIV/0!	#DIV/0!
0,000	0	0	#DIV/0!	#DIV/0!
1,370	930	971	1,04	0,02
#DIV/0!	0	0	#DIV/0!	#DIV/0!
#DIV/0!	0	0	#DIV/0!	#DIV/0!

Scenario 5: Year 2018 where conventional cars have been replaced by SAVs					
VMT increase of 11% according to Fagnant and Kockleman on overall traffic	V/C ratio based on Fagnants and Kocklemans assumptions [V/C*11%]	Capacity based on Fagnants for SAV2018 [Cnew=Vold/(V/C ratio SAV2018)] *Inserted in Visum*	Volume from new capactiy	NEW V/C ratio [Based on new capacity and new volume]	The increase in V/C ratio from Base [V/Cnewsav-V/Cold]
VMT increase %	V/C ratio SAV2018	Cap2018SAV			
1,11	0,26	901	232	0,26	0,03
1,11	0,26	901	232	0,26	0,03
1,11	0,54	5405	2901	0,54	0,05
1,11	0,52	5405	2801	0,52	0,05
1,11	0,49	5405	2681	0,50	0,05
1,11	0,54	5405	2901	0,54	0,05
1,11	0,04	3153	120	0,04	0,00
1,11	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	0,22	901	252	0,28	0,08
1,11	0,70	901	653	0,72	0,10
1,11	0,20	3153	704	0,22	0,04
1,11	0,26	3153	866	0,27	0,04
1,11	0,77	1802	1362	0,76	0,06
1,11	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	0,77	1802	1362	0,76	0,06
1,11	0,00	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	0,86	901	735	0,82	0,04
1,11	0,00	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	0,00	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	0,63	901	557	0,62	0,05
1,11	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	1,04	90	86	0,95	0,02
1,11	1,51	901	1298	1,44	0,08
1,11	0,96	901	860	0,95	0,09
1,11	0,86	901	791	0,88	0,10
1,11	0,36	901	323	0,36	0,04
1,11	1,86	901	1608	1,78	0,11
1,11	0,96	901	860	0,95	0,09
1,11	1,41	901	1218	1,35	0,09
1,11	0,96	901	860	0,95	0,09
1,11	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	1,26	901	1099	1,22	0,09
1,11	1,71	901	1489	1,65	0,11
1,11	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	1,20	901	1062	1,18	0,10
1,11	0,90	901	843	0,94	0,12
1,11	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	0,56	901	480	0,53	0,03
1,11	0,84	901	743	0,83	0,07
1,11	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	0,63	901	557	0,62	0,05
1,11	0,49	721	356	0,49	0,05
1,11	0,00	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	0,46	901	435	0,48	0,07
1,11	0,13	901	117	0,13	0,01
1,11	0,00	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	0,23	901	206	0,23	0,02
1,11	0,00	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	0,57	901	515	0,57	0,06
1,11	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	0,00	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	1,14	901	973	1,08	0,06
1,11	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
1,11	0,57	1802	1017	0,56	0,05
1,11	0,08	901	96	0,11	0,03

Scenario 6: Year 2040 where conventional cars have been replaced by SAVs				
Scenario 2040 with 11% increment on V/C ratio [V/C*11%]	Capacity based on Fagnants for SAV2040 [Cnew=Vold/(V/C ratio SAV2040)] *Inserted in Visum*	Volume from Visum with new calculated capactiy	NEW V/C ratio [Based on new capacity and new volume]	The increase in V/C ratio from Base [V/Cnew sav-V/Cold]
V/C ratio SAV2040	Cap2040SAV			
0,32	901	232	0,26	0,03
0,32	901	232	0,26	0,03
0,67	5405	2901	0,54	0,05
0,64	5405	2801	0,52	0,05
0,61	5405	2681	0,50	0,05
0,67	5405	2901	0,54	0,05
0,05	3153	120	0,04	0,00
#DIV/0!	0	0	#DIV/0!	#DIV/0!
0,28	901	252	0,28	0,08
0,87	901	653	0,72	0,10
0,25	3153	704	0,22	0,04
0,32	3153	866	0,27	0,04
0,96	1802	1362	0,76	0,06
#DIV/0!	0	0	#DIV/0!	#DIV/0!
0,96	1802	1362	0,76	0,06
0,00	0	0	#DIV/0!	#DIV/0!
1,07	901	735	0,82	0,04
0,00	0	0	#DIV/0!	#DIV/0!
0,00	0	0	#DIV/0!	#DIV/0!
0,79	901	557	0,62	0,05
#DIV/0!	0	0	#DIV/0!	#DIV/0!
1,29	90	86	0,95	0,02
1,88	901	1298	1,44	0,08
1,20	901	860	0,95	0,09
1,07	901	791	0,88	0,10
0,44	901	323	0,36	0,04
2,31	901	1608	1,78	0,11
1,20	901	860	0,95	0,09
1,75	901	1218	1,35	0,09
1,20	901	860	0,95	0,09
#DIV/0!	0	0	#DIV/0!	#DIV/0!
1,56	901	1099	1,22	0,09
2,13	901	1489	1,65	0,11
#DIV/0!	0	0	#DIV/0!	#DIV/0!
1,49	901	1062	1,18	0,10
1,13	901	843	0,94	0,12
#DIV/0!	0	0	#DIV/0!	#DIV/0!
0,69	901	480	0,53	0,03
1,04	901	743	0,83	0,07
#DIV/0!	0	0	#DIV/0!	#DIV/0!
#DIV/0!	0	0	#DIV/0!	#DIV/0!
0,79	901	557	0,62	0,05
0,61	721	356	0,49	0,05
0,00	0	0	#DIV/0!	#DIV/0!
0,58	901	435	0,48	0,07
0,16	901	117	0,13	0,01
0,00	0	0	#DIV/0!	#DIV/0!
0,28	901	206	0,23	0,02
0,00	0	0	#DIV/0!	#DIV/0!
0,71	901	515	0,57	0,06
#DIV/0!	0	0	#DIV/0!	#DIV/0!
0,00	0	0	#DIV/0!	#DIV/0!
1,41	901	973	1,08	0,06
#DIV/0!	0	0	#DIV/0!	#DIV/0!
#DIV/0!	0	0	#DIV/0!	#DIV/0!
0,71	1802	1017	0,56	0,05
0,10	901	96	0,11	0,03