Future scenarios for self-driving vehicles in Sweden

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1 Introduction

The development of Self-Driving Vehicles (SDVs) is fast, and several vehicle manufacturers have announced that they will launch fully self-driving vehicles to the market around year 2020 ([Watch] 2017). However, what the consequences of SDVs for users, society and the environment will be are still open questions. SDVs can become an important part of the solutions to challenges such as congestion and use of the limited space in urban environments, but they can also induce more traffic and higher energy consumption ([Gruel and Stanford] 2015 [Litman] 2015).

SDVs are predicted to have a large impact on future life and mobility, as a potential paradigm shift, and decisions made today will affect the development. Therefore, understanding possibilities and challenges with SDVs for

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the future is important for stakeholders such as policy-makers, authorities and industry. 

Predicting the impacts of SDVs is a complex task, since there are still so many open questions about their role in the society (Litman, 2015; Townsend, 2014). Examples of open questions are: Where will SDVs be allowed to drive? Will it be feasible for SDVs to co-exist with manually driven vehicles? How will society accept them? Will they be used primarily as private or shared vehicles? How safe will they be? How secure will they be? How will SDVs affect acceptable commuting times and choice of travel mode?

In this study, a scenario-based approach is taken, and four plausible scenarios for the development of self-driving vehicles in Sweden are developed. These scenarios create a platform for discussions on introduction of new policy measures, new legislation, and infrastructure investments, as well as for identification of research and development gaps.

It should be noted that the scenarios describe plausible futures, not the most wanted (Lindgren and Bandhold, 2009). The most wanted future differs between different stakeholders, and is probably a mix of the scenarios developed in this work. Identification of the most wanted future is a topic for decision makers in both the public and private sectors. Still, the scenarios developed in this study form an important platform for discussions.

1.1 Definitions

In this work, the term self-driving vehicle, or SDV, is used for automated road transport vehicles that can operate fully or partly without a human on-board who is responsible for the operation. In literature several different terms are used in the same meaning: Autonomous Vehicles (AV), Connected Automated Vehicles (CAV), Automated Road Transport Systems (ARTS). However, these names also include more details about the self-driving vehicles. For example, autonomous means that the vehicle operates without support of an external system, while CAT and ARTS indicates that the vehicle operates with support of an external system. In this work the distinction between these different types of self-driving vehicles is not necessary and therefore we have chosen the more general term self-driving vehicle.

The level of automation describes “how self-driving they are”. For this, the five level classification by SAE International (International, 2016) is used in this work. The classification is explained in Table 1. To clarify the interpretations of the SAE level examples are also provided in the Table. When referring to SDVs in this work, SAE levels 4-5 are considered.
<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No automation</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>Driver assistance</td>
<td>ABS, cruise control</td>
</tr>
<tr>
<td>2</td>
<td>Partial automation</td>
<td>Lane following, adaptive cruise control</td>
</tr>
<tr>
<td>3</td>
<td>Conditional automation</td>
<td>Auto pilot functions</td>
</tr>
<tr>
<td>4</td>
<td>High level automation</td>
<td>Fully self-driving under certain conditions</td>
</tr>
<tr>
<td>5</td>
<td>Full automation</td>
<td>Fully self-driving anywhere</td>
</tr>
</tbody>
</table>

Table 1: The SAE levels of road vehicle automation.

2 Related Work

Most literature on SDVs treats the technical development, see for example (Piao and McDonald, 2008), but there are recent contributions on social and system level impacts.

In the literature studying the impact of SDV, most studies consider automation at level 5, i.e. when vehicles are fully self-driving anywhere. It is also at that level most potential is expected be released (Litman, 2015). In Litman (2015) and Fagnant and Kockelman (2015) potential positive and negative impacts of SDVs on society are listed. Among positive effects are increased traffic throughput leading to less congestion, improved traffic safety and reduced crash costs, decreased need for parking places, and improved mobility for people without a driver’s license (Harper et al., 2015). SDVs are also seen as a potential enabler for shared mobility services. On the other hand, among the negative effects of SDVs are an expected increase in the consumption of transport, which leads to an increase in total vehicle kilometers traveled (VKT) (Davidson and Spinoulas, 2016), an effect that is further reinforced by empty vehicles driving on the streets as well as by a shift from public transport to new affordable mobility services with SDVs. This will increase the number of vehicles on the streets and lead to increased energy consumption and congestion. Furthermore, since the SDV technology is expected to be expensive, at least for the nearest future, segregation may be a consequence of the development.

One field of research studies the potential impacts of SDV through simulations of different use cases such as: autonomous shared taxis (Burghout et al., 2015), a shared service with different penetration levels (OECD - International Transport Forum, 2015; Burghout et al., 2015), or new concepts as in Schoettle and Sivak (2015), where in-family car and ride sharing are studied. In Chen and Kockelman (2016) the effects of pricing of a shared autonomous taxi service are studied. These
simulation results provides upper or lower bounds on the potential impacts, but should not be consider as realistic levels in a real future world since they don’t take behavioral changes, such as travel demand increase induced by the increased accessibility or shifts between transportation modes, into account. As expressed by Stocker and Shaheen (2016): “any new transportation service introduced into an ecosystem of existing travel options will have impacts on subsequent travel behavior”. Furthermore, the simulations don’t take potential effects of competing suppliers into account. For example, Burghout et al. (2015) and OECD – International Transport Forum (2015) both simulate only one single fleet of shared SDVs to meet the travel demand, but a plausible situation is that there will be several competing suppliers available in the same way as there are several car-sharing operators or taxi operators in many cities today. In Litman (2015) the level of car and ride sharing is identified as a parameter having impact on the development of SDV, since sharing also means that the cost of the new technology will be shared between users. The uptake of new mobility options, such as SDV car or ride sharing will be different in different user groups and depending on the current choice of mobility mode (Krueger et al., 2016). To include factors such as behavioral changes and business impacts in simulations is challenging since there are many unknown variables.

