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Interventions to Reduce Car Use: A Meta-Analysis

Ester Al-Salehi

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Interventions to Reduce Car Use: A Meta-Analysis

The thesis work carried out in Transportsystem

Ester Al-Salehi

Norrköping 2023-06-15







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Abstract

Transportation has become an essential part of people's lives to move from one place to another, increasing the transport mobility for passengers. Therefore, road transport accounts for the second largest contributor to greenhouse gas emissions in Europe, and to increased congestion. Hence, reducing the share of car use can lead to reduced greenhouse gas emissions, congestion, etc. However, not all types of car travel could be reduced, therefore there is a need to maintain certain transport demand. Instead, passenger transport could be made more efficient, such as utilizing time, space, vehicles, and fuel in the movement without any waste (Gudmundsson 2015). Efficiency in passenger transport could be achieved through a variety of interventions that aim to decrease the share of car use. The aim of this master thesis is to state interventions that reduce the share of car use and achieve efficient passenger transport.

To fulfill the aim of this thesis it is required to perform a literature search. In this thesis, a systematic literature and document review was conducted. This method involved creating a criterion that limited the selection of the articles, in terms of what the articles should contain to also ensure the quality of the selected articles. For example, the selection of literature was based on the location of the interventions, such that different interventions should not only be placed in capital cities but also in smaller cities. The selection of literature resulted in selecting different peer-reviewed articles and grey literature that studied different intervention types that reduced car use in the city center. Furthermore, the selected literature presented the effect (i.e., the share of car use reduction) of the intervention. From the literature was 48 city cases of interventions identified, and categorized into 12 intervention types: congestion charge, parking charge, parking management, access limitation, mobility service, shared mobility, travel planning, and app for sustainable mobility competition. On which some were based on ex-post (before/after study) and others ex-ante (model-based study).

In the analysis of the literature, it emerged that interventions with an awarding system have achieved a higher effect in reducing car use, through motivating travelers with awards in terms of money or points. Of all presented intervention types, the analysis indicated that shared mobility, mobility service, and congestion charge have the highest average effect in reducing car use. However, considering different effects (i.e., reducing congestion, greenhouse gas emissions, etc.), then it may be another type of intervention that is more appropriate. Therefore, some intervention types may have a higher effect in reducing car use and others have a higher effect in reducing greenhouse gas emissions.

The conclusion of this thesis based on the selected effect (i.e., the share of car use reduction), is that shared mobility, mobility service, and congestion charge have on average the highest effect in reducing car use. However, regardless of intervention type, the mutual aim of transport interventions is to facilitate sustainable travel behavior and affect travel perception throughout influencing travel choice. Transport intervention focuses on influencing travelers to switch from car to for instance public transport or non-motorized transport modes, as well as consider making the trip in the first place.

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1 Introduction

1.1 Problem background

Transportation has become a big part of people's lives to sustain a higher quality and standard of life. To be precise, passenger transport, which denotes the movement of people between an origin and a destination, has become essential in people's lives (Fox 2002). Transportation increases the mobility of passengers, while on the other hand, transportation is associated with negative environmental impacts. Transport accounts for the second largest contributor to greenhouse gas emissions in Europe (EEA, 2019), where three-quarters are from road transport. A large proportion of road traffic consists of cars, where car travel offers, among other things, more comfortable and less time-consuming travel. However, this large proportion of car use constitutes an obstacle to meeting existing EU and national climate policy goals (Kuss et al., 2022). Additionally, this large proportion of car usage contributes to increased noise levels, congestion, a sedentary lifestyle, and several other negative effects (Olsson et al., 2018). Therefore, there is a greater potential for reducing emissions by reducing car travel. Furthermore, reducing car travel can promote equity in urban space since a car user uses 3.5 times more physical space than a non-vehicle user (e.g., a cyclist, car, etc.). However, not all types of car travel can be reduced as there are important trips contributing to society's development. While at the same time maintaining the need for transportation, passenger transport can be made more efficient, such as utilizing time, space, vehicles, and fuel in the movement without any waste (Gudmundsson 2015). Cities all over the world aspire to achieve more efficient passenger transport in and around cities (Kuss et al., 2022), where transport efficiency is measured by the transport modes effect on the environment and society. For instance, travel time, travel cost, congestion, vehicle filling rate, emissions, etc., are some examples of how transport efficiency could be measured. Henceforth, the perceived transport efficiency is mainly aimed at society and partly at the traveler (Gudmundsson 2015). In like manner, could transport efficiency regarding the vehicle type and vehicle fuel achieve efficient transport by replacing car fuel with less harmful fuel or changing to electric cars to reduce emissions.

A variety of interventions that will address specific transport problems, in terms of travel mode choice on a local, regional, or national level have been introduced by Loorbach and Rotmans (2010). An auspicious approach to establishing an intervention is through introducing a long-term perspective in policymaking the so-called transport policy measures, creating interactions between different stakeholders. The transport policy measures focus on decreasing single car travel (i.e., one person transport), and increasing efficient passenger transport. These measures could be categorized as soft and hard. A soft transport policy measures denote mobility management tools or psychological and behavioral strategies. The former refers to the development of intervention strategies that encourage travelers to voluntarily change behavior that has a negative impact on the environment. The latter denote measures that involve workplace travel plans, which motivates employees to choose public transport over cars; school travel plans, which inspires parents to not use the cars when driving or picking up the kids at

school; and others such as personalized travel planning, marketing of public transport, and travel awareness campaigns. Meanwhile, the hard transport policy measures denote the increased costs for car use, improvement of infrastructure for public transport, and rationing or prohibition of car use (Bamberg et al. 2011).

