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Assessing the potential for improving public transport in rural areas by using driverless vehicles

Joel Norman

UPPSALA
UNIVERSITET

Teknisk- naturvetenskaplig fakultet
UTH-enheten

Besöksadress:
Ångströmlaboratoriet
Lägerhyddsvägen 1
Hus 4, Plan 0

Postadress:
Box 536
751 21 Uppsala

Telefon:
018 – 471 30 03

Telefax:
018 – 471 30 00

Hemsida:
http://www.teknat.uu.se/student

Abstract

Assessing the potential for improving public transport in rural areas by using driverless vehicles

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Driverless vehicles might fundamentally change the transport system in multiple ways. Reducing driver costs in mobility services could create opportunities for new mobility concepts. Research on driverless vehicles have previously concentrated on urban areas, though driverless vehicles in rural areas could have greater positive effects. Hence, the aim of the study is to see how driverless vehicles can be used in rural areas to contribute to a more sustainable transport system. Three rural mobility concepts for driverless vehicles are developed and by applying these to different case locations, the feasibility of the concepts is discussed. Interviews with local actors in Sweden were conducted to learn about general and local challenges with specific case locations. What rural mobility concept for driverless vehicles to use depends on access to public transport, distance to main roads and spatial density of travel demand. A modelling approach of a first and last mile feeder service is used to evaluate the feasibility of this mobility concept further. Model results show that driverless shuttles can feed travel demands of 100-150 passengers daily and still perform alternative tasks. Even though rural areas have general challenges, local issues also need consideration to optimize the benefits of the services. Public transport authorities are experts on local challenges and could take more responsibility in questions regarding driverless vehicles. For instance, flexibility, accessibility and equality could be improved by merging routes and shorten travel times for entire bus routes. Furthermore, other societal functions can be developed by reinvesting capital in other areas.

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Ämnesgranskare: Anna Pernestål
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Sammanfattning

Transportsystemet som vi känner det idag står inför flertalet utmaningar. Kanske är automatisering den allra största utmaningen då det fundamentalt kan ändra hur transporter görs idag. I ett utopiskt förarlöst samhälle finns inga bilköer, automatiska trafikljus, godsfordon utan förarhytter samtidigt som de miljöfarliga utsläppen minskar. Detta är ofta den glorifierade bilden många har när förarlösa fordon diskuteras. Men framväxten av förarlösa fordon kan också leda till mer negativa effekter.

Tidigare har forskningen om förarlösa fordon fokuserat på stadsmiljöer, men fördelarna med att införa förarlösa fordon kan vara större på landsbygden. Genom att minska förarkostnaden i olika mobilitetstjänster kan delningstjänster, taxibolag och kollektivtrafiken öka sin lönsamhetsgrad. Detta möjliggör omfördelning av kapital och således också nya mobilitetskoncept. Syftet med detta arbete var således att bidra till forskningen kring förarlösa fordon på landsbygden och hur dessa fordon kan bidra till ett mer hållbart transportsystem. För att besvara syftet togs tre nya mobilitetskoncept för förarlösa fordon på landsbygden fram. Rimligheten för dessa mobilitetskoncept diskuterades sedan i ljuset av landsbygdsområden med olika förutsättningar. Intervjuer utfördes med olika kommuner och kollektivtrafikmyndigheter för att få information kring generella och lokala problem på de olika platserna.

Ett av de nya mobilitetskoncepten för förarlösa fordon på landsbygden var en delad och anropsstyrd taxitjänst, de andra koncepten var områdestrafik och en första- och sista-milen tjänst med matartrafik för att räta ut busstråk. De två senare koncepten kan i många fall kombineras för att optimera fördelarna för byarna där dessa tjänster skulle användas. Dessa två koncept kan främst användas i byar med närhet till större landsvägar med tillgång till kollektivtrafik och med högre rumslig densitet av reseefterfrågan. En delad och anropsstyrd taxitjänst skulle snarare kunna användas i mer avlägsna byar utan närhet till kollektivtrafik och med lägre rumslig densitet av reseefterfrågan.

En modell skapades för att vidare analysera och utvärdera mobilitetskonceptet med matartrafik för att räta ut stomlinjerna. En by testades baserat på dess förutsättningar med reseefterfrågan, tidtabell, avstånd till närliggande huvudled och dagens hastighet på autonoma poddar. Utöver detta testades olika värden på dessa parametrar för att simulera likvärdiga byar men med någon skillnad mot basfallet. Resultat från modellen visade att förarlösa poddar kunde mata 100 till 150 människor dagligen och ändå ha tid för alternativa uppgifter.

Kollektivtrafikmyndigheter och kommuner har stor kunskap kring vilka lokala utmaningar och förutsättningar som finns inom ett visst område och skulle kunna ta mer ansvar i frågor som rör förarlösa fordon på landsbygden. Genom att ta mer ansvar i dessa frågor skulle dessa aktörer kunna förbättra kollektivtrafikens flexibilitet, tillgänglighet och jämställdhet. De lokala effekterna av koncepten kan skilja sig åt, exempelvis kan den delade taxitjänsten leda

till förbättrad turismnäring eller ökade pendlingsmöjligheter, och matartjänsten kan leda till sammanfogade eller förkortade stomlinjer och förkortade restider for hela stråk. Genom att minska förarkostnaden skulle också kapital kunna omfördelas och andra samhällsfunktioner skulle kunna gynnas, exempelvis hälso- och sjukvården som ofta konkurrerar med kollektivtrafik på regionnivå.

Huruvida mobilitetskoncepten för förarlösa fordon på landsbygden skulle förbättra hållbarheten beror till stor del på vilka resor som ersätts. Om gång- och cykelresor ersätts kan de miljöfarliga utsläppen öka, men om bilresor ersätts kan utsläppen minska. Ökat resande för äldre, yngre och rörelsehindrade skulle kunna öka antalet fordonskilometrar. Däremot skulle dessa grupper bli mer socialt inkluderade och således skulle den sociala hållbarheten i dessa fall kunna väga upp det ökade antalet fordonskilometrar.

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List of abbreviations

CoT	*Cost of Time*
DV	*Driverless Vehicles*
FMLM	*First Mile Last Mile*
ITRL	*Integrated Transport Research Lab*
KPI	*Key Performance Indicator*
KTH	*KTH Royal Institute of Technology*
SAE	*Society of Automotive Engineers*
UL	*Upplands Lokaltrafik*
VKT	*Vehicle Kilometers Travelled*
VTI	*Swedish National Road and Transport Research Institute*

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1. Introduction

Imagine a transport system with driverless vehicles where cars are designed as gyms or living rooms and where trucks only consist of cargo space (Einride 2018). The transports are no longer just a mean for moving people and goods, they are activities where people can meet and have a good time or do their daily exercise (Wadud et al. 2016; Papa & Ferreira 2018). People share vehicles, the public transport operates seamlessly, and cyclists and pedestrians keep the cities vibrant. Roads can fit more vehicles since the distances between vehicles are shortened and crossings and traffic lights are fully automated (Fraedrich et al. 2018). Congestion don't exist, and the speed limits can be higher due to increased safety when removing the driver (NHTSA 2008; Wadud et al. 2016; Papa & Ferreira 2018). Smart vehicles can see if its passengers are in a bad condition and operate as ambulances and get clearance on its way to the hospital. Safety, equality, welfare and climate aspects are enhanced in this scenario (Papa & Ferreira 2018).

Now, imagine a transport system where cars will be driving around empty to avoid parking fees (Litman 2018) and people use the car for trips between classes at a campus (Docherty 2018) since walking or cycling has become dangerous (Papa & Ferreira 2018). Everyone uses their private car since they don't have to perform the driving task anymore and can work or study during the trip (Pernestål & Kottenhoff 2018). Private traffic further increases by the reduction of taxi prices (Taiebat et al. 2018) and increased attractiveness of the private car. Driverless vehicles learn who to save based on social and economic status of the passengers at an accident, causing greater equality gaps (Papa & Ferreira 2018). Pedestrians force vehicles to stop by walking on the road just for fun, causing congestions (Docherty 2018). Increased car dependency leads to removal of bike lanes and pavements and cyclists and pedestrians moving in the wrong lane or crossing the street are penalized (Papa & Ferreira 2018). Reduced safety for cyclists and pedestrians will make people want to use cars, increasing the number of vehicle kilometres, which in turn have negative environmental effects (Alessandrini et al. 2015; Papa & Ferreira 2018) and will contribute to a poor quality of life.

The first scenario represents sort of a utopian scenario that people might tend to visualize when thinking of driverless vehicles. The second scenario is more of a dystopia that we would want to avoid at all costs. Researchers, debaters, car companies and tech companies all invest more time and money than ever before into the area of driverless vehicles (Heineke et al. 2017) though many challenges and disagreements still need to be solved. Today, the debate about driverless vehicles is led by actors with interest in portraying the technology in a positive manner (Papa & Ferreira 2018). Some say there will be commercial driverless cars in 2020 and some say we will have to wait until 2050, but to this day there are no fully automated vehicles on the market (Litman 2018; Shladover 2018). Some argue for the opportunistic scenario and some mean that the dystopic scenario is more likely, but more research in driverless vehicles and their expected impacts on the transport system and society is clearly needed. Though, as the former scenario shows, there are a lot of potential opportunities with implementing driverless vehicles. To reach this scenario, laws and regulations, financial incentives (Pernestål & Kristoffersson; Docherty 2018), technology and public attitudes need to be transformed (Taiebat et al. 2018).

The transport system today is facing multiple disruptive trends of which automation is one. Others are connectivity, new mobility services and sustainable trends like electrification and biofuels. To limit the temperature rise to 2 degrees Celsius (UNFCCC 2018), the transport sector needs to reduce its emissions, making the sustainable trends important. Today the transport sector is accountable for about a fourth of the global CO_2 emissions (IEA 2018) and about a third of the Swedish CO_2 emissions (Trafikverket 2018). Ride-sharing services are environmentally friendly examples of mobility services that have grown in popularity recent years (Taiebat et al. 2018). Carpooling is another sharing service that could potentially be environmentally friendly (Sunfleet; DriveNow 2019). Together with public transport, which can also be viewed as a sharing service, these services are important when aiming for more sustainable transports. However, the technology of automation itself seems to have marginal effects on reducing emissions, it's rather the system effects from the use of driverless vehicles that will affect the climate (Milakis et al. 2017; Wadud et al. 2016). More efficient driving and platooning would reduce emissions, but increased car-use would offset these reductions and even increase the emissions (Litman 2018).

With these disruptive technologies, researchers are quite convinced that the public transport will change, though they disagree on how it will change (Heineke et al. 2017). For instance, some say that the attractiveness for public transport will increase because of reduced ticket prices due to removal of the driver while others say that the attractiveness will decrease due to decreasing costs of private cars (Fraedrich et al. 2018; Glasare & Haglund 2018; Guerra 2016). Today public transport is the most space efficient transport mode and exists in different ways. For instance, subways, trains and buses operate in cities as an alternative to private cars, cycling and walking. Subways are usually limited to city centres while trains and buses also operate in rural areas. Since public transport is the most space efficient option and cities won't be able to manage increased private traffic, some argue that the public transport must remain even in a driverless future, especially during rush hours (Glasare & Haglund 2018).

Most research, commercial initiatives and testing efforts on driverless vehicles are also concentrating on cities (Pernestål & Kristoffersson 2018). Multiple test projects have been performed all over Europe (Alessandrini & Mercier-Handisyde 2018) and in Sweden (Nobina 2018a; Nobina 2018b; S3 2018), all focusing on urban areas. Perhaps the first thing that comes to people's minds when talking about driverless vehicles is an Uber-like service operating the same way as today, but without the driver. Even though most research on driverless vehicles is focused on urban areas, some argue that the potential benefits from driverless vehicles are greater in rural areas (Meyer et al. 2017).

One of the problems with implementing driverless vehicles on the market is the safety issue. The safety depends, among other things, of human to vehicle interaction (Fraedrich et al. 2018) and according to a survey based on a test conducted in Switzerland, these interactions seemed to be a major concern in the public opinion (Wicki & Bernauer 2018). The issue became even more spoken of after the fatal accident with an autonomous car in Arizona in the early 2018 (Levin & Wong 2018). In rural areas the environment looks different, there are empty country roads and less people roaming around in the streets, causing fewer interactions (Berg 2018). Also, the issues with city traffic don't necessarily translate to rural areas, for example two of the major problems with city traffic are congestion and lack of parking space which aren't problematic in rural areas (Pernestål & Kristoffersson 2018; Milakis et al. 2017). Rather, problems with the transport system in rural areas are low redundancy and flexibility of mobility services and long distances (Hansson & Karlsson 2018).

Differences with transports in urban and rural areas are more significant when talking about public transport. In cities, the population density is higher and the distances between target points are shorter. Hence, the occupation rates are higher and the degree of self-financing for the public transport is higher in cities than in rural areas (Berg 2018). Due to these financial challenges, the flexibility, frequency and accessibility of the public transport system are poor in rural areas leading to a modest level of attractiveness (Skånetrafiken 2018a). In public transport for buses, the cost of the driver is almost 50 percent of all operating costs (Hallberg; Hedlund 2018). Reducing the driver cost would enable re-investing capital to improve the service quality by increasing frequency or exploiting new areas. Since the public transport is functioning relatively well in cities, the benefits for a driverless public transport service could be greater in rural areas. For instance, it would be affordable to operate vehicles in new ways, which makes it interesting to study driverless vehicles in a rural setting.

So, what role will the public transport play in a future transport system in rural areas? Which problems does the public transport have to solve there and how can driverless vehicles contribute to solving these problems? Public transport and shared travelling could be used as a tool to increase sustainability in rural areas. Shared services would enable more mobility options (Berg 2018), decrease the dependency of the private car (Urry 2004) and reduce greenhouse gas emissions without compromising accessibility too much. Shared services are needed to solve congestion issues and reduce emissions in cities (Litman 2018; Pernestål & Kristoffersson 2018), but how could driverless mobility services function in rural areas? Would these services be integrated in the public transport or complementary services? Who would be responsible for the costs, would the cost structure be the same and will travellers be affected? Would a future with driverless vehicles lead to a sustainable transport system in rural areas?

1.1 Aim of study and research questions

The aim of this thesis is to study how driverless vehicles can be used in rural areas to improve the public transport. To fulfil the aim, the goal is to study existing problems in the public transport in rural areas and how these problems can be solved by driverless vehicles and if these solutions can contribute to a more sustainable transport system. Further, the purpose of the thesis is to contribute to the research on driverless vehicles in rural areas where research is lacking. Another contribution of this thesis is to develop a new modelling approach for evaluation of driverless mobility services in rural areas. The overall aim of the study is to contribute to the following question:

- How can driverless vehicles be used in rural areas to contribute to a more sustainable transport system?

To contribute to this question, this thesis aims to answer the following research questions:

1) How can new mobility concepts for driverless vehicles be used in rural areas to improve the public transport?
2) How can the service quality of the public transport be improved by using driverless vehicles?

In addition to addressing the above stated research questions, further contributions of the work in order to generate more detailed insights on the research questions are:

- the performing of case studies in multiple municipalities to identify characteristics of rural environments where the new mobility concepts for driverless vehicles can be applied,
- the development of a simulation model to evaluate the feasibility of a concept for driverless vehicles in rural areas and
- an application of the simulation model on one of the identified real-world scenarios of implementation of driverless vehicles.

1.2 Delimitations

Driverless vehicles are discussed in multiple contexts, though this thesis focusses mainly on new mobility concepts for driverless vehicles in rural areas to improve the public transport. To do this, this thesis was delimited in automation level as well as in time and space.

1.2.1 Delimitations in automation level

The most established definition on different levels of automation for vehicles is made by the Society of Automotive Engineers (SAE), see table 1 (SAE, 2014). Full automation (level 5) is not yet possible, though many test projects have been performed on level 3 and 4 (Alessandrini & Mercier-Handisyde 2018; S3 2018). The levels are defined by different factors but most important is the dynamic driving task which is defined by operational and tactical aspects. The operational aspects include steering, accelerating and braking and the tactical aspects include responding to traffic situations. The dynamic driving task is not defined by strategic aspects like choosing destination. A distinction is made between level 2, where the dynamic driving task is performed by humans, and level 3, where the dynamic driving task is performed by the automated driving system. In this report, the focus is on level 4 and 5 of automation which differs from level 3 when an incident occurs. Level 3 automation handles an incident by switching to human driving whilst a level 4 and 5 automation system stays in automation mode (SAE, 2014).

In the literature the used nomenclature varies, and different phrases are used to describe the same phenomenon. ‘Automation’, ‘autonomous’, ‘driverless’ and ‘self-driving’ are common expressions, where the former one describes the different levels of automation and the latter three are used only for automation level 3 to 5, see table 1 (SAE, 2014). The mobility concepts for driverless vehicles in rural areas presented in section 5.1 in this report are assumed to operate on level 4 and 5 automation (SAE 2014) where there is no driver or host of the vehicle. Therefore, the phrase ‘driverless’ seems to describe the phenomenon studied in this thesis the best. However, on automation level 4 and 5 there could be a remote driver taking control of the vehicles when needed. A remote operator like this could potentially have control of multiple vehicles simultaneously.

Table 1: Levels of automation defined by SAE (2014).