Gruel and Stanford (2015) employ a speculative approach to identify scenarios for the impacts of SDV based on people’s behavior and choices, in a North American culture. Technological, policy and business aspects are for example not considered at all in the scenarios. Townsend (2014) discusses how digitization and self-driving vehicles may have an impact on the US society by describing different future scenarios. The method is based on the assumption that there are four archetype future development directions: “growth” (continuous growth according to the trends present today), “collapse” (some of the critical systems fail), “constraint” (one resource is limited), and “transformation” (innovation takes place).

Most of the literature on societal and high-level system effects of SDVs treats the situation in North America. In Europe, literature in this area is primarily from the Netherlands. Miliakis et al. (2017b) study potential societal impacts of SDVs and provide a literature review on the topic. The authors divide the impacts of SDVs in first, second and third level impacts. First level impacts include travel time, travel cost, road capacity, and traffic volume. Impacts on car ownership, land use and parking are classified as second order impacts, and energy efficiency, emissions, and traffic safety are examples of third level impacts. Miliakis et al. (2017b) show that literature predict first level impacts to be decreased travel times, increased road capacity, and increased traffic work. Furthermore, the authors come to the conclusion that research about second and third level impacts still is sparse.

In Miliakis et al. (2017a) scenarios for the development of SDV in the Netherlands are developed. However, the Netherlands and Sweden are dif-
ferent in several important aspects, such as population density, mode choice, infrastructure and industry. Therefore the present study, where focus is on the Swedish situation, will provide new knowledge and insights, and also provides a possibility to compare the results from the two studies.

3 Contribution

This study contributes to the understanding of impacts of self-driving vehicles on a societal level in the European context in general and the Swedish context in particular. The study takes business, technological, policy and behavior aspects into account, and develops four plausible scenarios for the development of SDVs in Sweden by year 2030 and with an outlook to 2050. The most important factors that affect the development are identified. Furthermore, the development of traffic volumes and fleet sizes are predicted for the different scenarios.

The scenarios will serve as a platform for discussions among public and private decision makers, and for identification of knowledge gaps and future research and development projects. The scenarios will also be used in the ongoing governmental investigation about future regulations for SDVs on Swedish roads (Bjelfvenstam, 2016).

Previous works, where scenarios for SDVs have been developed, are based on literature reviews (Townsend, 2014), or workshops performed by smaller groups of researchers (Gruel and Stanford, 2015; Miliakis et al., 2017a). This current work is unique compared to previous work due to the large group of 40 experts from 23 different organizations within the transportation sector that have been actively involved in form of three full day workshops. By using this approach, it has been possible to integrate knowledge about technology, business and policy from several different perspectives into the developed scenarios.

Furthermore, in contrast to most previous literature on the impacts of SDVs this study considers impacts of SDVs of automation level 4-5 and not only of level 5.

4 Method

In this section the scenario planning approach is described briefly, followed by a detailed description of the process applied in this work.

4.1 Scenario Planning

There are several forces and trends present, that will have an impact on the development of SDVs in Sweden. These forces and trends are uncertain and also counteracting, making the development of SDVs challenging
to predict. Therefore, a scenario-based approach is applied. The scenario planning method is often used when the focus is on the distant future. The scenarios themselves are different alternative plausible futures rather than traditional forecasts, and they are intended to span the range of possible futures (Derbyshire and Wright, 2017).

In literature, there are several different definitions of what a scenario is, for example “An inner, coherent view on how future will look like” (Porter, 1985) or “A well thought through answer on the question What is plausible to happen?” (Lindgren and Bandhold, 2009). Scenarios are the plausible and likely futures, not the most likely (they are called forecasts) or the most wanted (they are called visions) (Lindgren and Bandhold, 2009).

Among the advantages of the scenario planning method are that it is a format that corresponds to the way brains are working, that the method enhances unconventional thinking, and that the method reduces the complexity without over simplifying things (Lindgren and Bandhold, 2009; Wright et al., 2013).

There are a number of different approaches to scenario planning (Bradfield et al., 2005). In this project the Intuitive Logics (IL) approach is used, where the aim is to identify (four) scenarios that are plausible and different descriptions of the future, and at the same time internally consistent. There are variations in the IL method, see e.g. Derbyshire and Wright (2017); Vanston et al. (1977); Foster (1993), but the standard method contains the following steps: (1) identify issue of concern, (2) identify predetermined elements, called the certain development[^1] in this report, and critical uncertainties[^2], (3) recompose and cluster the critical uncertainties into clusters of strategic uncertainties (also called forces), (4) identification of two “extreme” but plausible sets of outcomes for each strategic uncertainty, (5) cluster the strategic uncertainties and (6) select the two clusters with greatest impact and uncertainty as the scenario dimensions. The scenario dimensions are then used to form a scenario matrix with four scenarios, and for each scenario an explanation based on causal logic is written to describe how the scenario will unfold from the present to the future.

4.2 The Scenario Development Process

The work to identify the scenarios in this project has been performed by an expert group and an analysis team. The analysis team consisted of the three authors of this report and two future strategists. The expert group has involved 40 persons from 23 transport organizations, including authorities, municipalities, lawyers, city planners, researchers, public transport opera-

[^1]: The certain development is a set of future trends that are predicted to have a very high probability to come true.
[^2]: Critical uncertainties are trends that may or may not come true, and whether they do or do not come true will have a great impact on the issue of concern.
The expert group met for three full day workshops with one month in between, marked with black frames in the Figure. The experts were selected to represent a wide variety of organizations. They were also selected due to their personal level of expertise in their field and their ability to be open-minded and future-sighted in their thinking and work.

The process used in order to develop the scenarios included the IL steps described above, and was complemented to also derive scenario descriptions and predictions of the consequences for SDVs in each of the scenario (see also Figure 1):

- **Identification of issue of concern (IL 1) (analysis group):** identification of the issue of concern: the future development of SDV in Sweden.
• **Trend analysis (IL 2)** (expert group): identification of trends that have an impact on the development of SDV. The trends were classified depending on their relative importance on the development of SDV (lower - higher) and their relative uncertainty (certain - uncertain), see Figure 2.

• **Certain development & potential scenario dimensions (IL 3-6)** (analysis group): The trends classified to have a relatively less impact on the development of SDV, area (A) in Figure 2 were not included in the following work. The trends classified as having high impact and being certain (Area C in Figure 2) were used to form a certain development. The trends classified as having high impact and as being uncertain (Area B in Figure 2) were used to formulate strategic uncertainties. From the strategic uncertainties the analysis team derived two preliminary scenario dimensions. By combining the two scenario dimensions four scenarios were formed.