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* (“system”) monitors the driving environment**						
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

1.2.2 Delimitations in time and space

Geographically the report focuses on rural as opposed to urban areas. This includes travelling in rural areas, from rural area to an urban area and vice versa, but it does not include travelling within an urban area. In this report, rural areas are defined by longer distances to city centers and with less than 5 000 permanent residents. These areas could be large enough to have certain social functions (e.g. schools, supermarkets and public transport), but don't necessarily need to have these functions. The main expected commuting direction is outbound from these rural villages towards a larger city or suburb. Also, this report does not touch either traffic in air, rail nor on water. The thesis primarily focuses on public transport with bus traffic, but feeder traffic that is later discussed could potentially be used in connection to train stations too. Further, the report focuses on passenger transports and does not include goods transports.

Sweden and the Swedish public transport system were considered in this study. Only Sweden was considered, partly because research and interest in driverless vehicles are strong in Sweden and multiple tests have been and are currently being performed in the country (Nobina 2018a,b; ITRL 2018; S3 2018). Furthermore, there are rural areas spread out all over the country with different conditions and features in Sweden. To answer the research questions, multiple case studies were performed to discuss the results in different conditions and features. The case studies performed were Trelleborg, Östhammar and Eskilstuna municipalities. These case studies were chosen since actors in these areas showed interest in the study and the locations were somewhat similar.

As stated earlier, there are no level 5 automation vehicles on the streets yet. Hence this thesis focuses on a potential future scenario where the required technology, laws, regulations and attitudes are in place for a driverless transport system. Many challenges still need to be dealt with before reaching such a scenario (Litman; Shladover 2018). The exact horizon of when this will happen is difficult to estimate, but it's important to note that the thesis studies potential mobility services in a future driverless society and not in the next coming couple of years.

1.2.3 Sustainability delimitations

Sustainable development is based on economic development, social development and environmental development (United Nations General Assembly 2005; European Commission 2017) and sustainability is in general terms discussed as the endurance of a process or a system. In this report sustainability is primarily discussed in terms of social and environmental development. Though economic development is not discussed explicitly, reduced driver costs that come with driverless vehicles is what makes reinvestments in public transport and other public sectors possible. The definition of social development used in this report is: '*Social sustainability occurs when the formal and informal processes, systems, structures and relationships actively support the capacity of current and future generations to create healthy and liveable communities. Socially sustainable communities are equitable, diverse, connected and democratic and* *provide a good quality of life*' – Western Australia Council of Social Sustainability (2000) quoted in Partridge (2005 pp. 9). To define environmental sustainability in this thesis, the definition of the Brundtland Commission is used: '*Sustainable development is development that meets the needs of the present without compromising the ability of the future generations to meet their own needs*' – UN Commission (1987 pp. 41). Social and environmental sustainability are often discussed in terms of the Sustainable Development Goals (SDGs). In this report, social sustainability relates mostly to SDG 10 '*Reduced Inequality*' and 11 '*Sustainable Cities and Communities*' while environmental sustainability relates to SDG 9 '*Industries, Innovation and Infrastructure*' and SDG 13 '*Climate Action*' (European Commission 2019).

2. Background

This section first presents the current situation of the transport system and its growth during the 20th century. After this, a more futuristic scenario with driverless vehicles is presented along with previous and current test efforts on autonomous vehicles and new mobility concepts. In the transport sector there are large negative environmental effects which are discussed after the driverless vehicles are presented. Next, public transport and its challenges in rural areas are presented to end this section.

2.1 The development of the transport system

Since the automobile arrived the infrastructure has been adapting to our travel behavior and spatial constraints have been relieved. During the growth of the car-industry, urban development in the outskirts of cities has been made available at the cost of congestion, increased emissions and parking problems (Alessandrini et al., 2015). From increased car use new industries have developed, and automobiles and transports have become important growth indicators in today’s economies. Present infrastructure ideals promote the car as the primary means of transportation (Berg 2018) and the system of the automobile has become a system that enhances its own strength (Urry 2004). This has led to difficulties of changing the role of the car and the way the society is built. Usually the car is only used during a fraction of the day and mostly during peak hours (Alessandrini et al. 2015). As opposed to the public transport, cars are parked just outside the door, more journeys are made available and people can leave whenever they want, causing a greater sense of freedom (Urry 2004). Public transport on the other hand doesn’t operate everywhere, runs after a timetable and stops only at pre-decided locations (Berg 2018). Thanks to flexible door-to-door transports, the car has become a status symbol (Alessandrini et al. 2015). Transports are rarely the goal, but rather a means to get to an activity. Therefore, travel times affect the possibility for people to perform the desired activity (Bångman & Nordlöf 2018), where the car most times is the faster option in rural areas (Hedlund 2018).

Vehicles that don’t need a driver has been discussed since the mid-1900s (Shladover 2018). The air traffic has the autopilot and there are subway trains in Copenhagen (Metro Service, 2018) and Singapore (Government of Singapore, 2015) operating without drivers. Though total automation (automation level 5) has not yet been reached for regular road vehicles, but only for other transportation modes.

2.2 Driverless vehicles

The technology of driverless vehicles consists of radars, lidars, sensors, cameras, GPS systems, and navigation systems using objects on the side of the road to navigate. These objects could be lines in the road, pavements, buildings, trees or other objects. The technology is developing in a fast fashion but still there are regulations in Sweden disallowing tests with driverless vehicles. Autonomous vehicles might be tested if there is an operator ready to take control of the wheels at any given time (Brümmer et al. 2018). This makes it difficult to realize effects from driverless vehicles in the public transport, since the cost of the operator can't be removed yet.

For public actors it could be just as important to view the driverless technology as a welfare issue as a technological, legal or safety issue (Fraedrich et al. 2018). Hoadley (2018) criticizes public actors for not taking enough responsibility in the automation matter. These actors could be the experts in a regional setting and could also account for the welfare of the population as well as reduce emissions by providing a good public transport service.

2.2.1 Testing efforts of autonomous shuttles

Multiple test projects with autonomous vehicles have been carried out globally. A major project called CityMobil2 was performed in multiple locations in Europe with the aim of overcoming barriers for autonomous vehicles. Autonomous shuttles in this project were used in designated areas like campuses or in segregated lanes in urban areas (Alessandrini & Mercier-Handisyde 2018). In Sweden there have been three test projects in 2018 and 2019. One of these projects was performed in Kista, Stockholm, which is a tech hub in central Stockholm with a lot of people in motion throughout the day (Nobina 2018a). People found the safety of entering the vehicle the most concerning part and thought that there should be a host controlling tickets and ensuring safety on the bus (ITRL 2018). The second project started in the end of 2018 in Barkarbystaden, located just north of Stockholm, where autonomous shuttles serve as an integrated part of the local public transport system (Nobina 2018b). The third test project is performed at Chalmers, Gothenburg, but will proceed to be tested at Lindholmen too (S3 2018). Chalmers is a technological university in Gothenburg and Lindholmen is a business and research hub with focus on future mobility (Lindholmen 2018). All projects described were performed in different types of city settings.

2.2.2 Autonomous shuttles

In the test projects described above, the vehicles used have been autonomous shuttles similar to the one in figure 1. These shuttles can be operated in open traffic but can operate with increased speed in segregated lanes (Alessandrini & Mercier-Handisyde 2018). They could also operate on bike lanes since they are slow and not too big. Some actors in the field of autonomous shuttles are also discussing the chances of using the shuttles on bicycle roads. They can reach a speed of about 40-50 km/h (Brümmer et al. 2018) but in the tests performed, the speed hasn't reached more than 20 km/h (Alessandrini & Mercier-Handisyde 2018). Depending on the model, these shuttles have a capacity of about 12 to 16 people at a time. Usually they're run on electricity and can operate during a whole day in the public transport before it needs charging (Brümmer et al. 2018).

Figure 1: Autonomous shuttle from Navya (Navya 2018).

2.3 Mobility concepts for driverless vehicles in urban areas

Since the research about driverless vehicles in rural areas is at an early stage it is important to identify possible use cases. Pernestål and Kottenhoff (2018) identified several use cases for driverless vehicles as complements to the public transport in Stockholm. The use cases presented by Pernestål and Kottenhoff (2018) are feeder services, shortened bus routes, cross-connections and area traffic.

2.3.1 Feeder services and shortened bus routes

Feeder services can be used for shorter distances than one kilometer, e.g., for older people, disabled people or people carrying heavy luggage. It could risk the daily exercise of people and lead to public health issues. Since a service with normal buses usually isn’t motivated for shorter distances, the costs for the public transport would probably increase. If the feeder’s service distance would be longer than one kilometer it could replace a standard bus route and reduce costs for the public transport operator as well as increase the accessibility and attractiveness of the public transport. Feeder services can also be used on the first mile and last mile to shorten bus routes and make on-demand services possible. Furthermore, shortened bus routes with feeder lines could increase the area of which travelers could easily reach public transport. In this way, more people could be integrated to the public transport system (Pernestål & Kottenhoff 2018).

2.3.2 Cross connections

Short waiting times are important for the attractiveness of the public transport system, but for cross-connection routes this is difficult since most passengers travel to a central area. The customers travelling between routes are fewer than the ones travelling in and out of the central areas, which leads to difficulties motivating the routes from a financial standpoint. In off-peak hours this service could be on-demand (Pernestål & Kottenhoff 2018).

2.3.3 Area traffic

Area traffic is used to serve a defined area, e.g., an industrial area, a campus or a housing block. The service could be synchronized with the traffic outside its jurisdiction and become a feeder line to the public transport. A disadvantage with this service is that it competes with walking and cycling, which could get public health effects (Pernestål & Kottenhoff 2018).

2.4 Environmental effects

Increased car-use has already been an important reason for the growth of oil-rich countries. Indirectly, car-use has also been the reason for multiple wars during the 20th century (Urry 2004). Reducing car-use, increase public transport-use, and replacing fossil fuels with biofuels or electricity would lead to reduced emissions from the transport sector (UL 2018a), and perhaps even prevent future oil conflicts.

Environmental effects do not come from automation per se but can be facilitated by automation. If an autonomous car is used in the same way as the conventional car than there the environmental effects will be the same. But if autonomous functions that makes the driving more fuel-efficient there could be positive environmental effects from automation. Some effects, like automated eco-driving, can come directly from more efficient driving by automating the vehicles, but would probably be offset by increased vehicle kilometers traveled (VKT), which comes from facilitating the (Wadud et al. 2016). It's important to note that the emissions could well increase if the driver's cost of time (CoT) is reduced vastly. CoT in a context of driverless vehicles means that the drivers don't have to perform the dynamic driving task, but can get work, studying or other things done while in the vehicle (Wadud et al. 2016). Increased automation could hence potentially increase private traffic, so to make the transportation sector more environmentally friendly, the transport system probably needs to be redesigned.

Depending on what transport mode is used and the alternative cost of the travel, CoT-values differ. Bus travelers are assumed to have a smaller sacrifice of travel time than car users. If people are in a hurry, they have higher alternative costs, and when people are in a hurry they use faster vehicles to be sure to arrive on time. Therefore, bus travelers' CoT is lower than car-users' (Bångman & Nordlöf 2018).

VKT is an indicator of whether net emissions increase or decrease. If the number of vehicles decrease by 10 percent but the vehicles left are utilized 50 percent more, then the total VKT increases as well as the emissions to the atmosphere (Richter 2018). If the accessibility is increased and ticket prices and drivers cost of time are reduced, the total VKT is assumed to increase due to increased attractiveness for private cars and taxi services (Taiebat et al. 2018). Using public transport or sharing services is an alternative to reduce private transports and reduce total VKT. Since more people use the same vehicles, there would be less vehicles on the road which is why sharing services are considered environmentally friendly (UL 2018a). Sharing services have not only led to less cars on the roads, but also their members have reduced their car use. The members don't need to own their own vehicle (Hoadley 2018) and one car in a driverless sharing service could, in optimal conditions, replace up to 18 privately owned driverless cars (Pernestål & Kristoffersson 2018). Being a member of a shared driverless taxi service would be a more sustainable alternative than using a privately-owned car since the net vehicle kilometres travelled would decrease (Litman 2018).

Swedish public transport administrations work hard to become more climate smart by replacing most of the vehicles driven on fossil fuels to vehicles driven on biofuels, electricity, or at least hybrid-options (UL 2018a). In urban environments public transport is the most space efficient transport mode (Glasare & Haglund 2018) and is often marketed as a climate smart option. The environmental benefits in public transport is a result of that more people use the same vehicle (UL 2018a). However, public transport is not necessarily climate smart unless a certain number of people use the service (UL 2018a). Sustainability-wise it's important that the new customers come from car-users and not from cyclists (Hedlund; Ahlberg & Wirén 2018).

2.5 Challenges for public transport in rural areas in Sweden

Public transport is organized for the public to use and consists of a system of transport modes and vehicle types (NE 2018). In Sweden there are local authorities providing public transport solutions in limited areas (e.g., Skånetrafiken, Upplands Lokaltrafik (UL) and Sörmlandstrafiken) combined with the government providing national services (e.g., SJ). Unlike car-use, public transport is fragmented and it's not uncommon that journeys require multiple changes (Urry 2004).

In Sweden the public transport is unregulated but public authorities operate these services to the greatest extent. The public transport in Sweden is approximately funded half by tax money and half by revenue from ticket purchases (Region Uppsala 2018a; Skånetrafiken 2018a). By adding routes that are not economically sustainable is therefore an issue since only a small group of people benefit from that route, while a large group must pay for it. Tax money for the public transport normally competes with healthcare and welfare, meaning that if the public transport has more self-financing, capital could be reinvested to other societal functions.

In cities transport modes like trams, subways, trains and buses are common since this is the most space efficient mode of travelling. Often these transport modes operate on dedicated lanes or on segregated infrastructure which makes it a faster option than using the private car (Glasare & Haglund 2018). All these modes of public transport operate to reduce congestion and parking issues in city environments, where the population density and travel demand are higher (Pernestål & Kristoffersson 2018; Milakis et al. 2017). The degree of self-financing is higher in cities than in rural areas due to a larger customer base resulting in higher occupancy rates. More customers per vehicle leads to a lower relative cost for the drivers, which is about 50 percent of all operational costs in public transport for buses (Hansson & Karlsson; Hallberg; Hedlund 2018). Consequently, removing the driver, or at least using a remote operator, would have greater effects on public transport in rural areas. For instance, the road network is complex and difficult to change in urban areas, which is not the case in rural areas. So by removing the driver in cities, the service quality could decrease since no operator would be in the vehicle to help older people or mobility impaired. Perhaps this effect could be offset for public transport in rural areas by investments in new routes or increased frequency (Nyström & Olsson 2018). Reducing costs by removing the driver could hence potentially solve some of the challenges for the public transport in rural areas. Some of the challenges for public transport in rural areas are presented below.

2.5.1 Accessibility and flexibility challenges

Challenges in rural areas differ from those in urban areas due to different geographical and demographical conditions. Many rural areas face ageing populations and are less dense. Further, the distances are longer between destinations due to more scattered living making it less economically viable to operate a decent and effective public transport service (Berg 2018). Rural pre-conditions cause issues regarding flexibility and accessibility which result in poorer service and lower departure frequency (Berg 2018).

2.5.2 Equality challenges

Lower travel demand and longer distances might also cause equality issues in different forms, e.g., reduced mobility redundancy, increased ticket prices and social exclusion. If public transport operates in a village but departures are cancelled due to bad weather and someone's car has broken down, this would mean that this person can't make it to work. Therefore, it's important with a reliable and effective public transport service (Hansson & Karlsson 2018). If it's not financially viable to operate public transport in a village, vulnerable social groups without other mobility options will be even more vulnerable. They become more dependent on getting a ride from a friend or a relative. Also, since occupancy rates are lower in rural areas, ticket prices are often higher which further makes these groups further vulnerable (Berg 2018). With poor public transport, people living in rural areas can't invite friends or family over for dinner and a glass of wine since it wouldn't be possible to get home in the evening. This is an equality issue since it leads to social exclusion of people living in rural areas (Pettersson-Hernestig 2018).

2.5.3 First and last mile challenges

Not only is the travel demand lower and the distances longer, the quality of the infrastructure is often poorer in rural areas. Together, these are causes to a problem known as the first mile or last mile-problem (FMLM). The FMLM issue is a barrier for people to use the public transport and is about how people transport themselves from their homes to the public transport (Pernestål & Kottenhoff 2018). Also, the longer distances between people's homes and bus stops, the more the car is used as a transportation mode (Glasare & Haglund 2018). There is often a lack of pavements and bike lanes, road lighting and the roads are not as well maintained in rural areas. During a cold and dark winter day with slippery roads people don't want to walk a few kilometers on the roadside to get to the bus stop or train station, especially not children, older people or mobility impaired. With less accessibility and mobility, villagers might take the car instead since the car is parked just outside the house (Berg; Hansson & Karlsson 2018).

Some people are too comfortable to walk or cycle to the bus stop and prefer taking the car, but some people are willing to use these transport modes to get to the public transport (Berg 2018). This means that using driverless vehicles driving this distance might reduce walking and cycling, which would not only lead to public health issues (Hedlund 2018) but also to increased vehicle kilometers traveled (Hoadley 2018).

2.6 Shared mobility services

Lately, different types of sharing services have grown in popularity and today there are plenty of services on the market. Beyond public transport, perhaps the most known sharing services are car-sharing and carpooling. With increased interest in sustainable transports, awareness about sharing services have increased and many car producers now have their own sharing service (e.g., Sunfleet; car2go; ReachNow; Groupe Renault 2019). Locations of sharing services are usually placed in larger urban areas (e.g., Groupe Renault; car2go 2019). Shared autonomous vehicles in city environments could also reduce road congestion and increase the use of public transport (Richter 2018). But not much research has been done about how on-demand sharing mobility services might be designed and implemented in rural areas.