• **Scenario workshop** (expert group): The expert group verified the preliminary scenario dimensions, and identified the development of the society in general and mobility and SDV in particular in the four different scenarios.

• **Preliminary scenario descriptions** (analysis team): Based on the material from the scenario workshop the analysis team created scenario descriptions.

• **Scenario review & Consequence analysis** (expert group): The expert group reviewed the consistency in the scenario descriptions. Based on the scenario descriptions, the expert group made predictions on consequences on the development of SDVs from several perspectives: development of different levels of automation, total vehicle kilometers driven, fleet size, and penetration rates in the different scenarios. The process for the consequence analysis is described below.

### 4.2.1 Consequence analysis

To estimate the development of SDVs in the four scenarios the expert group was asked to analyze the consequences for and predict the development of SDVs in the different scenarios in three ways:
Predict the years for emergence, growth and saturation of SDV level 4 and 5 for each scenario.

Predict the total fleet size and the share of SDVs level 4 and 5 for each scenario for the years 2030 and 2050 respectively.

Predict the total volume of vehicle kilometers driven and the share of that produced by SDVs level 4 and 5 respectively.

During this process step the experts were asked to first make individual estimations. After that the experts were divided into groups of four to five persons, and were asked to agree on a group estimation.

5 Results

5.1 The certain development - where the world is going

The “certain” development as identified by the expert group is presented in Figure 3 and can be summarized as follows.
- **Technology**, where the trend is a continuously fast development including development of high capacity communication technology such as 5G, more precise geo-positioning technology, and high level of connectivity.

- **City Life**, where the trend is continuous urbanization leading to an increased competition for the space in the city and decreased number of parking places. Another important trend is the regional enlargement leading to longer worktrips and increased demand for mobility.

- **Life Style & Demography**, where the trend is increased search for a smooth, friction free life. Quality of life and how time is used will be important, but there will be an increased difference in what different people interpret at “high quality time”. There is a trend that younger people take driving licenses later in life but at the same time people are more mobile and drive higher up in the ages. Furthermore, there is a trend of increased flexibility in work life where people can work from home or other places.

- **Business**, where there is trend that it will be profitable for enterprises to be sustainable. New business models related to mobility and transportation will be invented and tested, but it is difficult to predict which of them that will be competitive in the future and who will be the main actors.

- **Policy and Governance**, where one strong trend is that the Ministry of enterprise will support the development of industry and business related to self-driving vehicles and aim for making Sweden a test bed for innovative mobility solutions. Furthermore, there will be a harmonization of communication and data integrity within EU, at least at some level.

- **Transport & Mobility**, where one important trend is a development where vehicles reach higher levels of automation (even if they do not reach automation of level 4 or 5). There is also a trend towards exchanging costly labor hours with automation. New types of vehicles will appear, including a development of small busses or pods that will complement high capacity public transport.
The trends listed above and in Figure 3 are not intended to be general or complete, but contains instead a selection of trends that are considered to be particularly important for the development of SDVs in Sweden.

5.2 Strategic Uncertainties

The trends that were classified to have an uncertain outcome and at the same time are important for the development of SDV were formulated into strategic uncertainties, where each trend has two possible outcomes, see Table 2. The strategic uncertainties expected to have the largest impact on the development of SDV were formulated into eight potential scenario dimensions. The potential dimensions are presented in Table 3. The potential dimensions belong to three main areas: technical development (D1 - D3), urban policy / planning (P1-P2), and consumer behavior (C1-C3).

In the study, it is assumed that the general political situation in the world has not changed disruptively by 2030, and wild cards such as that EU falls apart or that free trade decreases radically are not considered.

The development related dimensions (D1-D3) where identified to be closely related to the other dimensions: (D1) was identified to be a consequence of (P1), (D2) was interpreted as a potential root cause for (C3), and (D3) closely related to (P1) and (C1). Therefore, Urban policy / planning and Consumer behavior were chosen as the dimensions to span the scenario matrix. The dimensions where formulated as:

**Behavior** Whether people buy in on the sharing economy (consumption of services rather than ownership) and to what extent this is reflected in the solutions that have reached market attention.

**Policy** Whether the ambitious goals that policy and authorities have in order to change society are followed by proactive handling and new solutions and ways of organizing things, or whether implementation is deemed to be done within today’s national and international structures. A consequence of the second outcome of this axis is that commercial actors will be given the opportunity to lead the development.

5.3 The Scenarios

The selected scenario dimensions create the scenario matrix that gives four scenarios, see Figure 4. The four scenarios are:

1. **Same, same, but different** where urban policy-making and planning are proactive and are leading the development, but shared solutions have had a limited breakthrough.
<table>
<thead>
<tr>
<th>Trend</th>
<th>Outcome A</th>
<th>Outcome B</th>
</tr>
</thead>
<tbody>
<tr>
<td>De-urbanization</td>
<td>Automation makes longer distances less un-attractive.</td>
<td><em>No counter trend identified.</em></td>
</tr>
<tr>
<td>Peoples’ acceptance of sharing</td>
<td>Sharing not accepted</td>
<td>Increased acceptance for sharing</td>
</tr>
<tr>
<td>Integrity</td>
<td>People have high integrity and are reluctant to share data.</td>
<td>People are OK with sharing data.</td>
</tr>
<tr>
<td>Growth of shared transport services</td>
<td>Significant and fast increase of MaaS (Mobility as a Service).</td>
<td>Smaller and slower increase in MaaS.</td>
</tr>
<tr>
<td>Private car ownership</td>
<td>Private car ownership and driving decreases drastically.</td>
<td>Continuous interest in driving / having access to your own car.</td>
</tr>
<tr>
<td>Trust in authorities</td>
<td>Mistrust towards authorities increases, instead people trust commercial organizations.</td>
<td>People begin to trust authorities again.</td>
</tr>
<tr>
<td>SDVs are accepted</td>
<td>People accept SDV, are curious and want to test.</td>
<td>People are reluctant to SDV, do not understand what SDVs are good for.</td>
</tr>
<tr>
<td>Focus in media</td>
<td>Media focuses on problems and accidents.</td>
<td>Media focuses on potentials and benefits.</td>
</tr>
<tr>
<td>Cyber security, data security, communication technology</td>
<td>High system reliability is achieved.</td>
<td>Hackers tend to always be &quot;one step ahead&quot;.</td>
</tr>
<tr>
<td>Type</td>
<td>Alternative outcomes</td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Development (D1)</td>
<td>Technological, policy &amp; business barriers leads to poor and scattered MaaS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technological, policy &amp; business barriers are resolved and good MaaS can be developed</td>
<td></td>
</tr>
<tr>
<td>Development (D2)</td>
<td>Fail to reach high technology security/safety</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reach high technology security/safety</td>
<td></td>
</tr>
<tr>
<td>Development (D3)</td>
<td>Automation levels 3 and 4 are not passed (too expensive compared to benefits)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fast development of SDVs of automation level 5.</td>
<td></td>
</tr>
<tr>
<td>Urban policy/planning (P1)</td>
<td>Urban planning/policy reactive / out of phase</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Urban planning/policy in place</td>
<td></td>
</tr>
<tr>
<td>Urban policy/planning (P2)</td>
<td>Public development and financing of public transport</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Private actors develop and commercialize public transport</td>
<td></td>
</tr>
<tr>
<td>Consumer behavior (C1)</td>
<td>Private products</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shared services</td>
<td></td>
</tr>
<tr>
<td>Consumer behavior (C2)</td>
<td>Private (physical) space</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shared (physical) space</td>
<td></td>
</tr>
<tr>
<td>Consumer behavior (C3)</td>
<td>Increased requirement on integrity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Willingness to trade personal data for better services</td>
<td></td>
</tr>
</tbody>
</table>
2. **Sharing is the new black** where urban policy-making and planning are proactive and are leading the development, and shared solutions have had a major breakthrough.

3. **Follow the path** where urban policy-making and planning are slow and commercial actors lead the development, and shared solutions have had a limited breakthrough.

4. **What you need is what you get** where urban policy-making and planning are slow and commercial actors lead the development, and shared solutions have had a major breakthrough.

The scenarios are described in more detail in the following sections, both with a story and a fact box. The descriptions in this section are fictitious stories, written from year 2030 perspective. In the Figures 5, 7, 9 and 11 illustrations of the scenarios are shown.

Figure 4: The scenario dimensions and the four scenarios.
5.4 Same, same, but different

A lot has happened since mid 10’s. The combination of increasingly visible climate changes and usage of the possibilities provided by digitalization has changed Sweden during these last 15 years. Now we can realize that one of the most important changes was that both private and public sectors managed to implement the high ambitions that during the first decades of the millennium tended to stay as just good intentions. Digitalization has contributed to a radical change in how society is organized and many services that support everyday life decisions are now available.

But there is one trend that we saw in the 10’s that didn’t bloom: the willingness to share our private belongings and space. The Swedes, as Europeans in general, didn’t buy in on the sharing services regardless of whether it comes to sharing data, transport or things. Integrity and ownership turned out to be more important for people than trend spotters believed fifteen years ago. Therefore consumer patterns are still much the same, while production methods have changed to become far more sustainable.

It wasn’t only the unwillingness to change behavior that stopped the sharing economy. Cyber-attacks and digital wars during the early 20’s led to reluctance to share personal data and raised high barriers for all actors aiming at delivering new services based on personal data. Hacker attacks in the national health care data system led to that people no longer trust the state to provide sufficient data security levels. This has also led to a new market for bots that take care of a person’s individual data on the internet.

There have been major changes as to energy consumption. Today only renewable sources are used and CO2 emissions have decreased significantly. Sweden became a pioneer, and the Western world and China followed. Even
the US followed when it was realized that solar power became much more profitable than fossil alternatives. The big shift to electric vehicles happened during the late 20’s, and statistics from 2029 show that now the electric car fleet is bigger than the fossil fuel driven one, and that almost all new cars are mainly electrically driven. This shift was driven by policy, and the fact that in 2025 fossil fuel driven vehicles were forbidden in many cities played an important role. Today, charging infrastructure is well developed, and electric roads are built along the main roads.

The street space has changed a lot since the 10’s when focus was very much on cars. Today, pedestrians and cyclists are in focus. During mid 20’s several city centers were closed for private car traffic, and cafés and restaurants took over the streets. New policies have raised the costs for having private cars in the cities radically. Congestion charging levels are now based not only on time of the day, but also on which street is used, the size of the car, how many passengers it has and local emissions. This has slowed down urbanization and led to that people work from home or from local co-working spaces. Commuting is done by public transport, electric bikes or one of the new light electric vehicles that were introduced during the 20’s.

5.4.1 Implications for SDVs

To reduce CO2 emissions, fees and taxes have made flying very expensive. Instead car, bus and train travel has increased. Platooning services with virtually connected buses and cars that decrease cost for fuel and energy, have increased. It is also possible for private car users to connect to the bus trains, so that the driver can use the time for sleeping and working instead - a service that has become affordable due to subsidies. Advanced traffic control systems and digital infrastructure have paved the way for advanced driver systems.

In addition, self-driving shuttle busses that connect remote parking areas with public transport or business areas are now common.

An overview of the scenario is shown in Figure 6.

5.5 Sharing is the New Black

After some years of unrest in the world during the second half of the 10’s, when people had a weak trust in the society, the development of the society started for real in the beginning of the 20’s. A key factor was the broad political commitment in Sweden after the election in 2022. Impatient inhabitants saw extensive consequences of the climate change and were tired of the politicians’ empty talks about investments in sustainability and digitalization that had no effects. The election 2022 was a major success for the new “Green Future Party”, that together with established parties managed
Figure 6: An overview of the scenario Same, same, but different.