2.6.1 Complementary public transport services

In some cases, complementary services can be used for people living in sparsely populated areas. The flexibility of complementary services varies between different public transport administrations. Support vehicles can operate after a timetable and have fixed stops but can also function as door-to-door alternatives (UL 2019a; Kristiansson 2018). Orders must be done prior to departure, in some cases two hours before departure (UL 2019a) and in some cases longer (Kristiansson 2018). Complementary services like these are often used in areas where the travel demand is very low, and in most cases operated by taxis. Like all public transport, passengers pay for a regular ticket to use the complementary services but for the public transport administration, the service is much more expensive to operate (Hallberg 2018). Sörmlandstrafiken doesn't even market their complementary service due to the high costs of its operation (Nyström & Olsson 2018).

3. Methodology

To answer the research questions and fulfil the purpose of the study, a wide methodological approach was used, which is presented at first in this section. After this, the data collection methodology including interviews and statistical data is explained. A short description of modelling approach is then presented, before the section ends with an explanation of how the remainder of the report is structured. Since one purpose of this study is to develop a new modelling approach for evaluation of driverless mobility services in rural areas, this model and its results are mainly described in the results section.

3.1 Performing the study

Since there isn't a lot of research made on driverless vehicles in rural areas, information on the research area first had to be retrieved. A general literature review was performed mainly to learn about challenges with the public transport system in rural areas and how these challenges could be solved by driverless vehicles. A qualitative approach was used in order to identify rural mobility concepts for driverless vehicles (DVs) and real-world case locations where these mobility concepts could be applied. This was done by performing case studies and conducting interviews with local actors in Trelleborg, Östhammar and Eskilstuna. The rural mobility concepts for DVs were developed with the purpose of overcoming the previously mentioned challenges for rural public transport mobility and was developed mainly after interviewing the actors in Trelleborg. During the interviews with actors in Östhammar and Eskilstuna the mobility concepts for DVs in rural areas were further developed and revised.

When the rural mobility concepts for DVs had been developed they could be applied to real-world case locations based on the information received in the interviews conducted with local actors. Pros and cons of how the rural mobility concepts for DVs could be implemented in different case locations and how the public transport in the area would be affected were later discussed. To test the feasibility of one of the rural mobility concepts for DVs a model was developed and used to simulate the features of a real-world case location. At this point, data could be collected on the real-world case location to simulate the model.

The level of detail of analysis of the study can be seen in figure 2 to get a better understanding of how the study was performed. In this case, the timeline of the methodological steps corresponds with the level of detail showed on the x axis. Results from each methodological step are presented in the chapter showed in the box above or below the respective methodological step.

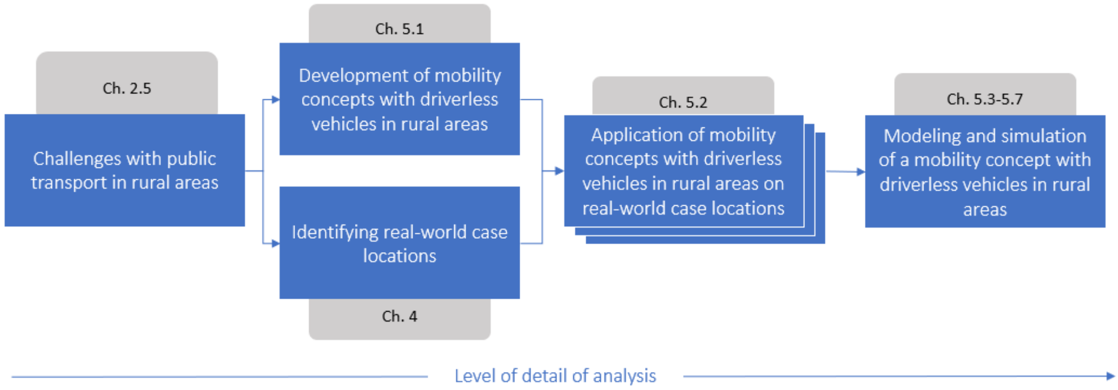

Figure 2: Methodological steps of the study.

3.2 Data collection

Different methods were used to gather important information needed to answer the purpose. To get an understanding on challenges with public transport in rural areas and opportunities with driverless vehicles, general information was first collected. The literature focused on three areas: 1, driverless vehicles, 2, public transport and its challenges in rural areas, and 3, sustainability measures relevant to driverless vehicles and rural public transport. Interviews was also used as the main source of data collection for information about the case locations. Statistical data from one of the case locations was finally used to test the feasibility of one of the rural mobility concepts for DVs. However, seminars and conferences on relevant subjects was also a part of the data collection, e.g., Iain Docherty's seminar at ITRL in October 2018 (KTH 2018).

3.2.1 Case studies

The case study is a common qualitative methodological approach used to study, interpret, analyze and understand the meaning of the studied phenomenon (Patel & Davidson 2011). An inductive approach doesn't intend to verify existing research but rather to contribute to creating new theories or provoke new thoughts (Siggelkow 2007). In this thesis, the rural mobility concepts for DVs were developed together with a high-level modelling approach.

Three case studies were performed to discuss how different environments could affect the use of a rural mobility concept for driverless vehicles. Information found in the interviews with local actors varied and would probably have been different if another case study had been performed as well. A case study makes it possible to study processes and changes within defined limits with a holistic perspective (Patel & Davidson 2011). By performing three case studies, these could be compared and discussed in the light of its differences and similarities. If only one case study would have been performed, the results could have been too biased and formed after local problems found only in that specific case study (Bryman & Bell 2003). However, with three case studies the rural mobility concepts for DVs could be discussed in different settings, making the resulting mobility concepts for DVs more generalizable.

3.2.2 Interviews

Interviews were mainly performed during the first part of the study. The semi-structured interview is the heart of a study with a qualitative approach (Gioia et al. 2013) and was thus used in this thesis. Since the respondents are the ones with expertise on the different areas, the interviews can take different directions and using semi-structured interviews allows the respondents to lead the interviews forward. With pre-decided topics and questions the risk for interviews leading in the wrong direction is reduced (Bell 2006), thus different interview tools were used to make sure the outcome of the interviews was relevant. The choice of approach is based on that some answers might need follow up questions. For instance, it’s important to understand the underlying issues with an unattractive public transport service at a certain location to be able to develop a service with the aim of increasing the attractiveness of the public transport.

The interviews acting as a base for the case building were recorded and roughly transcribed. Information used from all interviews used in the report were then sent to the respective respondent for a chance to see if the interpretation and use of the information was correct. Respondents had the chance to revise and clarify eventual misconceptions at this time.

3.2.3 Interview respondents

Interview objects were chosen with regard to the objects’ areas of expertise. The interviews with municipalities, counties and public transport administrations were concentrated to the local surroundings to learn about challenges, develop rural mobility concepts for DVs and find case locations. To get different perspectives, municipalities and public transport administration in the same area were interviewed in all locations except for Östhammar. Hence the Uppsala case was only based on the interviews with UL. The different interviews conducted can be seen in table 1. Information from interviews with actors at Region Skåne, Trelleborg municipality and Skånetrafiken in particular helped develop the rural mobility concepts for DVs. The purpose of the interviews with UL, Eskilstuna municipality and Sörmlandstrafiken was rather to improve the rural mobility concepts for DVs further and to see whether these areas could be of interest for simulations.

Table 2: Conducted interviews.

Respondent	Organization	Date [yyyy.dd.mm]	Length [hh:mm]	Interview type
C. Pettersson-Hernestig	Trelleborg municipality	2018.21.09	00:25	Telephone
J. Hansson, S. Karlsson	The Swedish transport administration	2018.25.09	01:05	Telephone
J. Berg	VTI	2018.01.10	00:50	Telephone
J. Hedlund	Region Skåne	2018.03.09	00:50	Personal
M. Åstrand	Trelleborg municipality	2018.03.09	01:05	Personal
H. Kristiansson	Skånetrafiken	2018.04.09	00:45	Personal
I. B. Alhassan	UL	2018.12.10	01:05	Personal
T. Hallberg	UL	2018.06.11	00:55	Personal
K. Nyström, K. Olsson	Eskilstuna municipality, Sörmlandstrafiken	2018.13.11	01:35	Personal
E. Jenelius	KTH	2018.23.11	00:35	Personal
J. Ahlberg, A. Wirén	Ramböll	2018.19.12	01:30	Personal

3.2.4 Interview tools

Different interview tools were developed depending on the purpose of the interview and the respondent’s area of expertise. When developing interview tools, it’s important that the purpose of the study shines through and that the answers lead the discussion around the research questions forward (Gioia et al. 2013). All interview tools can be found in Appendix A. Below is a brief description of how the interviews differed in shape and structure.

During the first two interviews, the focus was on general issues with public transport, challenges with the transport system in rural areas and driverless vehicles. Questions like ‘*What barriers are there for public transport traditionally?*’, ‘*What possibilities are there with driverless vehicles?*’ and ‘*Which are the pre- and counter-arguments for public transport in rural areas?*’ were asked.

In the following six interviews, the focus was on getting an understanding for local challenges including public transport, the geographical and demographical environment, infrastructure and travel patterns for the specific area. Questions asked were ‘*How do the problems and challenges with the public transport look like in the rural areas?*’, ‘*How does the area look?*’ and ‘*Is there a concrete example of how driverless vehicles could solve any problems today?*’.

The interview with Erik Jenelius was performed to get tips on how the conceptual cases could be modelled. Questions in this interview focused on which software to use and tips on how to model public transport and transports in rural areas. Information from this interview was used as a start for building the model rather than as a contribution to background information or to develop the conceptual cases.

Ramböll released a report on autonomous shuttles integrated in the public transport system in rural areas during the time of this thesis. Similar rural mobility concepts for DVs were discussed in this report (Brümmer et al. 2018), and therefore this interview was conducted. The interview mainly concentrated on the findings from the report but was also an opportunity to present the rural mobility concepts for DVs proposed in this thesis and get their feedback on these since they were had expertise on the area. Questions discussed were for instance '*What actors will be the most important in a service like this?*' and '*How could the flexibility and accessibility be affected?*'.

3.2.5 Statistical data

Data used in the modeling was provided by Skånetrafiken (Kristiansson 2019). The data from Skånetrafiken was based on tickets bought along route 145 during 2018 where weekends and holidays were filtered out. Mean values, standard deviations and customer distributions could then be calculated from the data. The customer distributions were then fitted to the corresponding departure for each timetable.

3.3 Modeling

To test the feasibility of a rural mobility concept for driverless vehicles on a basic level, a model was developed and simulated. The mobility concept was applied to a case location from which data was acquired. Discrete-event simulation modeling was used to model the rural mobility concept for driverless vehicles. By using the work of a single queue and single server by Law and Kelton (2000), the structure of the model was developed. This type of modeling changes states of variables instantly at discrete points in time. These points in time are times when an event occurs, in this particular case when customers arrive to the queue or when they depart from being served (Law and Kelton 2000).

To measure different key performance indicators (KPIs) during a simulation, statistical counters were used. Other important components used were state variables, events and different routines. The logic of the model can be understood by following the flow chart created by Law and Kelton (2000) in figure 3, which also shows the most important routines used.

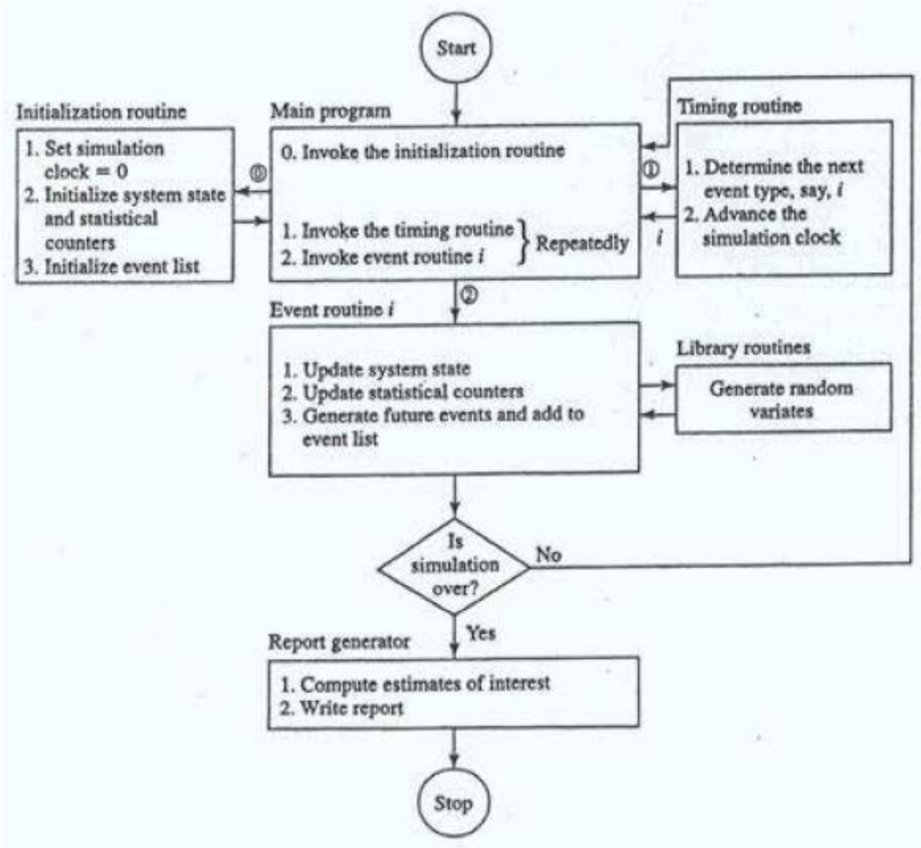

Figure 3: Flow chart describing the logic of the model (Law & Kelton 2000).

3.3.1 Stochastic modeling

In Law and Kelton's (2000) model a number of stochastic variables are used. For instance, the arrival times of customers to the queue are independent and identically distributes and the same applies for departure times. This means that these variables are chosen from certain distributions and differ from time to time with a certain deviation. The stochastic approach was used to resemble variations in the daily public transport use like number of daily travelers and departure times of buses. Extreme cases were not accounted for in the model. Because of variations between simulations, multiple simulations had to be performed to get a reasonable result.

3.3.2 Further model explanation

Proposed rural mobility concepts for DVs and their applications are contributions to the research field and parts of the purpose of this thesis. The same applies for the model approach and these are hence presented in the next section. How the discrete-event simulation modeling with stochastic variables was applied on the rural mobility concept for DVs is explained after these mobility concepts are presented in the results section. Detailed descriptions of variables used, and simulations made are thus not presented in this section.

4. Description of real-world case locations

In this section, the findings from interviews performed in the case studies are presented. The section starts off by describing the environments of the case studies with focus on demographic, geographic and infrastructural factors as well as public transport situations. It ends by describing data provided by Skånetrafiken.

All case locations have different features. The areas differ in demography, geography, infrastructure, travel patterns and public transport service. Three municipalities and public transport authorities were studied to develop the mobility cases and find applications for the cases – Trelleborg municipality, Östhammar municipality and Eskilstuna municipality. Skånetrafiken, UL and Sörmlandstrafiken are the public transport authorities of the respective municipality. In the municipalities studied there are villages or areas where the concepts could be applied, which are presented below.

4.1 Trelleborg municipality and Skånetrafiken

Skånetrafiken is self-financed to 57 percent in average, though most of the revenue come from the strongest routes, such as between Malmö and Lund. Since there is no economy in operating public transport in rural areas, the minimum resources are supplied there. This also applies for the development of the public transport system in Skåne, which is prioritized to the dense routes (Kristiansson; Hedlund 2018). The rural population in Trelleborg has a negative growth (Kristiansson 2018) and the number of travelers is decreasing (Hedlund 2018). This leads to decreased supply frequency which in turn makes even more people willing to use other transport modes. To find a way to deal with driverless vehicles is critical for Skånetrafiken's business to survive from companies like Uber. Yet they want to deal with driverless vehicles in a way that public transport doesn't take shares from cycling or walking since this could have effects on the public health (Hedlund, 2018).

In the municipality of Trelleborg the regular public transport doesn't reach all areas, which means that a local complementary service operated by taxis, called Närtrafik, is needed for people living too far off public transport routes. People living outside of a radius of two kilometers from the nearest bus stop in Trelleborg municipality have the right to use this type of demand-based traffic once a day which means that it could not be used for commuting. Figure 4 shows Trelleborg municipality and its public transport network. Trelleborg is the seat of the municipality and is located at the border of the municipality. The white area in figure 4 illustrates the regular public transport area, and the green area illustrates the Närtrafik area (Kristiansson 2018). Hiring local services, is expensive for the region. This service is demand-based and takes its customers to either a county town, a public transport stop, or all the way to the target point but not to locations outside the municipality. In some cases, the Närtrafik operates between predetermined stops according to a timetable but doesn't run if no one demands it

(Hedlund; Åstrand; Kristiansson, 2018). People ordering Närtrafik must call and order the vehicle from two hours to three working days in advance (Åstrand 2018).

Figure 4: Public transport in Trelleborg municipality. White areas are operated by buses and green areas are operated by "Närtrafik". 1, Grönby, 2, Alstad and 3, Västra Vemmerlöv.

In the municipality of Trelleborg they have set goals to expand the network of bike roads to simplify getting to and from the public transport (Åstrand, 2018). They also have plans to expand and develop certain villages called "livskraftiga orter". These villages hold certain value for the municipality and investing in better public transport to these villages are often political decisions (Hedlund 2018). Even if the public transport to such a village has low self-financing, the municipality sometimes makes additional purchases to increase the frequency or to keep certain routes open. Another goal is to improve the availability of the public transport to give people living in rural areas more mobility options (Åstrand, 2018).

Skånetrafiken has an on-going super bus project similar to bus rapid transit (BRT). The service is characterized by high quality, efficiency and service. The super bus concept will be used on routes with a high demand of public transport, but where the demand is not high enough to build railway. Skånetrafiken aims to increase the attractiveness for the public transport in eight selected routes by increasing simplicity, comfort and punctuality. The bus stops along the route gets upgraded to stations with proximity to relevant society functions. There should be bicycle lanes and parking slots for commuters to get to the stations in a simple and fast way. Buses in these routes will be quieter and more luxurious than regular buses and the bus traffic will be prioritized and be given the fastest possible route. Crossings will be rebuilt and there will be prioritized bus lanes to reduce the total travel time. To reduce the travel time further, some stops considered less important will be removed (Region Skåne, 2018; Lindblom, 2014).

4.1.1 Grönby

Northeast of Anderslöv lies Grönby, on the border of having access to public transport. About 200 people live here, about four kilometers from Anderslöv, which is the second largest town in the municipality. In Anderslöv there are schools, workplaces and different kinds of community services and the town has about 2,000 inhabitants. There is a bus route passing through Anderslöv (Kristiansson, 2018) but to get there from Grönby, one would have to walk along the roadside on one of two different country roads. One of the roads is bigger with better sight but has more traffic than the other road (Åstrand, 2018). Further northeast from Grönby lies the largest area of Närtrafik in Trelleborg municipality and a few more villages, according to figure 4. There are no bicycle roads between Grönby and Anderslöv, but only a smaller and curvy country road with poor sight (Åstrand 2018). From Anderslöv, travelers can use route 144 to get to Östra Grevie, which has a train station with trains towards Malmö and Trelleborg (Skånetrafiken 2019a). Travelers can also use route 183 to get directly to Trelleborg (Skånetrafiken 2019b).

4.1.2 Alstad

In Alstad there is about 200 people living. It is situated along the same country road as Anderslöv but closer to Malmö and Trelleborg. Alstad is double covered by public transport, one route that comes from Anderslöv and goes towards Östra Grevie (route 144) that has a train station with departures towards Malmö or Trelleborg (Skånetrafiken 2019c). The other route comes from Svedala and goes to Trelleborg (route 145) (Skånetrafiken 2019d). In Svedala there's another train station with destinations in Malmö and Ystad (Skånetrafiken 2019e). Route 145, see figure 5, takes a detour of approximately five minutes to pick people up in Alstad (Åstrand 2018). According to Google Maps, this distance takes four minutes with public transport one-way, which gives a total time for the detour of eight minutes (Google Maps 2019). For the people living in Alstad this might not be a distracting moment but for travelers going to or from Svedala, this moment might feel annoying. There are no community services in Alstad except for a smaller kiosk, a school (Åstrand 2018) and a golf course. However, politicians have discussed closing the school since there are too few students. If the school were shut down, the children would need other means of school rides (Ekstrand & Valgeirsson 2018). On the route there is a second, shorter detour in Minnesberg. As seen in figure 5, route 145 also passes by a village called Västra Vemmerlöv that isn't connected to the public transport in any way (Skånetrafiken 2019c).

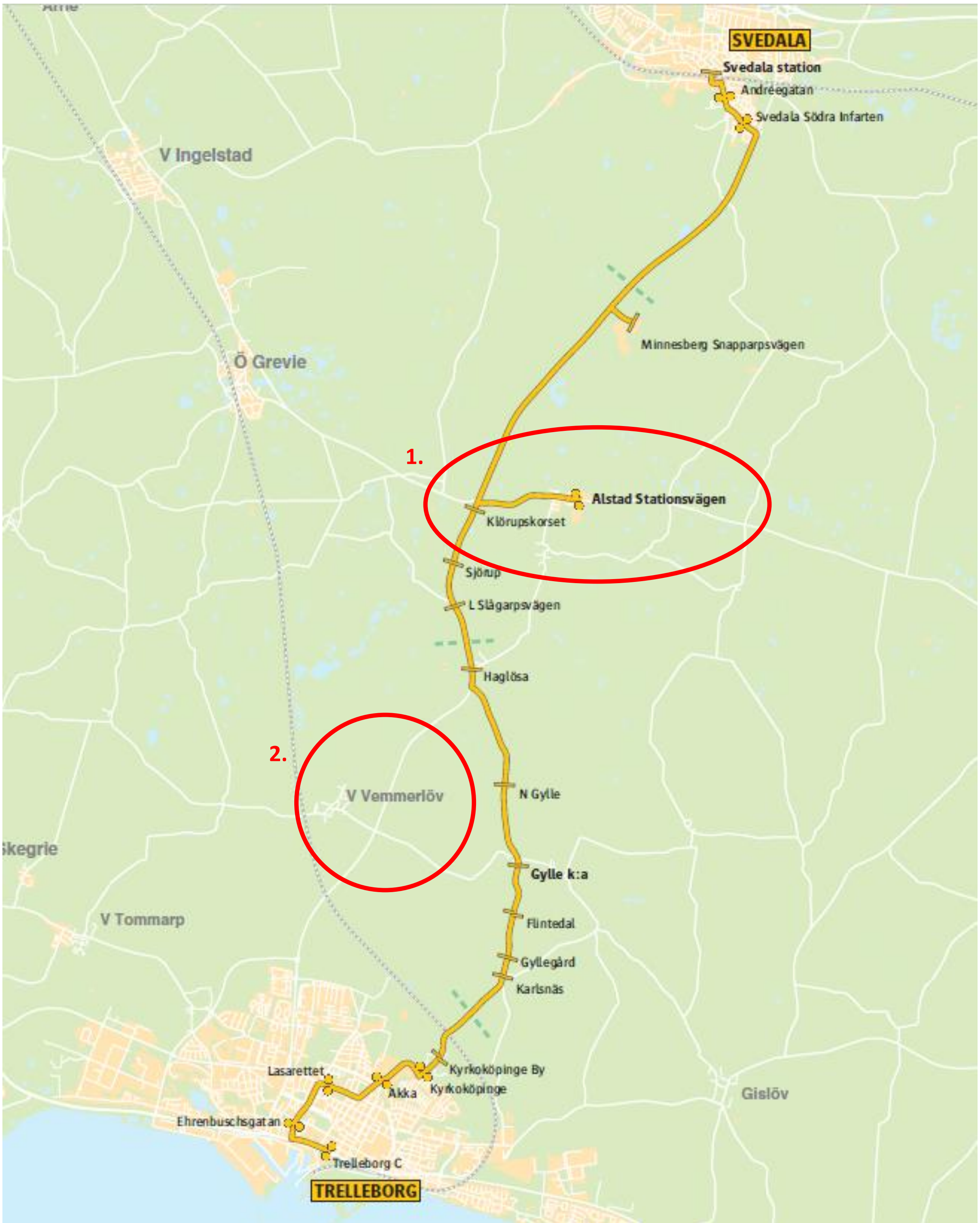

Figure 5: Route 145 between Svedala and Trelleborg (Skånetrafiken 2019c). 1, Alstad and 2, Västra Vemmerlöv.

4.2 Östhammar municipality and Upplands Lokaltrafik (UL)

The regional seat in Östhammar municipality is the city of Östhammar, located in the northeast corner of the municipality, as seen in figure 6. UL had a self-financing level of

47 percent in 2017 (Ohlsson Lundh 2018), which is ten percent less than Skånetrafiken. The share of public transport users is decreasing, but regional public transport is constant (Hallberg 2018). There are no trains operating in Östhammar municipality, which makes the regional buses even more important (UL 2016). UL wants the public transport to be a good alternative for mobility impaired people. To do this they want to increase the availability which in turn would lead to a more equal public transport service (Ohlsson Lundh 2019a). Yet all inhabitants don't have access to public transport, while the strong routes are doing well. Rural areas are often hit hardest by this since it's not financially viable to operate there (Hallberg 2018). Further, UL wants to reduce their emissions and contribute to more sustainable travelling (UL 2018a).

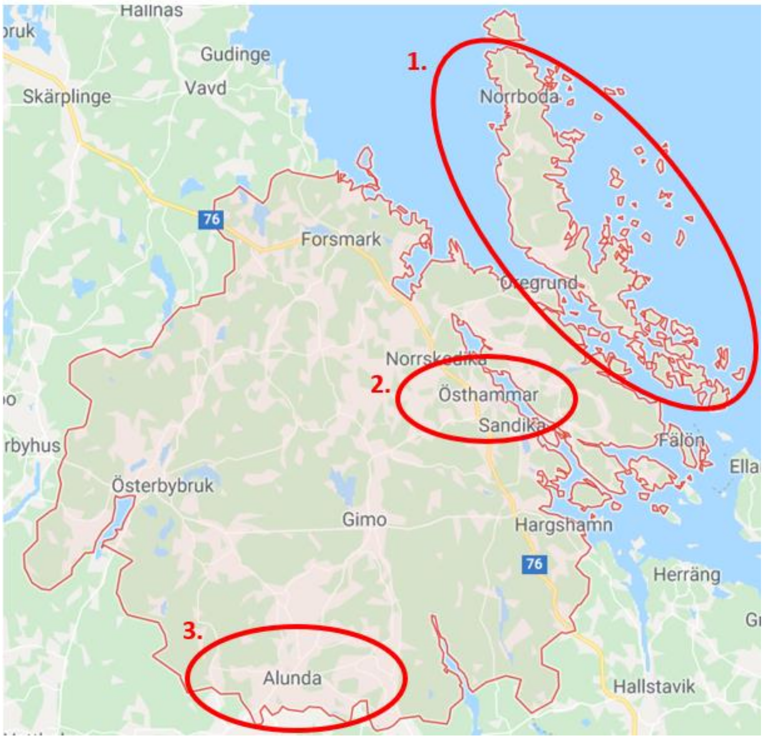

Figure 6: Östhammar municipality (Google Maps 2019). 1, Gräsö, 2, Östhammar city and 3, Alunda.

UL also has complementary services, operating for example northeast of Östhammar on an island called Gräsö. This service functions as public transport and is operated by timetable, have fixed stops but must be booked 3 hours in advance (Hallberg 2018). UL uses taxis to operate these routes and one journey costs the same as a regular bus ticket for the travelers, about 30 SEK (UL 2018b).

4.2.1 Gräsö

On Gräsö the public transport is only scheduled for school rides during mornings and afternoons, during other times the traffic is on-demand (Hallberg 2018; UL 2018c). Other rides are operated by taxis and the cost could be up to 1,000 SEK if passengers are travelling from the farthest north to the south of Gräsö (Hallberg 2018). This gives a self-financing rate of about 3 percent if there's only one passenger. Most amenities and social service functions are located in Öregrund, which requires a short ferry trip to the mainland, but there is a school, a grocery store and a church on the island. Most people use their houses on Gräsö during their holidays and weekends, but about 700-800 people live here permanently (Upplandsstiftelsen 2018).

4.2.2 Alunda

Alunda is located at the southeastern corner of Östhammar municipality, halfway from Östhammar to Uppsala nearby a large country road. Buses are both going towards Uppsala and Östhammar from Alunda. Route 886 goes from Uppsala to its end-point in Alunda, and when reaching Alunda it circles around the village to pick up and drop off passengers (UL 2018d). Going from Alunda bus terminal to Uppsala central station takes 41 minutes, but for people living at the far end of the encirclement, it takes another 10 minutes. Route 811 goes all the way between Uppsala and Östhammar but does not encircle Alunda, but just stops by the village on the main country road (UL 2018e). Taking both route 811 and 886 in regard, there are departures three or four times an hour in both directions. Route 811 and 886 between Alunda and Uppsala can be seen in figure 7, where route 811 only differs from route 886 at the red markings. In Alunda there are supermarkets, gas stations, schools, churches, sports centers and football fields. About 2 000-3 000 people live here (Östhammar municipality 2015).

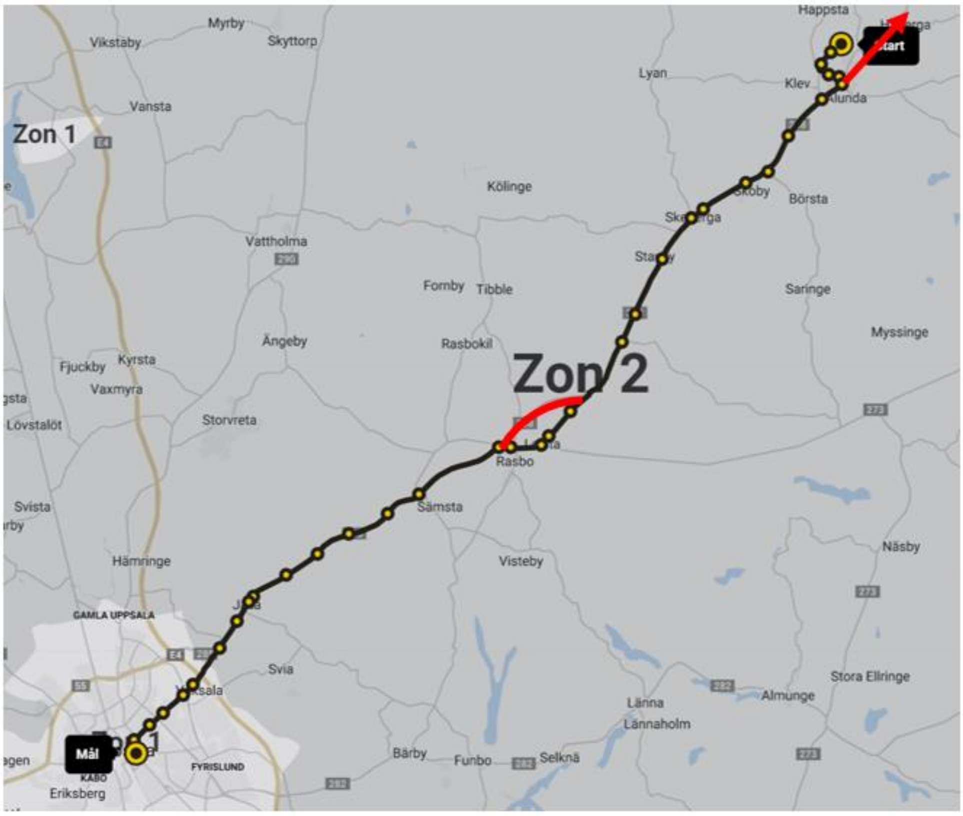

Figure 7: Route 886 between Alunda and Uppsala (black line) and route 811 between Öregrund and Uppsala (black and red line) (UL 2019b).

One goal of UL is to improve the public transport along the Uppsala to Öregrund route. About 20,000 people live along this route and it is one of UL's most frequently travelled regional routes (UL 2016), and the goal is to increase the travelling on this route by 30 percent. To do this, car-users must be attracted by the service and the communications and capacity must be able to manage this increase (Ohlsson Lundh 2019a).

4.3 Eskilstuna municipality and Sörmlandstrafiken

In Eskilstuna the challenges differ from the ones in Trelleborg. There are more villages that have more than a couple of hundred inhabitants (Nyström & Olsson 2018) and the city of Eskilstuna is located in the center of the municipality, as seen in figure 8. Since Eskilstuna is located centrally in the municipality, public transport needs to operate in many different directions to cover the whole municipality. Though for most cases, no changes between buses are needed. North of the city of Eskilstuna lies the quite segregated city of Torshälla with about 10,000 inhabitants. Further north is the shoreline of Mälaren where the villages of Kvicksund, Mälarbaden and Sundyholm are located from west to east. Torshälla, Kvicksund and Sundbyholm are also development areas in the municipality. The city of Torshälla is an important node for people living along the shoreline of Mälaren with its two schools, multiple workplaces, other social services like supermarkets, sports centers and its connections to Eskilstuna. The public transport is working well between Eskilstuna and Torshälla since there are a lot of travelers and the travel time quotas are quite good (Nyström & Olsson 2018).

Figure 8: Eskilstuna municipality (Google Maps 2019). 1, Kvicksund, 2, Mälarbaden and Mälbyviken and 3, Sundbyholm.

The best working routes in Eskilstuna municipality are self-financed to about 30-40 percent while on the worst routes this rate drops to 8-12 percent. Eskilstuna municipality belongs to the county of Sörmland and is the purchaser of the public transport services from the public transport authority. This means that the municipality bare the cost of the larger part of the public transport, which differs from the case in both Östhammar and Trelleborg where the regions bare these costs (Nyström & Olsson 2018). Furthermore, Sörmlandstrafiken struggles with the general public transport challenges in rural areas. They want to offer a service for as many as possible, but the service depends on where people live, where they are going and on their financial situation. Sörmlandstrafiken also want more people to travel, but not during the peak hours. Eskilstuna municipality rather needs the public transport to develop the development areas and keep the student base in the schools (Nyström & Olsson 2018).