Figure 7: An illustration of the scenario Sharing is the new black.
to implement a whole set of new solutions, called the “10 Actions List For Future Sweden”, later simply called “the List”. Political scientists mean that the List was the most important political action during the last century, in particular since the organizational structure of and culture within authorities have changed completely. The List included both concrete measures to minimize private car usage and to develop and integrate digitalization to achieve truly sustainable solutions, but also central data collection and governance. New solutions for public transport and city planning were not only supported by public actors, but were also driven by them. Public actors initiated cooperation with selected companies to create new concepts for city planning and traffic, and the minister of industry proudly announced the last week that the concept was now exported to the Netherlands.

Sweden has a progressive legislative support for self-driving vehicles, and a city planning that enables the technology for example by preparing physical and digital infrastructure and by dedicating lanes and roads to self-driving vehicles. This has led to that Sweden has become a test site for large global enterprises to try out new technology. A majority of Swedes use automated solutions in their every-day lives. At the same time a counter movement has started to grow, and it does not only include independence activists who warn about the “big brother development”, but also common people who have started to raise questions about what the personal data owned by the public sector really can be used for, and if it is safe for cyber-attacks.

New rules in the larger cities forbid privately owned cars in city centers, and vehicles must be both fossil free, connected, and share data to the public cloud. Support from legislation and subsidies have made charging infrastructure well developed over the whole country. Wind and solar energy together with batteries in facilities are currently making Sweden fossil free at a rapid rate, and the main national roads are electrified.

The public medical record systems in the Swedish health care sector provided a unique possibility for medical research during the 1990’s, and have again become a gold mine for transport research and development, in combination with publicly collected mobility data. The public sector adopted the block chain technology early, and that has led to a trust in general. There have been attempts from hackers to get hold of the data but coordinated efforts within EU have helped authorities to protect themselves. This made it possible to release the 2nd generation congestion charging system in 2027, based on GPS technology that automatically log all vehicle movements, and new traffic control systems are being created to ensure the societally most efficient traffic control.

A new public transport concept has been developed as a partnership between public sector and selected mobility suppliers. Door to door trip using a single ticket is the philosophy. During the last years of the 10’s it was called “Mobility as a Service”, but today no one calls it anything
else than just D2D (door to door). D2D has drastically changed public transport, and private enterprises have completely taken over the services in rural areas. In the beginning, this was a loss business, but infrastructure investments from the government have supported the deployment of self-driving vehicles on dedicated roads, and as drivers in the vehicles no longer are necessary, operation also in rural areas slowly begins to become profitable for the operators.

5.5.1 Implications for SDVs

The development of SDV has been supported both by the shared D2D solutions, where the technology costs are divided by several users. Also, the investments in supporting and dedicated infrastructure have supported the development of SDV, in particular with level 4 automation. The mobility has drastically increased for a large share of the population compared to 2017, including people without a driving license, disabled and elderly. After the D2D functions have been introduced also in rural areas, there is a tendency that people move from the city to rural areas.

On overview of the scenario *Sharing is the new black* is shown in Figure

![Diagram](image-url)
5.6 Follow the Path

The high ambitions of a sustainable and fossil free Sweden in the end of the 10’s have partly failed. Effects of climate change are for sure visible, but the Swedes (and the rest of the population in the Western world) weren’t prepared to fundamentally change behavior. Privately owned or leased cars, shopping malls and a dream of winter holidays in Thailand still dominate life. E-commerce has grown, but still the physical experience of shopping is important to people and shopping is often integrated with some kind of particular “experience”.

New services hasn’t been adopted at the rate that was expected by some innovators during the 10’s. A first sign of this was when Car2Go closed down in Stockholm in 2016. A more protective development started with the election of Donald Trump for president in the US, and it continued with increased tolls and barriers between countries. This slowed down development in the US and also in Europe and opened up for the growing markets in Asia. The Swedish government has struggled to find functioning alliances between parties, which has led to new technology being used to improve existing solutions rather than finding new solutions. It is not lack of ambitions or will – rather the opposite, but the authorities simply did not manage to look beyond the most urgent challenges.

There have been vast development steps in technology. Voice control functions flawless, and advanced navigation services, drones and VR-technology belongs to everyday life. The Swedes live a comfortable life, supported by advanced technical solutions, but without sharing of data between persons and organizations. All trials attempts to create standards for data exchange have been stopped by hackers, and after several attacks into the on journal
the medical record systems in the early 20’s, the amount of data collected has drastically been reduced. Focus on cyber security is high, and this has slowed down the development of self-driving vehicles since they are required to be more or less totally autonomous (driving without V2V\textsuperscript{3} or V2I\textsuperscript{4} communication). The traditional car manufacturers have taken the lead in the development and outperformed the small, innovative suppliers that tried to enter the market during the 20’s.

Urbanization and population growth has made the congestion situation worse than ever, but still the privately owned and occupied used car is the norm in 2030. High capacity public transport is an alternative in urban regions, but suburbs still lack attractive public transport alternatives. During the end of the 10’s there were signs of a developing sharing trend, but except for a few early adopters it did not have a breakthrough. People found it more convenient with private cars.

Life in 2030 reminds pretty much of life during 2017, but supported by smarter technology solutions.

5.6.1 Implications for SDVs
China’s economy has continued to grow and China is today the world’s leading nation in innovation, and several completely new cities with infrastructure dedicated for SDV:s have grown up there and become a new type of test-bed for technology solutions where fully self-driving vehicles operate. In Sweden, self-driving is focused on advanced driver assistance systems, and the cars can for example be self-driving in situations of congestion or on highways. Private car ownership (or private leasing) gives a lower fleet turnover rate and slows down the penetration of new technology.

An overview of the scenario Follow the path is given in Figure 10.

5.7 What You Need is What You Get
Digitalization has led to a rich world of new services that makes everyday life smooth - and the curious and progressive majority of the Swedes do not only like them, they love them. The change from ownership to sharing that could be seen as early signals during the late 10’s has totally exploded during the last years. The enterprises that have been successful are the ones that managed to collect unique data from their customers and transform it to new solutions. Personal data is the most important asset.

Public actors intended to take the lead in the development, but due to challenges to find collaborations, they were too slow compared to commercial alternatives. Driven fromSupported by the Ministry of

\textsuperscript{3}V2V = Vehicle to Vehicle
\textsuperscript{4}V2I = Vehicle to Infrastructure
Figure 10: An overview of the scenario *Follow the path*.