Eskilstuna municipality has a vision to develop the public transport in a certain way, and they are prepared to invest in this vision. But by using driverless vehicles they believe that they would be able to save capital, for instance by not having to build ring routes connecting existing routes and by reducing the driver cost. Though Eskilstuna municipality believe that they can free resources with driverless vehicles, they are aware that the public transport might change a lot in a driverless future. In the future, they want to make the public transport more of an activity or increase the service by, for example, delivering online-purchased food or borrowing books from a mobile library (Nyström & Olsson 2018).

4.3.1 The shoreline of Mälaren

The area along the shoreline of Mälaren is an expansive area and villages and neighborhoods are integrating at an increasing pace. Today there are mainly summer houses there, mostly populated by people with high socioeconomic status with at least one or two cars per family. At an increasing rate though, people are becoming all-year residents of these villas and neighborhoods are growing along the lakeside (Nyström & Olsson 2018).

Kvicksund, which is one of the development areas in Eskilstuna municipality, has a train station between Eskilstuna and Västerås. In Kvicksund there is also a bridge crossing Mälaren which makes it an important node in the transport system. No public transport goes between Kvicksund and Torshälla but between Kvicksund and Eskilstuna there are both bus and train routes (Nyström & Olsson 2018). In Kvicksund there is a grocery store, a sports club and a school but no other social services.

Figure 9: Picture of Torshälla, Mälarbaden and Mälbyviken (Google Maps 2019).

Bus route 20 operates from Torshälla to Mälarbaden (Sörmlandstrafiken 2018a) and about one kilometer next to it is route 21 operating to Mälbyviken (Sörmlandstrafiken 2018b). Torshälla, Mälarbaden and Mälbyviken can be seen in figure 9. These areas are located about 3-4 kilometers north of Torshälla (Nyström & Olsson 2018), and the bus takes about 10-15 minutes. Mälarbaden and Mälbyviken could today be seen as parts of Torshälla. From Sundbyholm, bus route 9 goes directly to Eskilstuna without changes (Sörmlandstrafiken 2018c). This indicates that the public transport covers a large part of the shoreline of Mälaren in Eskilstuna municipality.

Mälarbaden, Mälbyviken and Sundbyholm are located nearby one another, but Kvicksund is located further to the west. The area between these villages is expanding and houses are constantly being built. Yet people working in Västerås must take public transport to Eskilstuna (which is in the opposite direction) to get on the train since there is no public transport alternative to Kvicksund (which is in the same direction as Västerås). This causes a lot of commuters to use their private car instead of the public transport (Nyström & Olsson 2018). In Kvicksund there are about 1,000 inhabitants and in Mälarbaden, Mälbyviken and its surrounding area there are about 6,000 people living (Eskilstuna municipality 2016). Sundbyholm has about 2,000 citizens (Nyström & Olsson 2018). There are not many social service functions in either of these villages, except for a couple of restaurants in Sundbyholm.

5. Results

This section begins with a description of new mobility concepts in rural areas and how the mobility concepts might be applied to the case studies performed. A model used to evaluate one of the rural mobility concepts for DVs is then described before the results of the model and the cost of time analysis are finally presented.

5.1 New mobility concepts for driverless vehicles in rural areas

With reduced driver costs thanks to driverless vehicles, public transport could operate in new ways and raise the attractiveness of the public transport by overcoming some of the barriers. The rural mobility concepts for DVs presented earlier in the report were developed in an urban context (Pernestål & Kottenhoff 2018) and might not function the same way in rural areas. To account for the rural settings, new mobility concepts with driverless vehicles were developed. In all rural mobility concepts for DVs, the service vehicle should be able to communicate with the public transport to minimize the waiting times at the bus stops.

The new rural mobility concepts for DVs consist of a shared on-demand taxi service, area traffic and an application of first mile and last mile (FMLM) feeding. The FMLM application is a feeder service where the main bus routes can be straightened out and use feeder traffic to nearby villages. All rural mobility concepts for DVs are closely related but have important differences in their design. However, a public transport service might vary during the day and season, depending on traits of a village.

5.1.1 Shared on-demand taxi service

An on-demand service could work like a car-sharing service but in rural areas and without a driver. Car-sharing services are today almost exclusively used in city environments. The service works like the Uber Pool service. A taxi is ordered to transport a person from location A to location B and on the way, it could pick up co-travelers if they are heading in the same direction and are not located too far off. All passengers split the travel costs when they are travelling together, which reduces the cost for each traveler. This option takes slightly longer if there are additional pickups, but still provides a flexible door-to-door service (Uber, 2018). In a rural context this could improve the flexibility and accessibility, especially for non-car owners. A more flexible service without fixed stops could reach more places and increase the customer base. It could also reduce car ownership for families currently owning multiple vehicles. This rural mobility concept could be useful in areas that are too thinly populated for buses to operate.

The shared on-demand taxi service is similar to complementary services used by people located outside of public transport areas but with the difference that it’s driverless. For the consumers using the service, it could provide more flexibility than the existing complementary services since this concept is a door-to-door service. Either the service could be run by a private company as a complement to the public transport, or the service could be publicly procured by public transport authorities in each county and be integrated in the public transport system.

If the private car had broken down, the service could function as a backup mobility option to increase the mobility redundancy in the operating area. Furthermore, the service could probably improve the equality by reducing the social exclusion for people using the service. The service would enable people to go to the pub or visit some friends for dinner and a glass of wine without having to drive themselves. Results of this would be that vulnerable groups would become less dependent on getting rides from neighbors or family and could move around more freely. However, this would also lead to more journeys and more vehicle kilometers travelled which would cause more emissions to the atmosphere. Also, in urban areas taxis rarely have to drive long distances to pick up customers but in rural areas this might be the case. If there is only one passenger per journey, this service would probably not be environmentally smart since the taxi would have to drive empty to pick up the customer and then take the customer to the desired location. If the customer would have used a private car, the distance would only have been from its home to the desired location. Moreover, the status and flexibility of owning a car might make people not want to replace the privately-owned car with a shared driverless taxi service (Richter, 2018).

5.1.2 Area traffic

Instead of using area traffic at an industrial area or at a campus like Pernestål & Kottenhoff (2018) discussed, the driverless vehicles could serve a rural village. Depending on the size of the village, the service vehicles used could be of a certain capacity. Probably a bus with over 50 seats would not be needed, but more likely a shuttle or a car to increase occupancy rates and the level of self-financing. Like the shared taxi service, equality could be improved by having more mobility options to participate in other social events.

Since the infrastructure is not as developed in rural areas as in urban areas, walking or cycling on the roadside could be dangerous and risky (Hansson & Karlsson; Berg 2018). With area traffic vehicles, people wouldn't have to risk this. Nevertheless, distances within a village is often within walking or cycling range, and the risk of impairing public health could instead increase due to reducing these transport modes (Pernestål & Kottenhoff 2018; Hedlund 2018). A service should instead be designed as to take transport shares from car users, if possible. Incentives to encourage walking and cycling could be to improve the infrastructure for this target group. Building pavements and bicycle roads with lighting could be one example of this (Ahlberg & Wirén 2018).

The service vehicles wouldn't have to be limited to one village but could operate in and between multiple villages close by, functioning more like cross connections (Pernestål & Kottenhoff 2018) and connecting villages to each other. If a driverless vehicle could be used in villages located some distance from the closest public transport stop, it could function as feeder traffic. In turn, this could increase the customer base for the public transport since the reach would increase. For the villagers this could either mean a timetable-based service with fixed stops or a demand-based service, depending on the travel demand. Using driverless vehicles in area traffic as feeders this way could help to overcome the barrier of the FMLM problem. This could make public transport available for people that prior to this did not have this accessibility. Also, the distances to get to the public transport would be reduced and by this, less people would be likely to use the car (Glasare & Haglund 2018).

One issue with this type of service is that during off-peak hours, people don't use public transport to the same extent. Therefore, the vehicles should have alternative tasks to make the service economically viable. If the service vehicles had other areas of use than just transports, the service quality could be increased further and help repay the investment needed in the vehicles. Depending on the alternative areas of use, equality could be further improved.

5.1.3 First and last mile with straightened bus routes

The FMLM concept is similar to area traffic and these concepts can be used together in one service. This concept focuses more on feeding travelers from rural villages to a nearby main bus route than transport people within a village or between villages. Due to financial constraints it isn't viable for public transport to operate in villages located too far away from the main route. With feeder traffic, these villages could now be reached. Feeding can be done by driverless shuttles or cars, depending on the travel demand. However, it's easier to see how a shuttle service could be integrated in the public transport system, which is the focus of this concept. Figure 10 is a visualization of the concept of FMLM with straightened bus routes. The red, curvy line represents how bus routes sometimes look today. The black horizontal line represents how the main bus route can be straightened out and the vertical lines to the rural villages represents feeder traffic the first and last mile to villages located nearby the bus route.

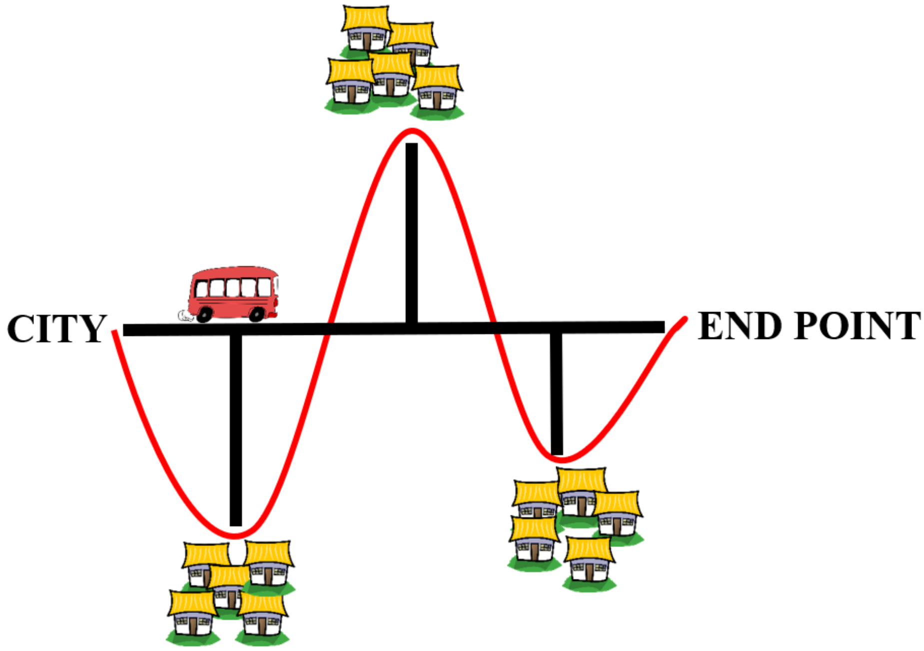

Figure 10: Visualization of the FMLM concept of straightened bus routes.

An FMLM shuttle service feeding to new, previously hard-to-reach, villages would increase the accessibility of the public transport. The aversion to use public transport for people living in these villages could with this feeder service be overcome, and less would have to use their private car. Car-ownership could also be decreased since the number of mobility options would be increased and hence more people could in this way be included in the public transport.

So, a feeder service could increase the equality by reaching more villages located nearby the main route that were previously not connected to the public transport. Though a shuttle service feeding travelers could also replace existing routes of main buses. Sometimes, buses take off from the main road to pick up passengers from nearby villages, but this could be a dissatisfying moment for travelers already on the bus. These detours could now be disregarded. Bus stops could be placed along the main route at the closest slip roads of the passing villages, where driverless shuttles could feed people to the villages and back. The main buses will no longer have to take off from the main roads and go into nearby villages. By not driving through each village the bus could reach villages further away from the city center in less time than before. For these travelers, the attractiveness of the service could be increased thanks to reduced travel time. However, it would also result in a change of travel modes for the travelers using the shuttle service which have been proved to be costly (Bångman & Nordlöf 2018), which could reduce the attractiveness. This application is similar to the super bus concept in Skåne in a sense that their aim is to reduce number of stops and reduce the travel time (Region Skåne 2018), only this application is in a smaller scale.

A service like this could increase the attractiveness for the public transport if the net benefits are positive, which could be measured in cost of time (Bångman & Nordlöf

2018). Travel times for people boarding upstream of these villages would be shorter. For people who need to use the shuttle service it might take longer time, as they would have to make a change of transport modes. Minimizing the time of changes would therefore be an important design factor of the shuttle service and could probably be facilitated by interconnected driverless vehicles.

If the FMLM feeding service could be combined with area traffic, all these pros and cons would also be included in this concept. However, if no one used the feeder service it would only increase the emissions and be costly for the public transport. Also, it would require more vehicles than before, which comes with an investment cost (Brümmer et al. 2018). Area traffic could be used if the bus routes were shortened. Shortened bus routes (Pernestål & Kottenhoff 2018) could be seen as FMLM with straightened bus routes where the routes are straightened in either end of the route. In this case there are no travelers living upstream of this point reaping benefits of shorter travel times, so the benefits would rather come from increased flexibility. Potentially the frequency of the main bus route could increase since it wouldn't have as many stops as before.

However, since people often live more sprawled in rural villages than in dense urban areas, the distances are longer (Hansson & Karlsson; Berg 2018). For shuttles to drop people off at their homes could mean large diversions and dissatisfying extra travel times. Therefore, route optimizing within the use area would be necessary for the service to function as good as possible.

5.2 Applications of rural mobility concepts for DVs on real-world case locations

To understand how the rural mobility concepts for DVs could function in a real scenario, the concepts were applied to different case locations. Since the case locations have different features, the concept implementation differs between the areas.

5.2.1 Shared on-demand taxi service – Grönby and Gräsö

Both Grönby in Trelleborg municipality and Gräsö in Östhammar municipality have expensive complementary services running their routes with taxis. Journeys in Gräsö could be as expensive as 1,000 SEK, much because of the driver cost (Hallberg 2018). With a shared driverless taxi service integrated or complementing the public transport, the cost of these journeys could be reduced, and the self-financing level could increase from the previous 3 percent. Since there are a lot of summer houses on Gräsö, the actor providing the taxi service could dimension the supply depending on the current travel demand. Rides could go to tourist points and Gräsö could hence increase its tourism industry since it would be easier for people to discover the island. Increased flexibility would also mean that people would not have to take their private car to pick people up at the ferry, but travelers could use the taxi service. A system with greater connectivity would mean more flexibility, and the route would not have to be operated with fixed stops after a timetable. People would not have to order vehicles three hours in advance, which could increase the will to use the service.

Perhaps the on-demand taxi service would not be as efficient during times for school rides since the travel demand is probably higher at these times. Therefore, this must be investigated further by UL. Though during off-peak hours, vehicles could transport food to the school or deliver goods from the mainland to social services on the island. Also, increased flexibility combined with long distances on Gräsö could lead to more vehicle kilometers traveled (VKT) and increase emissions to the atmosphere.

In Grönby the benefits of a service would perhaps be even greater than on Gräsö. Since today's Närtrafik can only be used once a day it can't be used for commuting and is therefore barely used (Åstrand 2018). By reducing the costs of the driver people would be able to use the shared driverless taxi service for everyday commuting. Effects from this could be that more people would use the Närtrafik and start sharing vehicles for their daily commute. This would both be more financially viable for Skånetrafiken and better for the environment. By increasing shared rides, people have been more willing to use public transport, hence a long-term goal for the municipality should be to develop better public transport communications to Grönby.

Citizens of Grönby could use the service to get to Trelleborg to go to school or work together with people in the same neighborhood. As seen in figure 4, the Närtrafik area outside of Grönby is the largest in the municipality and some villages might be located closer to other central towns than Trelleborg or Anderslöv. In this case, Trelleborg municipality could cooperate with adjacent municipalities to for an even more flexible service. Otherwise, Närtrafik areas could be larger than the current ones, which could reduce the number of vehicles but perhaps increase the distances that the vehicles would run around empty.

Since the infrastructure is not that developed and pavements are missing between Grönby and Anderslöv, this service would increase the traffic safety in the area and parents would not have to worry about how their children are getting to and from school or other activities. It would also make it possible for citizens of Grönby to visit friends in other villages for dinner and a glass of wine, which would improve the equality.

5.2.2 Area traffic – Grönby and the shoreline of Mälaren

Grönby is located only four kilometers away from Anderslöv where many important social services exist, so area traffic could be possible here. With only 200 citizens and a location a few kilometers from the closest bus stop, it probably wouldn't be financially viable to operate a bus route there. Area traffic, either by driverless cars or shuttles could operate between Grönby and Anderslöv but also other surrounding villages. Since the journeys in this area would not be too long, the introduction of area traffic in the area could reduce shares of walking and cycling on the roadside which is potentially risky. However, reducing the daily exercise would have negative effects on the public health.

Area traffic could furthermore increase the customer base of the public transport if it could function as feeder traffic for the public transport. The white area in figure 4 is a two-kilometer radius from nearest bus stop, but with shuttles operating to and from the bus stop this area would be greater and Grönby could be included in this area. With greater catchment area for the public transport, the large area of expensive Närtrafik northeast of Grönby could be reduced. Reducing the Närtrafik would free up funds for Region Skåne to reinvest elsewhere. Citizens of Grönby and surrounding villages would now have other mobility options than just the car, which could lead to reduced stress over having a functioning car and reduced dependency of family members to give them rides. Integration of villages and a chance of living a more social life would be another effect for the people in Grönby. Furthermore, since Anderslöv is one of the municipality's areas of development, Grönby could in the long term become a part of Anderslöv.

During non-peak hours however, the vehicles might not be active transporting people around the village. Alternative tasks to perform for these vehicles could be to deliver food for schools, have coordinated rides for grocery shopping or taking sports teams to and from practices in Anderslöv. Of course, this also applies for the shoreline along Mälaren in Eskilstuna municipality.

Villages along the shoreline of Mälaren in Eskilstuna municipality stretches over a longer distance than Grönby and has a few areas with higher population density. With a growing area and more permanent residents, area traffic could connect these people in a better way. Even though public transport covers a large part of this area, there are no east-west connections between villages, but the routes are more or less north-south going. If you want to go from Mälarbaden to Mälbyviken you would first have to go to the central Torshälla to change buses. And if residents in Mälarbaden want to go to Sundbyholm, they'd have to go all the way to Eskilstuna first. Therefore, area traffic with driverless shuttles or vehicles would increase the flexibility and accessibility for these people. If driverless vehicles could operate according to the speed limit in the future, the area traffic service could go all the way to Kvicksund, otherwise commuting this distance would take a long time. Commuters working in Västerås would in this case have a better public transport service than before. If the public transport was improved in this area, the car ownership could decrease. However, since there are mostly people with high socio-economic status living there, the status of owning a car might be important and people would hence be reluctant to get rid of their cars.

Since the shoreline of Mälaren is more populated than Grönby and its surrounding villages, more vehicles might be needed. The vehicle fleet could be dimensioned after the seasonal travel demand, since many people still use their houses mainly during the weekends or in the summer. In some sub-areas along the shoreline, driverless cars could be used and in some more populated sub-areas, shuttles could be used.

As seen in figure 9, Mälarbaden and Mälbyviken are located with about 1-2 kilometers between them and about 3-4 kilometers from Torshälla. Instead of using two different main bus routes to these villages, the routes could be replaced by feeder traffic by shuttles since the distances are relatively short. However, since this area is more densely populated than both Alstad and Alunda, more shuttles could be needed and during peak-hours a main bus might even be motivated. In this case, the main bus routes would not only be shortened, but completely replaced. Though, since these areas are developing and expanding, a shuttle service might not be sufficient to cover the travel demand in a few years. Therefore, the concept of area traffic is preferred over an FMLM concept in this case, though it much depends on the travel demand.

5.2.3 FMLM straightened bus routes – Alstad and Alunda

As seen in figure 5, bus 145 takes a detour to pick up travelers in Alstad in Trelleborg municipality. This detour takes about eight minutes according to Google Maps but feels even longer (Åstrand 2018). A similar detour is done on the same route in Minnesberg. These detours take up a lot of time for travelers not living in these villages and reduces the travel time quotas. If the main bus route would be straightened out and the detours removed, the fare-time of the main bus would be shorter. This could make the public transport more attractive and attract more car-users. By not going into Alstad, the main bus could theoretically reach further away from Trelleborg city in shorter time than before, which could integrate more villages on the route.

Straightening route 145 in Alstad would mean that travelers going from Svedala to Trelleborg would have 25 percent shorter travel times each day. This would result in improved travel time quotas and would potentially attract more people to commute with public transport from Svedala to Trelleborg and the other way around. Since the travel time would be reduced, there could be more departures each day, which would increase the attractiveness of the service even more. Using a driverless shuttle service could not only replace the detours of the main buses going into Alstad, but it could also integrate Västra Vemmerlöv into the public transport. This would mean a larger customer base for the public transport and another mobility option for the citizens in Västra Vemmerlöv. As a part of Skånetrafiken's super bus concept, where straightening out routes and removing bus stops is prioritized (Region Skåne 2018), FMLM shuttle services could be more important. Even though route 145 is not in Skånetrafiken's plans to be a super bus route, it could work similarly but on a smaller scale.

Travel times are important measures for public transport customers. In the Alstad case, travelers boarding in Svedala heading to Trelleborg city would have reduced travel times, but the travelers in Alstad would probably have longer travel times. Especially since they would have to make a change of vehicles not previously needed. However, FMLM with straightened bus routes could be combined with the concept of area traffic that have many other advantages than just feeding travelers to the public transport. These advantages and alternative tasks could eventually offset the negative change in travel time.

Since there are two bus routes passing Alstad already, perhaps equality will not be affected more than that people wouldn't have to walk as far to the bus stop with a more flexible service. However, for the citizens of Västra Vemmerlöv an FMLM shuttle service would increase the mobility redundancy and reduce the social exclusion.

The case in Alunda in Östhammar municipality is different from Alstad. Here, route 886 encircles the village and route 811 stops by the village at the main road. With an FMLM service feeding travelers from the main road to the village, route 886 would not have to encircle the village. Depending on the time of the day, travelers could be transported along a route with fixed stops or directly to their homes. This would mean that bus route 886 and 811 would operate along the almost exact same road between Alunda and Uppsala, as seen in figure 7, and could possibly be merged. At the point marked in red in figure 7, a village called Lejsta, there could be another FMLM shuttle service feeding people to the bus stops along the main road where route 886 and 811 have been merged into one route. This would free up capacity in the form of main buses to be placed elsewhere. In this case, the public transport would be more efficient, and the remaining route could probably be operated with a higher frequency. Higher frequency on this route would potentially help UL to reach their target of 30 percent more travelling on this route. Similar to Skånetrafiken's super bus concept, there could be express departures that stops only at the major bus stops with a lot of travelers. Other departures could operate normally and stop at every bus stop along the way. This would give the travelers options to choose their departure after their specific needs and target points.

If the people living in Lejsta were fed to an express departure of the new route, perhaps their total travel time would not be increased at all. Though they would still need to make a change of transport modes, which could be dissatisfying (Bångman & Nordlöf 2018).

In the Alunda case, bus routes would be replaced by driverless shuttles and would not affect equality issues. Perhaps it could even reduce the service quality since there would be no operator on the bus, which could make it more difficult for older people or mobility impaired people to use the public transport. Since Alunda has a population of about 2,000-3,000 people and a lot of social service functions are located in the village, the feeder traffic could be used for these purposes during less busy hours of the day.

5.3 Model explanation

Since the super bus concept is on the agenda for Skånetrafiken and the travel times theoretically can be reduced for some customers on route 145 in Trelleborg municipality, this rural mobility concept was modelled and simulated. Modeling and simulation of the concept of FMLM with straightened bus routes were done in order to study the feasibility of a driverless shuttle service like this. Alstad was chosen since it is probably the most basic case of straightened routes since it has only one stop, therefore modelling and simulating this rural mobility concept for DVs could be done on a high-level. However, if a shuttle service were to be implemented in Alstad together with area traffic, there could be more stops along the way or even a demand-based door-to-door service during non-busy hours. If this was the case, more people could be integrated in the public transport system and reduce car-use, though feeder traffic with multiple stops were not tested in this model.

5.3.1 Stochastic variables

In public transport, the number of expected travelers daily and per departure varies from day to day. Therefore, these variables were stochastically distributed based on data from Skånetrafiken. Traffic situations can vary depending on weather, traffic lights and so on, thus the service time of the shuttles was based on a normal distribution. For instance, one day of simulation there could be eight people using the service and the next day it could be twelve, or the time between two bus stops could be four minutes at one journey and five at the next. In a case where there has been an accident on the route and obstacles are blocking the way the service time would increase drastically. This is not accounted for, but only the standard deviations of passengers boarding and the traffic situation (crossings, traffic lights etc.). Other extreme cases are nor accounted for. Furthermore, the arrival time of customers and departure time of shuttles were both stochastic variables. Arrivals to bus stops in public transport would probably increase exponentially in a real scenario, though in this thesis they were assumed to be normally distributed. Departure times of the shuttles were normally distributed with the boundary condition that it couldn’t depart before scheduled time.

5.3.2 One simulation run

The simulation started by determining design parameters and matching the daily distribution of customers with the respective timetable. After this, state variables, statistical counters and other variables were initialized, and the first event times were determined. One of these statistical counters was the number of departures which controlled for how many rounds the following process were to be run. Depending on if the next event was an arrival or departure, the respective routine was then called. In the arrival process the customers were put in a queue and in the departure process the shuttles picked up the customers and departed from the shuttle stop. During the departure process, statistical counters were updated and the service time for two one-way trips were determined (the first one-way trip was from the shuttle stop to the bus stop and the second one-way trip was the opposite direction). Finally, new arrival and departure times were decided, and the process were repeated if the departures had not yet reached the final departure of the day. When all departures of the day had been simulated, the KPIs were calculated and the results of the simulation were printed. KPIs used in this case were utilization rates, number of unserved customers and number of delayed departures. The model was run and tested using two shuttles, each with a capacity of 15 passengers. For each shuttle, empty runs and occupancy rates were calculated.

5.3.3 Assumptions and limitations of the model

Since the shuttle would probably pick up travelers on the way to the bus stop and drop travelers off on the way from the bus stop, the same number of stops were assumed in both directions. This means that the shuttle would have the same service time in both directions, though this might not be true for different times of the day. In the morning time people will probably commute in one direction and in the evening in the opposite direction. These flows were assumed to be similar but in opposite directions, thus only one flow was to be modelled.

The arrivals of travelers in the model were based on the average distribution of travelers during the day. All arrivals previous to a departure were in this model assumed to happen simultaneously at a normally distributed time. However, in a real-world scenario, the chance of people arriving at a bus stop would probably increase exponentially as the clock approached scheduled departure time. Furthermore, they would arrive independently of each other and at different times. In Law and Kelton's (2000) model, the waiting time of the customers waiting to be served was a resulting measure. Though in this case people arrive to the bus stop knowing that they will have to wait a few minutes, depending on their marginal. This time was assumed not to be costly since the travelers themselves decide how large time marginal they want. In this case it was more interesting to study the number of delays of the shuttles, since delay time is actually costly and dissatisfying for people.

Departure times were stochastically chosen from a distribution with the mean value as the scheduled departure time and a standard deviation. In the case with the one-way timetables from Alstad, e.g., towards Svedala, it is one hour between each departure and the shuttle takes maximum 35 minutes between the two bus stops. Therefore, the standard deviation in this case was small since the risk of the shuttles being late is almost negligible. If the intervals are shorter between departures and the shuttle have trouble operating according to the schedule, this standard deviation should be increased. Changing weather could also cause larger variations in the service times. However, this is not tested in this thesis.

5.3.4 Design parameters and sensitivity

The features of villages in rural areas can vary in geography, demography, quality of infrastructure and the availability of public service. For instance, some villages only have access to public transport once in the morning and once in the evening while some villages have access once every half-hour. In the model, some of these parameters are accounted for. These variables are the timetable, mean values, standard deviations and travel time which should reflect the availability of public transport as well as demographical and geographical factors respectively. However, the quality of the infrastructure is not accounted for in the model. The travel time in turn depends on the speed of the shuttle. What's interesting with these variables is that they simulate different features of villages and changing these variables would thus result in a more general feasibility study of the shuttle service. The base scenario is the features of Alstad with the timetable from route 145, the number of expected travelers daily and the standard deviations of the travelers as well as the travel time between the bus stop in Alstad and the main road.

5.3.5 Timetables

The timetables of the shuttles depended on the timetable of the main bus. Alstad bus stop is located between two county towns and people are traveling almost equally much to these target points. Timetables of the shuttle service were thus either based on scheduled departures only heading towards Svedala (every 60 minutes) or scheduled departures bound for both Svedala and Trelleborg (about every 30 minutes). There are as many departures in both directions which means that the latter timetable has twice as many departures as the former one. The latter timetable is settled by merging departures towards Svedala with departures towards Trelleborg throughout the day. For the shuttle service it's no difference which direction the bus is going in since the objective of the shuttle is to feed people to the bus stop by the main country road. One-way traveling was simulated in the base scenario. However, in a real scenario the shuttles would need to serve all departures from Alstad, i.e., two-way traveling, which was also simulated.

Since people don't want to wait between changes but don't want to be late for the connection, the scheduled departure time of the shuttle must be as close to the scheduled departure of the main bus as possible, but not as close as it would lead to missing the connection. This was accounted for when creating the timetable for the shuttle service. The mean service time for the shuttle was calculated, as well as the confidence interval for this mean value. To be certain to be on time for the connection, the 99^{th} percentile of the interval was reduced from the timetable of the main bus. This procedure was performed for all departures of the day to create a timetable for the shuttle.

According to Google Maps, it takes four minutes from Alstad to the main country road by public transport which means that the main bus would depart 4 minutes earlier than shown in the timetables from Skånetrafiken. The shuttle timetables accounted for this too. In the Alstad case, the timetables for route 145 between Svedala and Trelleborg were retrieved from Skånetrafiken (2018b).

5.3.6 Shuttle speed and travel times

Experiences from tests conducted with autonomous shuttles today is that they are slow, with maximum speeds of about 20 km/h (Alessandrini & Mercier-Handisyde 2018). In the future though, these shuttles will probably be able to operate according to local speed limits. However, technology used by driverless vehicles today might be sensitive to bad weather like heavy rains or snowfalls, which would force the shuttles to reduce their speed (Brümmer et al. 2018). Therefore, two different shuttle speeds were tested. The first speed tested was according to the speed limits, and the second speed tested was half the speed limits.

The normal travel times were received from Google Maps and timetables of the buses. However, tests with travel times of double the travel times were also performed. Running simulations with eight minutes instead of four is equivalent to simulating a village located twice as far away from the main road as Alstad.

5.3.7 Mean values and standard deviations

Data for travelers boarding at a certain bus stop on different routes during 2018 was provided by Skånetrafiken (Kristiansson 2019). When calculating mean values, standard deviations and variations between and during days, only data on weekdays was used. To see how many people were boarding during a certain time of the day, the timetable and data for the corresponding hour had to be matched. These figures were calculated in Excel and imported to Matlab. The distribution of travelers during an average day for all routes were similar, for instance the distribution of travelers boarding in Alstad heading towards Svedala can be seen in figure 11.

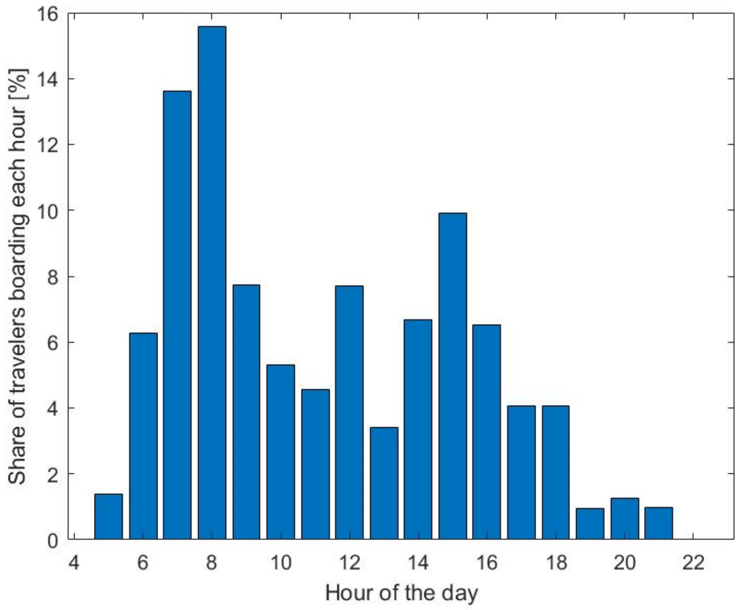

Figure 11: Expected travelers during an average day in Alstad with departures bound for Svedala.

The expected number of arrivals during the day were based on this distribution, but had a stochastic variation based on the standard deviation in the data sets. The mean values and standard deviations were the same during a complete simulation but the daily number of customers were stochastically chosen every day in one simulation. Respective mean value and standard deviation can be found in table 3.

Table 3: Expected number of daily travelers and standard deviations in the data on route 145 in Trelleborg municipality. Mean value = mu, standard deviation = sigma.

Direction	*mu*	*sigma*
Svedala-bound in Alstad	10.2	3.7
Trelleborg-bound in Alstad	9.7	4.5
Both directions in Alstad	19.9	8.2
Upstream of Alstad, Svedala-bound	125.6	24.7
Upstream of Alstad, Trelleborg-bound	108.7	24.0

To simulate different sizes of villages and their public transport using inhabitants, different values of mean values and standard deviations were tested. Values from the data sets were first tested, and then simulations with 5 times, 10 times and 20 times higher mean values were tested together with higher standard deviations. Results from these simulations show how the capacity of the shuttle service should be dimensioned in a village with different travel demands.

5.4 Simulations

Multiple simulations were performed, and all were performed for 100 days. In table 4 the different simulations and their choice of parameters are shown. Table 6 in section 5.6 shows the results from the simulations. When simulating, it was noticed that the results from Alstad with timetables based on scheduled departures heading towards Svedala or Trelleborg were similar. This is because there are departures once every hour and the mean values and standard deviations don’t differ much in these cases, as seen in table 3. Thus, only the Svedala-bound timetables and timetables for both directions are presented. Simulation 15 and 16 were only used in the cost of time analysis. Simulation 6 is henceforward referred to as the base simulation, since the parameters used in this simulation represents the situation in Alstad today the best.

Table 4: Parameters used in simulations.