- Asia leads the development of SDV, slower development in Europe
- Owning rather than sharing
- Autonomous rather than cooperative systems
- Advanced driver assistance systems
- Individual decisions based on digital decision support

Figure 11: An illustration of the scenario *What you need is what you get*. 
Enterprise and Innovation the approach became to create legislation that opened up for commercial actors, to let them drive the development.

The service landscape is dominated by large commercial actors that have created new and creative solutions and services, based on exploring data collected from the customers. Most of the companies are the same as fifteen years ago: Amazon, Facebook and Google. The evolution started with many start-ups and smaller companies providing pooling and sharing services, e-commerce and mobility services. Consolidation and purchase integrated those into the large enterprises. Google Maps took over traffic information flow, in the same way as Google Translate did with translation service, and outmaneuvered established suppliers such as TomTom and Berlitz during the first years of the 20’s. Similarly the big commercial actors have taken over services that previously were offered by the public sector, including e.g. public transport. The key success factors are speed, money, and the skill to collect and transform data into tailored services. For example, Google have built new roads to support their own transport service “Seamless”, a service that has its roots in their consolidation with Uber and Volvo Cars. A Swedish success story is Ericsson’s and Volvo’s joint investments to create an IT infrastructure for cloud services for SDV:s. The solution has been known as the most safe and robust solution on the market.

E-commerce has grown, and got support from the new trend of automated shopping. The systems do not only recommend clothes and products, but they also send the products directly to the customers home, without any involvement of the customer. This type of “bot-chosen” clothes, based on personal data, became immediately high status. Everything is shared: cars, trips, tools, dogs, and IKEA just released the new service DELA where customers share and exchange sofas. It has become a boom for providers of solution services, for example shopping malls run “hotlines” with automated vehicles to pick up customers and drive them to the mall for free. Another example is LinkedIn workplace, a service offer to employers, that provides “an effective and creative work production”. The service is based on an analysis of the employee’s current work load, the need for meetings between persons, and the employee’s private life and preferences, and recommends whether the person should work from home or go to work - and if so, an optimized transport is arranged.

Public transport is still operated by the traditional types of buses and trains as during the 10’s, and becomes less and less attractive in comparison to new shared services such as Google Seamless and Facebook Connect that has entered the biggerbeen introduced in the large cities. Rumors say that Google Seamless soon will offer Gothenburg to take over the operation of the whole public transport systemoperation to a very competitive price.

There is a big difference in the mobility solutions provided in the larger cities compared to the rural areas. The rural areas are not intentionally left behind, but the main customer base and profitability is are in the urban...
areas. Initiatives are taken by the government to force the companies to provide services also to rural areas, but so far they have lost this battle.

### 5.7.1 Implications for SDV:s

The development and deployment of SDV:s at automation levels 4 and 5 is driven by commercial forces, and the change goes fast. The high price for the self-driving technology is covered by speculative investments from commercial actors and as well as by sharing vehicles in new innovative services.

An overview of the scenario What you need is what you get is given in Figure 12.

### 5.8 The Development of SDVs

In this section the expert group’s predictions of the development of SDVs in the four different scenarios are presented. In all predictions 2016 is used as base level, and the experts where asked not to take the population increase into account.

The expert group’s predictions of the total volume of vehicles and the share of SDVs of automation level 4 and 5 for 2030 are shown in Figure 13. As shown in the Figure, the level of solutions based on sharing is expected to be the most important factor for the development of the fleet size and also the share of SDVs. Also, as shown in the Figure, it is expected to be
more vehicles in the scenarios *Follow the path* and *Same, same, but different*. However, also the level of policy commitment is expected to have an impact: the fleet size is expected to be larger in the commercially driven scenarios *Follow the path* and *What you need is what you get*.

The predicted volume of vehicle kilometers travelled (VKT), and the share thereof that are produced by SDVs of level 4 and 5 are shown for the different scenarios in Figure 14. The experts predict VKT to be the largest for *Same, same, but different* and *Follow the path* where ride sharing has not had a major breakthrough, while the share of level 4 and 5 SDVs are lowest in these scenarios. In the scenario *Sharing is the new black* the expert group estimated the VKT to decrease in relation to 2016. It was challenging for the expert group to predict the effects of the sharing economy on VKT, which is shown by the larger standard deviations in Figure 14a for *Sharing is the new black* and *What you need is what you get*. The VKT volumes are similar in 2050 and 2030, but the share of level 4 and 5 SDVs has increased and is at similar levels, around 55-60% in all scenarios.

The expert group was also asked to draw S-curves (Foster, 1985; Christensen, 1992) for the SDV development in each of the scenarios, and explicitly state years for the start, the region of maximum rate of progress, and the time where saturation is reached for each scenario. The expert group was asked to predict the share of SDV of level 4 and 5 at market saturation in each of the scenarios. The predictions were made individually, and the average results are shown in Figure 15 and in Table 4. The curves for the scenarios *Sharing is the new black* and *What you need is what you get* are similar, which indicates that the expert group expects the development of SDV functionality to be similar in those scenarios. The development is predicted to be slower in the scenario *Same, same, but different* and slowest in
Figure 14: The volumes of VKT in the different scenarios, for all vehicles (blue bars) and the share there of that are SDV of level 4 and 5 (red bars), as predicted by the expert group. The graphs show mean values and standard deviations.

Table 4: The average predictions of starting point, region of maximum rate of progress, the time where saturation is reached, and the share of SDV when saturation is reached.

<table>
<thead>
<tr>
<th>Scenario name</th>
<th>Start point</th>
<th>Max. progress rate</th>
<th>Limit</th>
<th>Saturation level (mean ± std)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same, same...</td>
<td>2030</td>
<td>2040</td>
<td>2056</td>
<td>59 ± 34 %</td>
</tr>
<tr>
<td>Sharing is...</td>
<td>2028</td>
<td>2034</td>
<td>2050</td>
<td>89 ± 9 %</td>
</tr>
<tr>
<td>Follow the path</td>
<td>2033</td>
<td>2039</td>
<td>2058</td>
<td>48 ± 38 %</td>
</tr>
<tr>
<td>What you need...</td>
<td>2027</td>
<td>2033</td>
<td>2050</td>
<td>83 ± 19 %</td>
</tr>
</tbody>
</table>

Follow the path. In none of the scenarios is the level of saturation expected to be 100%. The standard deviations of the predictions of saturation level are significantly higher for the scenarios Same, same, but different and Follow the path, showing that the experts disagreed on the expected development in these scenarios.