Simulation	Timetable	Speed	Travel time	Expected travelers	Standard deviation
1	Svedala-bound	Speed limit	4	10.2	3.7
2	Both directions	Speed limit	4	19.9	8.2
3	Svedala-bound	Speed limit	8	10.2	3.7
4	Both directions	Speed limit	8	19.9	8.2
5	Svedala-bound	Half speed	4	10.2	3.7
6 (base)	Both directions	Half speed	4	19.9	8.2
7	Svedala-bound	Half speed	8	10.2	3.7
8	Both directions	Half speed	8	19.9	8.2
9	Svedala-bound	Speed limit	4	10.2*5	10
10	Svedala-bound	Speed limit	4	10.2*10	10
11	Svedala-bound	Speed limit	4	10.2*20	20
12	Both directions	Speed limit	4	19.9*5	20
13	Both directions	Speed limit	4	19.9*10	20
14	Both directions	Speed limit	4	19.9*20	40
15	Trelleborg-bound	Speed limit	4	9.7	4.5
16	Both directions	Half speed	4	19.9*10	20

5.5 Cost of time analysis

To evaluate whether the shuttle service was beneficial or not for different travelers, time measures were recalculated into costs. Values for private regional bus travels for commuters were used (Bångman & Nordlöf 2018). Commuting values were used since data on weekdays was used to simulate the model and during weekdays most travels were assumed to be made by commuters. Cost of time (CoT) is a measure describing how much work a person could get done instead of doing a transport. E.g. one person is going from point A to point B and can choose from taking the car that takes 15 minutes and the bus that takes 30 minutes. Assuming that no work can be done in either the car or the bus, the CoT would be higher for the bus ride since the person would have 15 more minutes transporting than if the person was taking the car.

Values used were based on a CoT per person and hour. This means that if the travel time was 30 minutes and there were 4 travelers, the value had to be multiplied with a factor of 0.5 (half-hour) and a factor 4 (travelers) to get the total cost of time. CoT values were used for travel times, changes in transport modes and delay times (Bångman & Nordlöf 2018). All values used can be found in table 5. When calculating CoT, travel comfort and waiting times can also be included but this is not considered in this report.

The service in the rural mobility concept for DVs tested is performed by shuttles which today don't have any CoT values. Therefore, CoT values for shuttles were assumed to be the same as for buses.

Table 5: Cost of time values for private regional commuting journeys.

Value	Normal travel time [SEK/(traveler*hour)]	Change of mode of transport time [SEK/(traveler*hour)]	Delay time [SEK/(traveler*hour)]
Bus/shuttle	57	143	199

The number of travelers heading towards Svedala but boarding before Alstad could reap the benefits of reduced normal travel times. Vice versa for people heading towards Trelleborg but boarding before Alstad going south. The net benefits were then calculated by subtracting the total CoT for travelers boarding upstream of Alstad with the total CoT for travelers boarding in Alstad. The shuttle service will not affect people boarding downstream of Alstad and therefore these people are not accounted for in any way.

The data received by Skånetrafiken did only show number of travelers boarding the vehicles. Thus, the number of travelers going past Alstad and reaping the benefits from shorter travel times was unknown. But it was assumed that the travelers mainly consist of commuters and most workplaces are probably located in Svedala and Trelleborg. Therefore, it is assumed that travelers boarding upstream of Alstad go all the way to either end station and are able to obtain the benefits of shorter travel times.

CoT was not calculated for all simulations but was only done for simulation 2, 5, 6, 13, 15 and 16. These simulations were performed since they test different features of a service that could have been provided in Alstad. In these simulations the directions of travelling, population of the village and shuttle speed vary which captures two-way travelling, eventual population changes in Alstad and eventual technology improvements.

5.6 Simulation results

All results can be found in table 6 and the simulations corresponds to the parameter sets from table 4 in section 5.4. Simulations 1 and 2 use different timetables (one-way and two-way respectively), but the same shuttle speed and travel time. The number of departures is twice as many in simulation 2, but since Svedala-bound travelling and Trelleborg-bound travelling have similar expected number of travelers and standard deviations, these numbers are also doubled. Therefore, the share of empty runs of about 50 percent and the occupancy rate of about 3.7 percent are almost constant in simulation 1 and 2. The only difference between simulation 1 and 2 is the utilization rates, which is almost the double in simulation 2 with 17.0 to 32.7 percent. The results show that the shuttles are only used about a third of the day if they can operate according to the speed limits. It also shows that one shuttle is enough to manage the travel demand, and still the shuttle would operate without customers for half of all departures. However, all customers are served and there are no delayed departures in both cases.

Table 6: Results of the simulations during an average day.

Simulation	Utilization rate [%]	Shuttle 1		Shuttle 2		Unserved customers	Delayed departures [%]
		Runs with 0 passengers [%]	Occupancy rate [%]	Runs with 0 passengers [%]	Occupancy rate [%]		
1	17.0	50.6	3.7	100.0	0.0	0	0
2	32.7	53.8	3.6	100.0	0.0	0	0
3	30.4	50.8	3.7	100.0	0.0	0	0
4	58.5	53.9	3.7	100.0	0.0	0	0
5	30.2	49.6	3.8	100.0	0.0	0	0
6 (base)	58.5	54.9	3.6	100.0	0.0	0	1.5
7	56.4	49.3	3.9	100.0	0.0	0	0
8	99.5	54.6	3.6	100.0	0.0	0	97.1
9	17.0	8.5	19.9	100.0	0.0	0	0
10	17.0	0.0	39.2	95.4	0.6	0	0
11	17.0	0.0	65.3	74.7	13.6	2.85	0
12	32.7	15.3	19.5	99.8	0.0	0	0
13	32.7	4.3	37.5	95.0	1.5	0	0
14	32.7	2.9	61.2	75.6	13.7	15.9	0

For simulations 3 and 4, the travel time was doubled but the rest of the parameters remained unchanged. The only results changing from this was the utilization rate which was doubled. Simulations 5 to 8 tested the exact same things as simulations 1 to 4, with the only difference in the shuttle speed. Simulations 5 to 8 were run with a speed of half the speed limit, which caused increased utilization rates and delayed departures. As the speed was halved, the shuttles couldn't make it in time between departures, which was causing the delays. Delays are seen in simulation 6 and 8, which were simulations run with the timetable based on scheduled departures of the main bus towards both Svedala and Trelleborg. Thus, the shuttles could still manage to feed customers on all departures on time if the departures are scheduled an hour or more apart. Though the shuttles couldn't make all departures on time when the shuttle speed was halved if the time between the departures is closer to half an hour, especially if the travel time was doubled (see simulation 8). Furthermore, simulation 8 shows that the shuttle would had to operate during the whole day without a break, which is about 19 hours. All the first eight simulations had similar shares of empty runs, about 50 percent for shuttle 1 and 100 percent for shuttle 2, and occupancy rates, 3.7 and 0 percent respectively. Only one shuttle would be needed to manage the demand for the first 8 simulations without having any unserved customers. Yet to manage the tight schedule, if the speeds were reduced, and especially if the village was located further away from the main bus stop, more than one shuttle would be necessary.

Simulations 9 to 14 in table 6 show results from varying the expected number of daily travelers and its standard deviation (the former three are Svedala-bound and the latter are heading in both directions). The utilization rates and number of delayed departures were constant according to its timetable in these simulations. Results rather showed reduced shares of empty runs and increased occupation rates in the shuttles. When increasing the population by a factor of 10, one shuttle was not enough to manage the full travel demand. Nevertheless, the rate of empty shares for shuttle 2 was still high, which indicates that shuttle 2 was only used during peak hours. Also, the occupancy rate for shuttle 2 was relatively low. If the populations were increased by 20 times, the second shuttle became more important (lower rates of empty runs and higher occupancy rates), but there were now customers that would be unserved. Simulation 14 showed that in average almost 16 customers per day would be unserved, yet shuttle 2 ran empty in three out of four departures. This also indicates that shuttle 2 was only used during peak hours, and even then, two shuttles were not enough to cover the travel demand.

5.7 Cost of time results

The cost of time (CoT) results are presented for each simulation in table 7. These figures are based on the KPIs measured during the simulations and multiplied with the CoT values described in table 5. The benefits in column *CoT of travelers boarding upstream* minus the disbenefits in column *CoT of travelers boarding in Alstad* results in the total benefits for the route in column *Net CoT*. That the net CoT for all simulations is positive indicates that the travelers on the route will benefit from using the mobility concept of FMLM with straightened bus routes. Hence positive net CoT in table 7 represents cost reductions for the route.

Table 7: Total cost of time an average day for some of the simulations performed (positive Net CoT equals cost reductions).

Simulation	Reduced CoT for travelers boarding upstream [SEK]	Increased CoT for travelers boarding in Alstad [SEK]	Net CoT [SEK]
2	1 780.7	14.9	1 765.8
5	954.6	52.1	902.4
6 (base)	1 780.7	93.3	1 687.4
13	1 780.7	134.9	1 645.8
15	826.1	46.7	779.4
16	1 780.7	924.7	856.0

In simulation 2, the shuttle speed is according to speed limits, which is the speed a regular bus would have operated with and hence the total CoT for people boarding in

Alstad is only based on delay time and changing time. When the shuttle speed is set to half the speed limits, like in simulations 5 and 6, the people in Alstad had larger total CoT. The increased CoT depends on longer travel times when the shuttles are operating slower than according to speed limits. In this case the delay time was under a minute long and the changing time was also short. When these times are short, the total CoT is very low since the travelers boarding in Alstad are few compared to upstream of Alstad. Simulation 15 gets similar results as simulation 5 because the average numbers of customers in direction to Svedala and Trelleborg are similar.

When the traveling population in Alstad is assumed to have grown about ten times, the CoT for people boarding in Alstad is increased (see simulation 13). If the travel demand in Alstad is increased by ten times but the shuttles operate with the same speed as today, the CoT is increased a lot (see simulation 16). This is because more people will have longer travel times. However, people boarding upstream of Alstad reduce their travel time by eight minutes and people boarding in Alstad only increase their travel time by four minutes, which is why the net benefits are still positive. All simulations result in positive net CoT which proves that the shuttle service could be a decent tool to increase the attractiveness of route 145, especially for people boarding upstream of Alstad.

6. Discussion

This section begins with a discussion on when and where the rural mobility concepts for DVs could be implemented. Then a discussion on the feasibility of the FMLM with straightened bus routes and its application is presented, including important variables and features of villages using the service. After this, the sustainability of the rural mobility concepts for DVs is discussed before the section ends with a comment on potential model development and future research needed.

6.1 Generalization of results and case locations

Many transport challenges are similar in different rural areas and, in most cases, general issues like accessibility, flexibility, equality and first or last mile barriers exist in some way (Hansson & Karlsson; Berg; Brümmer et al. 2018) but varies in significance. On top of these challenges come local challenges that local actors need to be aware of and account for (e.g., Hedlund; Åstrand; Hallberg 2018). Section 5.2 shows that the rural mobility concepts for DVs can be applied in environments with different features. But how the concepts are applied to a certain environment differs a lot. The local variations are not only due to spatial and geographical factors but are also influenced by demographic and economic aspects. For instance, a shared on-demand taxi service could improve the tourism industry on Gräsö but could rather be a tool to enable everyday commuting in Grönby. Another example is how the FMLM service applied on route 145 in Trelleborg municipality could include Västra Vemmerlöv in the network but applied on Östhammar municipality it could merge two bus routes and free up capacity.

All over Sweden there are villages located in the middle of nowhere excluded from the public transport, but there are also villages placed nearby main roads where public transport operate. It’s not unusual that buses take detours in villages (like in Alstad), that they don’t take detours in villages (like in Västra Vemmerlöv) or that there are multiple bus routes operating nearby one another or even on the same road (like in Alunda and the shoreline of Mälaren). Trelleborg, Östhammar and Eskilstuna municipalities all have larger county towns and surrounding areas consisting of more or less rural areas. In these rural areas, there are main roads with villages nearby and smaller roads with longer distances to the main roads. The shared taxi service was applied in an area with more scattered villages with longer distances to the main road and without access to regular public transport. Villages located in these areas were served by different kinds of complementary services today and often had lower spatial density of travel demands. Spatial density of the travel demand means that the travel demand is more sparsely distributed within a specific area. One example of these case locations was Gräsö in Östhammar municipality.

The feeder service and area traffic were applied in areas consisting of villages located closer to main roads where public transport is operating. More specifically, these villages were located about 4 to 15 minutes away from the public transport and have higher spatial density of travel demands. One village representing these types of case locations was Alstad in Trelleborg municipality. Alstad was also the object for simulations and represented the base simulation with its fixed parameters. However, different sets of parameters were simulated to get a more general understanding of the feasibility of the feeder service. All of these results showed positive net benefits by implementing this service which indicates that the attractiveness of the public transport could be increased.

These are case locations that can be found all over Sweden, though distances between target points are often longer in the northern parts of the country. This makes it more difficult to operate a good public transport service. For instance, Arjeplog municipality in the north has a population density about a thousand times smaller than Trelleborg municipality (SCB 2019). However, since the driver cost is reduced, the shared taxi service could operate in Arjeplog as well. Perhaps the main benefit of the shared taxi service is the reduced cost of drivers. But to measure the total benefits of the shared taxi service, local features must be considered.

6.2 Feasibility of FMLM with straightened bus routes

The results from the base simulation show that one shuttle could cover the full travel demand today and still run empty for more than half of all departures. With 20 travelers an average day spread out on 34 departures, this is not difficult to imagine. A smaller shuttle or maybe even a car with four seats would have been enough to cover the demand, though this wasn't simulated in this thesis. With an occupancy rate of the shuttle of about 4 percent, it's safe to say that the service wouldn't be profitable in the simulated case. Especially not since it would occasionally arrive late for the scheduled departures. At least it wouldn't be a profitable service if it was only used as a feeder service for the public transport. Though if the shuttle was used for other things during times when the travel demand was low or when the shuttle was idle, more value could be found in the shuttle service.

The utilization rate in the base simulation was about 60 percent, but the time not spent in operation is only during short intervals and could probably not be spent performing alternative tasks. However, the shuttle left the shuttle stop empty about half of the departures. This model does not account for people off-boarding the bus, so there probably would be scenarios where the shuttle was empty leaving the village for the bus stop but picked up travelers at the bus stop and fed them back to the village. So, for the shuttle to perform alternative tasks, the public transport authority would need to decide departures during the day when the feeder service wouldn't operate. Which departures to refrain from would depend on the task that was to be performed, and when the task needed to be performed. Though it should be noted that different social services or activities would need to exist in order for the shuttles to perform alternative tasks.

Alternative objectives for service vehicles should be locally coordinated by municipalities and public transport authorities.

Results from the simulations show that the frequency of departures, the shuttle speed and the distance between public transport and the village affect the utilization rate of the shuttles and if the shuttles could depart on time. If the timetable is tight, the shuttle speed is slow, and the transport distance is long, the vehicles are utilized more and even delayed in the worst scenarios. If there were departures every half hour, 8 minutes by car between the main road and the village and a shuttle speed of half the speed limits was used, all departures were delayed except for the first one in the morning. Since the villages and main roads cannot easily be moved and people desire high frequency, the shuttle speed is important in order to avoid delays. Travel demand was critical during peak-hours and affected KPIs like the number of empty runs, the number of unserved customers and occupancy rates. It was proved that one shuttle with the capacity of 15 people could successfully feed about 100-150 travelers every day and still have time left over to perform alternative tasks. These results should be generalizable for other villages with features matching the general case location. Furthermore, if these parameters are available for another village, the feasibility of the service could be tested there as well.

If the tests were performed on a village situated further away than the base simulation case, for example represented by Västra Vemmerlöv, the shuttle speed could have been critical. This implies that to integrate villages far away from the public transport it is crucial for the shuttle producers to improve the technology to increase the speed of the vehicles. Though the speed of the shuttles is not only a technological issue, but there are also laws, regulations and other aspects that limit the speed (Brümmer et al. 2018). If testing efforts are performed before the shuttle speed can be increased, villages located relatively close to the main roads should therefore be used as case locations. Increased shuttle speeds would furthermore reduce the total cost of time (CoT) for travelers using the feeder service. However, if villages were placed further away from the public transport and the frequency was relatively high, then the shuttles wouldn’t have time to perform alternative tasks or recharging. Thus, it’s easy to understand that the shuttle speed is a vital factor for the FMLM service to function successfully.

Furthermore, if the shuttle speed is according to speed limits, the CoT for travelers in the simulated village, represented by Alstad, doesn’t increase too much. But since the CoT would increase for the citizens of the village, an FMLM service could be implemented in a village currently excluded from public transport (Hedlund 2018), like Västra Vemmerlöv. Although the CoT would increase for people in Alstad, the change of mode of transport time could be suppressed since people could probably wait for the bus while seated in the shuttle (Brümmer et al. 2018). If a village isn’t connected to the public transport network though, the car-dependency is probably more significant than if there was a connection. Also, if the village was located far away from a county town, not many would use their bicycles as their main mode of transport. Therefore, not as many shares would be taken from walking and cycling transports if the FMLM service was implemented in this village.

One shuttle almost managed the total travel demand even if the demand was ten times larger than in the base scenario. A second shuttle would only need to be used in five percent of the departures. This indicates that an extra shuttle was only needed during the peak. When the travel demand was twenty times larger than normal, the extra shuttle was only needed during one in four departures, and still about 15 customers were not served an average day. If the shuttle service wouldn't be dimensioned according to the peak travel demand, the public transport would miss out on some travelers. But if the supply was adapted after the peak demand, there must be other areas of use for the vehicles (Hallberg 2018).

6.3 Model development

The model used in this study has its limitations. To use the model when evaluating a feeder service for a certain case location, some features of the model need to be developed. One such thing would be to simulate customer arrivals to the shuttle stop independently and exponentially distributed, as discussed in section 5.3.3.

If the shuttle service should increase the flexibility and accessibility in a village, a feature modeling more shuttle stops should be considered. In Alunda, for instance, the main bus encircles the village and stops multiple times to pick up travelers but if the route is shortened it would only stop by the main road in Alunda and feeders would take over. These feeders would have to feed people around the village and stop at least at the same bus stops as previously, to not reduce the flexibility. If the accessibility in Alunda wants to be increased further, new routes must be modeled.

Travel demand in the model is only based on boarding passengers in the village, on-boarding passengers from the main route going to the village are not considered. This would cause larger travel demand, but in the opposite direction. Since most people don't work in rural areas the directional travel demands would vary during the day. In the mornings, the travel demand away from the village would be higher and, in the evenings, people would travel more into the village. This should however not affect the results since the average number of travelers in both directions should be similar on an average day. Perhaps, number of empty runs could be affected.

Furthermore, even though two shuttles are modeled, the model does not simulate different departure times from the village. If a village was situated further away from the main road than in Alstad and the departures of the main bus were scheduled with a higher frequency, one shuttle couldn't manage to be on time for all departures. Even if one shuttle could manage to feed all travelers, they wouldn't be on time. Therefore, two independently operating shuttles should be modeled. Neither does the model account for if one shuttle could feed travelers during busy hours in two rounds for one departure of the main bus. If this was to be modeled, would people consider taking the earlier round and have to wait by the main road or would everyone still aim for the latter shuttle departure? By operating this way, one shuttle would be able to cover a larger travel demand, but the travel times of the people in Alstad going with the first of these two rounds would increase vastly. The possibility of shuttles going multiple rounds with travelers should be considered since it could reduce the shuttle fleet. This would be an interesting aspect to study if real world tests were performed. If features like these were developed for the model and both travel flows were modeled, the results should be of greater help for public transport authorities to decide when the shuttles could be used for alternative tasks.

Finally, public transport authorities have a lot of data on travel behavior and travel patterns, though the model only use on-boarding data. The model could be improved if more sophisticated data was used. For instance, the model could benefit from data showing off-boarding passengers, trip lengths, between which bus stops people travel and delay times. These types of data would make the simulations closer to the real-world case than by only using statistics on the number of on-boarding passengers.

6.4 Sustainability of the rural mobility concepts for DVs

Public transport and shared mobility services are marketed as climate smart options, though this is only true if a certain number of passengers use the vehicles (UL 2018a). Sharing services have also proved to reduce private car use and increase the use of public transport (Richter 2018). If driverless vehicles are used in a shared taxi service in rural areas, it’s paramount that the trips are actually shared by two or more people. If there are taxis running around with only one person, VKT would probably be increased since the taxi would have to go empty from point A to pick up a customer at point B before taking the customer to point C. If the customer would have used a private car instead, the distance would only have been between B and C. In the same scenario with two customers, they would have used two different private cars instead of one shared taxi which could have caused more greenhouse gas emissions to the atmosphere.

Since people live more scattered in rural areas, the routes for the taxis would be less straight and distances larger. Sustainability-wise, the extra distances for picking up co-travelers should not be too long, but service quality-wise the extra distances must be longer than in urban environments or there will be no chance of sharing vehicles. If the service could be used by one person at a time, there is a risk that the service would rarely be used by more than one person at once. Though if the taxi would take a detour to pick up a co-traveler, it should be a trade-off cost between the benefit of sharing vehicles and the increase in VKT to minimize the emissions to the atmosphere. It seems reasonable that people could use shared vehicles during commuting hours. Yet during other times of the day it would be more difficult to find two or more people on the same route going towards the same destinations.

As for combined driverless feeder and area traffic, more local traveling with shuttles could replace walking and cycling in a village. Though it could also integrate more people in the public transport and replace commuting by car. Increased local traveling with shuttles could increase VKT while increased public transport use would reduce VKT. If the feeder service with area traffic was implemented in a village that already had access to public transport (e.g., Alstad), perhaps not so many new people would be integrated in the public transport, but more walking and cycling could be replaced locally. Though if the service was implemented in a village previously excluded from public transport (e.g., Västra Vemmerlöv) where the car dependency might be higher, more new people would be integrated in the public transport. Hence the VKT reducing effects could be greater in villages previously excluded from public transport. But if the car dependency is high and people are used to short travel times, they might be reluctant to trying the new service. This line of reasoning should be the same as when developing bus routes to new villages and is not specific for the feeder service or area traffic. How local travel habits would change versus how many new people could be integrated in the public transport network if a feeder service with area traffic was implemented in an area would require testing efforts. However, if the local travels were previously made by car, the feeder service would have positive effects on VKT in this aspect too. The shared taxi service would, in most cases, be used on longer distances than the feeder service and area traffic. Hence, it competes more with car-users than pedestrians and cyclists.

Important to note is that all shuttles existing today are driven on electricity. If the electricity mix in the country is clean, this is a more environmentally friendly option than operating the vehicles on fossil fuels and VKT is not as important an indicator of greenhouse gas emissions. The taxi service operates on longer distances and running on electricity could be more problematic.

Increased VKT is not sustainable when travels by cars, shuttles or buses replace travels previously made by walking or cycling. Though increased VKT is not necessarily bad by definition since it might improve the social sustainability. If mobility impaired, elderly or children would get a new mobility option then VKT might increase, but these people would no longer be excluded from participating in social events. Equality of a public transport service is important and if more people could be integrated in the public transport system, the service would be more democratic. With these rural mobility concepts for DVs, more people could probably be included in the public transport system and hence the equality would improve.

Moreover, replacing walking and cycling could reduce the daily exercise of commuters and impair the public health. Some researchers mean that shuttles could operate on bicycle roads, but this would make the shuttle service compete even more with cyclists, which is not desirable. Though if the shuttles would operate on bike roads, the flexibility could be enhanced, and travel times could potentially be decreased. During winters, bad weather or when carrying heavy luggage even cyclists might want to change transport modes.

6.5 Implications for public transport authorities and future research

Case locations have many general challenges which need to be considered, but for public transport authorities local challenges are just as important. The applications of the rural mobility concepts for DVs show how one concept can lead to different effects in different case locations due to local features. Public transport authorities and municipalities are experts on the local environment and need to form and implement the rural mobility concepts for DVs according to their knowledge. To be able to do this, the local actors need to take more responsibility for the transition to a driverless future and understand the possibilities and risks that come with the transition and the concepts.

Local actors also have the best knowledge on what alternative tasks the shuttles might perform during the day. If a feeder service with area traffic would be used to perform alternative tasks in a village, the local public transport authority would first need to decide which departures during the day to refrain from. Alternative tasks could preferably be performed during less busy hours of the day, when the travel demand is low. During these times, the main bus could go all the way into the village, or the main bus could operate on-demand into the village. This would result in no exclusion of the villagers, but also that the bus wouldn't take the detour unless there were travelers waiting to use the service. Examples of alternative tasks could be food deliveries to schools (after the morning rush), taking teams to practices (after the afternoon rush), goods deliveries, other postal services or morning paper deliveries. However, all idle time could not be spent doing alternative tasks since the vehicles need time for recharging. This also implies that the utilization of the shuttles can't be too high, or they will run out of battery power. This should be accounted for when implementing a shuttle service in a village.

As the rural mobility concepts of DVs should be compared to the current public transport, the concepts should also be compared to the increased flexibility and accessibility that will derive from private driverless vehicles or private taxi services with driverless vehicles. This needs to be done by public transport actors before driverless vehicles are launched on the market. Vastly reduced driver costs could make it profitable for private actors to operate taxi services also in rural areas. In this case it's important for public transport authorities to make sure that the sustainability of the transport system is maintained and improved (Hedlund 2018). Furthermore, to keep private taxi services from taking to large market shares in rural areas, a preventive action for public transport authorities could be to develop the public transport service. Even though it might be expensive to develop a driverless public transport service, the alternative cost of losing market shares to private actors might be even higher.

Though this is not only about losing market shares to private actors, but public transport authorities would also miss out on an opportunity to build an effective transport system in rural areas with state-of-the-art technology. Also, reduced driver costs would give the opportunity to counties to re-invest capital elsewhere to increase the attractiveness of the service. This could be done by implementing the rural mobility concepts for DVs on relevant case locations to increase flexibility and accessibility, improve equality and reduce emissions. Though if the service is already effective, more capital could be spent on the healthcare in the region since healthcare and public transport are often competing in the budget of counties or municipalities.

In order to contribute to more sustainable traveling, it’s important that the rural mobility concepts for DVs don’t replace journeys previously made by walking or cycling. Since the taxi service takes customers from their homes into the regional seats, this service probably wouldn’t replace walking or cycling. However, for the feeder service and area traffic it’s difficult to anticipate which travels will be replaced since these travels are shorter. Depending on which travels will be replaced, it could have either positive or negative effects on the climate and is hence important to study further before implementing the service. Though travels would not just be replaced, but new travels would be created, and some trips will no longer be made. How the number of trips is changed would be another important sustainability aspect, and also an aspect to consider when implementing a rural mobility concept for DVs.

Another area in need of future research is how many customers that could be integrated in the public transport along a route or in an area using the rural mobility concepts for DVs. Depending on the number of travelers that could be integrated, socio-economic analyses should be performed on the area or the route, to see benefits with the service. Pernestål and Kristoffersson (2018) noted that shared driverless cars in urban areas could replace up to 18 cars in optimal conditions, but how many cars and trips could the rural mobility concepts for DVs replace?

Since there isn’t a lot of research on driverless vehicles in rural areas, especially integrated in the public transport, the rural mobility concepts for DVs proposed in this thesis could be further developed and tested on other case locations. Doing this, more effects from the rural mobility concepts for DVs could be found and the concepts would hence be further evaluated.

7. Conclusions

Driverless vehicles can be used for many types of mobility concepts in rural areas. In this thesis, three different rural mobility concepts for DVs have been proposed. The proposed concepts are based on an assessment of how benefits from driving automation technology could be applied to face transportation challenges in rural areas. A shared taxi on-demand service could be used in rural areas with less spatial density of travel demand, longer distances to main roads and without access to regular public transport. Services feeding people the first and last mile between the public transport and villages could be used in rural villages with higher spatial density of travel demand located nearby main roads with access to public transport. Area traffic could in many cases be used in combination with a feeder service to create alternative values for the service in the targeted village.

Sustainability issues mainly depend on which type of travels will be replaced, removed or created by implementing these services. If car-travels are replaced then greenhouse gas emissions could decrease, though if walking and cycling modes were replaced by driverless vehicles, the emissions could increase. Mobility impaired people, older people and children might previously have been excluded from the public transport, for instance due to the risk of walking long distances to the bus stop on the roadside. If these people were integrated in the public transport using the concept of FMLM with straightened bus routes or area traffic in the village, the VKT would increase. Hence increased VKT could be seen as a result of improved accessibility for some travelers. Improved accessibility because of increased accessibility and VKT could be an effect of all proposed rural mobility concepts for DVs. However, replacing walking and cycling transport modes could impair the public health of a village by reducing the daily exercise which is not desirable. The shared on-demand taxi would mainly compete with car-use since it operates on longer distances than the other two rural mobility concepts for DVs. Hence, the risk of increased public health issues would probably be higher for the concepts of FMLM with straightened bus routes and area traffic.

All the proposed rural mobility concepts for DVs could improve the flexibility, accessibility and equality of the public transport. These benefits are achieved in different ways and with varying significance depending on the different rural mobility concept for DVs and the specific case location. The shared on-demand taxi service is highly flexible for the traveler in the sense that it is offered as a door-to-door option. Using the shared on-demand taxi service could also lead to greater equality improvements by reaching areas previously excluded from the public transport at a cheaper price than today’s taxis. Citizens of the new areas would now have increased redundancy of mobility options and could hence take part in more social events. Benefits from using the shared on-demand taxi service could be expressed in different ways depending on the case location, for example increased tourism industry or increased potential for shared commuting.

Benefits from the concept of FMLM with straightened bus routes and area traffic would rather come from overcoming first and last mile issues, scattered living in villages and long travel times along bus routes. Instead of walking or cycling along poorly maintained roads without lighting, people could use the feeder service, and instead of only having one bus stop in the middle of the village there could be more stops in different parts of the village. Though perhaps the greatest benefit of the concept of FMLM with straightened bus routes would be reduced travel times for people traveling the main bus route since the bus could now skip the detours. Furthermore, previously hard-to-reach villages excluded from the public transport could now be integrated and citizens of these villages could live more social lives. Reducing the total trip time for a majority of the travelers would improve the attractiveness of the public transport service. For instance, people using route 145 in Alstad could reduce their travel time by about 8 minutes per travel if the bus don't go into the village. Examples of positive effects using the concept of FMLM with straightened bus routes with area traffic are merged routes freeing up capacity and locally alternative tasks like school rides or food deliveries.

If the concept of FMLM with straightened bus routes would be used in a village then the travel demand, distance between the village and the main road, frequency of departures and shuttle speed would be important parameters. Since the main road and the village are fixed, the shuttle speed is an important factor as to whether the FMLM with straightened bus routes-concept could be used in a certain village or not. Shuttle speeds today are slow but if they were increased, more villages could benefit from this concept. A shuttle with the capacity of 15 people could feed about 100-150 travelers daily to the public transport and still have time to perform alternative tasks to create more value for the villagers.

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Appendix A – interview tools

Interview tool used for interview 2 and 3

1) Vilka barriärer finns det för kollektivtrafik traditionellt sett? (*Tekniska? Sociala? Ekonomiska?*)
2) Vilka möjligheter finns det med självkörande fordon?
3) Vilka är för- och motargumenten för kollektivtrafik på landsbygden?
4) Vilka transporter görs på landsbygden?
5) I vilka syften transporterar man sig i dagsläget? (*Pendling? Handling? Skjutsning?*)
6) Hur skulle en FMLM-tjänst kunna utformas och implementeras?
7) Hur skulle en anropsstyrd tjänst (dörr-till-dörr) med självkörande fordon kunna tas emot?
8) Hur skulle sådana tjänster kunna modelleras? (*Vilka data behövs?*)

Interview tool used for interview 4 to 9

1) Berätta kort hur ni jobbar med transportsystemet på landsbygden?
2) Hur ser problematiken och utmaningarna med kollektivtrafiken ut på landsbygden? (*Tillgänglighet? Kapacitetsproblem? Turtäthet? Kundunderlag? Ekonomiskt hållbart?*)
3) Vilka är era utmaningar i allt detta? Vilka behov och begränsningar har ni?
4) Hur ser området ut? (*Geografiskt? Demografiskt? Tillgång till skola/inköp etc? Specifika problem i specifika byar? Finns det något case? Kostnader/intäkter i kollektivtrafiken?*)
5) Vilka är de generella trenderna i utvecklingen av transportsystemet idag? (*Samåkning? Delningstjänster? Självkörande fordon? Elektrifiering? Uppkoppling?*)
6) Hur arbetar ni med alla dessa förändringar?
7) Hur ser ni på en framtid med självkörande fordon på landsbygden? (*Dörr-till-dörr-tjänst? First-mile last-mile-tjänst?*)
8) Finns det något konkret exempel på hur självkörande fordon skulle kunna lösa något problem i dagsläget?
9) Hur kan kostnader och intäkter i ett framtida tänkbart transportsystem förändras?
10) Vad mäter ni i dagsläget och vilka data har ni tillgång till?

Interview tool used for interview 10

1) Är det något speciellt att tänka på vid modellering av landsbygdstransporter?
2) Är det något speciellt att tänka på vid modellering av kollektivtrafik?
3) Kan du tänka på några viktiga skillnader i hur modelleringen kommer se ut för de konceptuella casen? (*För FMLM? För delade taxitjänster?*)

4) Räcker det att modellera ett visst stråk eller finns det någon poäng med att modellera hela kommunen? (*Macro, meso, micro?*)
5) Finns det färdiga paket med kod som man kan använda för att modellera detta? (*Vart finns den?*)
6) Vilken mjukvara passar bäst att modellera mina tjänster i?
7) Finns det speciella parametrar som det finns värde i att kunna variera för att undersöka vissa saker?
8) Är det några speciella parametrar som är mer värda än andra att mäta? (*Väntetid, cost of time, utsläpp, köbildning etc?*)
9) Kan man undersöka kapacitet? (*Tex att 5 fordon täcker 90% av behovet och 20 fordon täcker 100% av behovet.*)
10) Hur tar vi hänsyn till hållbarhetsaspekten här? (*Hur mäts hållbarhet?*)

Interview tool used for interview 11

1) Kan ni sammanfatta genomförbarhetsstudien i Skellefteå?
2) Är det några speciella problem ni hoppas lösa på landsbygden?
3) Vilka aktörer blir de viktigaste i en sådan här tjänst? (Vilka är de största utmaningarna i detta för olika aktörer?)
4) Vilka effekter hoppas ni uppnå? Mål i siffror? Förändrade kostnadsstrukturer? Miljömässiga konsekvenser?
5) Hur kan flexibiliteten och tillgängligheten påverkas?
6) Har ni funderat något i banorna av att modellera en sådan här tjänst? Vad skulle i så fall vara viktigt? Vad skulle man vilja mäta med en sådan modellering? Vilka parametrar skulle vara viktiga?
7) För vilka skulle en FMLM-tjänst kunna vara fördelaktig? De som bor i en by utanför stråket måste ju göra ett byte vilket kan vara jobbigt.