5.9 The Scenarios in Relation to Literature

Predicting the vehicle fleet size and VKT is a complex task as there are many and contradictory factors affecting them (Gruel and Stanford, 2015; Litman, 2015). Self-driving vehicles opens up for new possibilities to create new, attractive mobility services, where vehicles and rides are shared, and thereby decrease the number of vehicles needed and as well as VKT. On the other hand, such services could result in decreased price for transportation, an thereby increased demand for transportation leading to increased fleet
size and VKT. Self-driving vehicles opens up for new possibilities to create new, attractive mobility services, where vehicles and rides are shared, and thereby decrease the number of vehicles needed and as well as VKT. On the other hand, such services could result in decreased price for transportation, and thereby increased demand for transportation leading to increased fleet size and VKT. Other factors that may lead to increased fleet size and VKT include empty vehicles that may drive around and the fact that when there is no need for a driver the time in the cars can be spent on other activities than actually driving and we will probably make people be willing to spend more time in the vehicles. Furthermore, people without a driver’s driving license, for example such as young, elderly and disabled people, will get an increased possibility to “drive”.

In this project those factors affecting fleet size and VKT are not taken into account explicitly. Instead the expert group was asked directly about the estimates of fleet size and VKT, and their answers should be interpreted as “qualified guesses” rather than exact numbers. In this section the scenarios developed in the current project are compared with results from the literature. In the literature there are no exact matches with the scenarios in this project, but instead the previous results can be matched with one or a few of the scenarios. Therefore, where it is feasible, comparisons of the predictions of future fleet size and VKT are given.

In Chen and Kockelman (2016) simulations are used to investigate how different fare levels affect penetration of autonomous taxis (without ride sharing), when competing with private cars and share of public transport of 10-13% in the context of a city in US. In Chen and Kockelman (2016) it is assumed that private car and public transit fare levels are kept the same as today, i.e. that SDVs are not used for those transport modes. Under
Table 5: Fleet size and VKT for 2030 compared with the scenarios in OECD - International Transport Forum (2015) with 50% penetration rate.

<table>
<thead>
<tr>
<th>Scenario name</th>
<th>OECD scenario</th>
<th>Fleet size</th>
<th>Fleet size OECD</th>
<th>VKT</th>
<th>VKT OECD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same, same...</td>
<td>Car share w. pt</td>
<td>122</td>
<td>82</td>
<td>118</td>
<td>151</td>
</tr>
<tr>
<td>Sharing is...</td>
<td>Ride share w. pt</td>
<td>86</td>
<td>78</td>
<td>90</td>
<td>130</td>
</tr>
<tr>
<td>Follow the path</td>
<td>Car share w.o. pt</td>
<td>132</td>
<td>107</td>
<td>119</td>
<td>191</td>
</tr>
<tr>
<td>What you need...</td>
<td>Ride share w.o. pt</td>
<td>97</td>
<td>102</td>
<td>104</td>
<td>160</td>
</tr>
</tbody>
</table>

the assumption that SDV are too expensive for private ownership in the scenarios in this project, the setting in Chen and Kockelman (2016) relates most strongly to the scenarios Same, same, but different and Follow the path, where individual solutions are the norm. The lower fare level of $0.75 per mile that gives a share of SDV of 39% can be interpreted as Same, same, but different. The estimated share of SDV in Figure 14a is 31%. The higher fare level of $1.00 per mile that gives a share of SDV of 14.36% can be interpreted as Follow the path. This can be compared with 21% as shown in Figure 14a. In both cases the predictions given by the expert group and in Chen and Kockelman (2016) are of the same magnitudes.

OECD - International Transport Forum (2015) simulates eight different scenarios: ride sharing with and without high capacity public transport available, and car sharing with and without high capacity public transport available, all four of these for penetration rates of 50% and 100%. The ride sharing scenarios can be matched with Sharing is the new black and What you need is what you get, respectively. The scenario with car sharing and public transport can be matched with Same, same, but different. The scenario with car sharing without public transport can serve as an indicator of the development in Follow the path, but with the notes that in Follow the path there will probably also be a significant amount of privately owned or leased SDV, something that is not considered at all in OECD - International Transport Forum (2015).

The expert group estimates the penetration of SDV in Sweden to be 22-53% by the year 2030, see Figure 13, depending on what scenario is considered. In Table 5 the simulation results from OECD - International Transport Forum (2015) for 50% penetration are compared with the estimations by the expert group for 2030. In general, the expert group gives higher estimations of fleet size and significantly lower estimations of VKT.

Burghout et al. (2015) present simulation results on how shared SDV, including both car sharing and ride sharing scenarios, can replace private car usage. Public transport is left outside the simulations meaning that no modal shifts are considered. Furthermore, penetration rate is set to 100%,
Table 6: VKT for 2050 compared with the scenarios in Burghout et al. (2015). $x \text{ min } + y\%$ means that the ride start window is $x \text{ min}$ and the accepted increase in trip distance to make the ride shared is $y\%$.

<table>
<thead>
<tr>
<th>Scenario name</th>
<th>(Burghout et al., 2015) scenario</th>
<th>VKT</th>
<th>VKT (Burghout et al., 2015)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same, same...</td>
<td>Car sharing</td>
<td>120</td>
<td>124</td>
</tr>
<tr>
<td>Sharing is...</td>
<td>15 min + 30%</td>
<td>80</td>
<td>76</td>
</tr>
<tr>
<td>What you need...</td>
<td>10 min + 50%</td>
<td>101</td>
<td>89</td>
</tr>
</tbody>
</table>

i.e. all private car trips are replaced by shared SDVs. Instead Burghout et al. (2015) consider different levels of accepted ride start time windows and levels of accepted increase in travel time. To compare with the scenarios the assumption is made that higher political coordination is interpreted as higher requirements on people to coordinate rides. In Table 6 the results from Burghout et al. (2015) are compared with the expert group predictions for 2050. However, while Burghout et al. (2015) consider 100% penetration, the penetration rate predicted by the experts is around 50-60%. Therefore, this comparison should mainly be used to confirm the internal order between the scenarios rather than the levels.

Fagnant and Kockelman (2014) show that a penetration rate of 3.5% (of rides) of SDV car sharing gives up to 11% increase in VKT due to the need for relocation, depending on accepted waiting times and fleet size, which are in line with the expected increases in VKT in Figure 14a for Same, same, but different and Follow the path.

In Schoettle and Sivak (2015) a case is analyzed where SDVs are used for car (and ride) sharing within a family, a case that reflects the scenarios Follow the path and Same, same, but different. It is shown by Schoettle and Sivak (2015) that family car sharing could reduce vehicle ownership by up to 43% while the usage of each vehicle would increase by 76%, excluding empty vehicle kilometers driven to relocate the vehicles.

Davidson and Spinoulas (2016) compare 100% penetration of SDV in three scenarios; with privately owned SDVs, single occupant shared SDVs (car sharing), and multiple occupant SDVs (ride sharing), and show that privately owned SDVs lead to around 40% higher VKT than in the sharing cases. In the simulations in Davidson and Spinoulas (2016) the two sharing scenarios result in the same level of VKT. The reason is that ride sharing reduces the mileage cost compared to car sharing, and thereby the total travel demand and trip lengths will increase in the ride sharing scenario. Privately owned vehicles can be compared with Follow the path, car sharing with Same, same, but different and ride sharing with What you need is what you get. None of the scenarios in this project reaches 100% penetration, but
comparing with the predictions for 2050 the VKT levels for *Follow the path* seems to be underestimated.

[Gruel and Stanford (2015)](#) identifies and models three scenarios on a high system level using Causal Loop Diagrams: (1) Our travel behavior is not changed with the introduction of SDV, (2) Since the time in the vehicle can be used in other ways, we travel longer and tend to live further away, and (3) We leave private car ownership for car sharing. In all scenarios VKT increase. All those scenarios relates to *Follow the path* and *Same, same, but different*, and supports the expert groups predictions that VKT will increase.

[Childress et al. (2015)](#) and [Kröger et al. (2016)](#) have studied the scenario where SDV are used as private cars, and where no vehicles are allowed to drive empty. This results in around 5% increase in VKT. The no-empty-drives assumption can be interpreted as a policy measure taken in the *Same, same, but different*.

Predicting the impact of SDV on fleet size and VKT is challenging, not only since there are several potential scenarios. Aspects such as shifts of passengers between different modes (e.g. from public transport to SDV taxis) and change in travel behavior and travel demand when new services arise are not taken into account in previous simulations in the literature. In addition, previous literature typically ignores the effects of business models or that there may be competing suppliers or services. Instead simulations are often based on the assumption that only one fleet is used to meet the travel demand ([Burghout et al. 2015](#), [OECD - International Transport Forum 2015](#), [Fagnant and Kockelman 2014](#)). To better understand the impacts of SDV on fleet size and VKT, simulations and analysis taking also those factors into account are needed. However, the previous results are still interesting as bounds for the impacts, or as indications of directions of change.

### 6 Conclusions and Future Work

In this report four plausible future scenarios for the development of self-driving self-driving vehicles in Sweden up to the year 2030 have been presented. The scenarios are based on the input from 40 experts from more than 20 different organizations within the transport and mobility sector in Sweden.

To derive the four scenarios, both the highly probable future development of the society and mobility pattern, called “the certain development” in the report, as well as strategic uncertainties have been identified. The strategic uncertainties have been used to identify two scenario dimensions:

**Behavior** Whether people by in on the sharing economy (consumption of services rather than ownership) and to what extent this is reflected in the solutions that have reached market attention.
Policy  Whether the ambitious goals that policy and authorities have to change society is followed by proactive handling, new solutions and ways of organizing things, and taking lead in the development of society and cities or whether commercial actors will have the leading role.

The two scenario dimensions have been combined to form a scenario matrix with four scenarios:

1. **Same, same, but different** where urban policy making and planning is are proactive and leading the development, but shared solutions haves a limited breakthrough.

2. **Sharing is the new black** where urban policy making and planning are is proactive and leading the development, and shared solutions haves had a major breakthrough.

3. **Follow the path** where urban policy making and planning is are slow and commercial actors lead the development, and shared solutions haves had a limited breakthrough.

4. **What you need is what you get** where urban policy making and planning is slow and commercial actors lead the development, and shared solutions haves had a major breakthrough.

planning is slow and commercial actors lead the development, and shared solutions haves had a major breakthrough. The four scenarios have been described both in text and with estimations of the impact on vehicle kilometers traveled (VKT) and fleet size. Predicting VKT and fleet size turned out to be a challenging task for the experts in the project, and the variation in predictions where large. The predictions have been compared with previous literature. A direct comparison is difficult to make since there is a discrepancy in context and assumptions between the current study and previous literature. However, the predictions in this work points in the same direction as in previous literature and are not conflicting.

One main conclusion that can be drawn from this work study is that societal and transportation policy making and planning will have a large impact on the consequences of SDVs in society and on the environment. The scenarios presented in this report are plausible, but without any ranking of what is a “wanted” or a “not wanted” scenario. It is clear that actions and decisions made by policy makers today will have a strong impact on the role SDVs will have in the future society and cities. Therefore, it is highly
important for policy makers, planners and other decision makers to explore their possible decisions and the expected outcomes from them. It is challenging but important to understand the long term impacts of SDV, and how they depend on decisions made today. In this report four plausible scenarios have been developed and described, but there is still a need for detailed analyses and simulations of the development of SDVs and the consequences on parameters indicators such as traffic flow, social equality, accessibility, and safety is needed. There is also a need for a deeper understanding in of the consequences of business models and behavioral changes. This report, similarly to previous literature on the impact of SDV, has been focused on person transportationpeople’s daily travel. To get the full picture about the impact of SDV it is also important to consider freight transportation.

References