Several cities have combined interventions and policy instruments to successfully reduce car use, and switch to a mode of more efficient transport (Kuss et al. 2022). For instance, combining the push- and pull approach; the push measure refers to using for example road pricing or regulations, which provides financial incentives for car use reduction, while the pull measures refer to incentivizing other travel mode substitutes to the car through improving public transport service, cycle paths, etc. However, there are various ways of creating an intervention by combining push- and pull approaches; the effects depend on the characteristic behavior of the population, and the differences in the supply of car alternatives and transport modes available. Therefore, it is also important to evaluate the efficiency of an intervention to ascertain the effect per invested cost, when comparing different interventions.

This master thesis will analyze the effect of different interventions in terms of reduced share of car use in and around cities. An analysis of model-based (so-called ex-ante) and before/after (so-called ex-post) studies, that include interventions to reduce the share of car use will be provided. The results of the analysis on ex-post studies will be compared to the ex-ante studies, in terms of simulation results and real measured results. This comparison aims to identify differences and similarities in the achieved effect from the interventions; as well as, to evaluate the intervention effect in terms of location and the extent of effect to achieve car use reduction. This is because the identified intervention types have used different methods to measure the intervention effect. Such knowledge is needed to comprehend interventions and policies that cities can adopt to reach a reduction in car use and reduce greenhouse gases.

1.2 Purpose and Aim

The aim of this master thesis is to identify interventions that reduce the share of car use in and around cities.

The purpose of this study is to compare interventions through analyzing ex-post and ex-ante studies that focus on interventions to reduce the share of car use. In addition, efficient passenger transport will be analyzed in terms of filling rate of vehicle. The effect of the identified interventions will be evaluated in terms of location and the extent of effect to achieve car use reduction. In addition, a table with all identified interventions and their effect will be presented of ex-post and ex-ante studies.

1.3 Research questions

This master thesis will fulfill the purpose of the work with the help of the questions below, where the main focus of these questions will be on analyzing effects seen in ex-ante and expost studies.

- How can the effect of transport interventions be identified and measured?
- How can different interventions reduce car use?
- Which interventions have the highest size of effect on reducing car use?

Question 1 is for revealing what the effect of the interventions means, to further understand the use of the intervention in different locations. Question 2 is suitable to reveal the different interventions for how they can be used in terms of extent (e.g., local and regional level) to reduce car use. Question 3 enables to focus on the interventions with highest achieved effect size of reducing car use.

The purpose of this thesis is related to identifying transport interventions and their achieved effect, understanding how different interventions can reduce car use. In addition, to identify which interventions have the highest effect on reducing car use. The analysis of ex-post and exante studies of interventions to reduce car use, will enable the evaluation of intervention effect of reduced car use. This thesis analysis of efficient passenger transport in terms of filling rate of vehicles will also contribute to answering how interventions reduce car use. The end goal is to compile a comprehensive table of identified interventions and their effect on reducing car use, which will help inform future policy and decision-making in the transportation sector.

1.4 Method

The identification of effects from interventions that aims to reduce car use and achieve efficient passenger transport from ex-post studies as well as ex-ante studies will be conducted through a systematic review of grey literature, case studies, and peer-reviewed articles. The identification of literature will be conducted through the databases *Scopus*, *ScienceDirect*, *Google scholar*, *CIVITAS*, and *Elits*. The collection of literature will be screened against a criteria that specify what the articles should include.

The following step after selecting the literature will be to categorize the interventions according to intervention category, ex-post/ex-ante, policy measure, intervention type, model type, and intervention approach. Additional information about the interventions, such as city, stakeholders, effect (i.e., the share of reduced car use), etc., will be given. The provided categorization will enable the identification and comparison of the intervention types to be clearer, in terms of better organize, understand, prioritize different intervention types that could be implemented. Trough applying a categorization of the interventions, it becomes easier to recognize which intervention types that achieves higher effect addressing specific transport problems. The categorization also helps the decisionmakers and planners to choose the best intervention type for the specific problem and enable to allocate resources well, as well as identify gaps that can be improved. Furthermore, the effect of the interventions will be evaluated in terms of location and the extent of effect to achieve car use reduction.

The systematic review method is chosen because it enable to identify a broad range of different interventions to reduce car use, and provide well-founded information about how to measure intervention effect, as well as contribute to evidence-based practice in this subject. For instance, a comprehensive review conducted by Kuss et al. (2022) reviewed numerous ex-post studies of different transport interventions to reduce car use. An alternative method that can be used is creating a model over a chosen region and evaluate one or several interventions for this region. For instance, Eliasson et al. (2013) developed a model to analyze how congestion charge can reduce car use in Stockholm. The advantage of studying a specific region is the increased understanding of the size and type of the city. The advantage of using a model to evaluate interventions is that it can provide a more realistic evaluation, in terms of adapting the model to be similar to the chosen region. Furthermore, a model allows more flexibility of being able to adapt and change parameters in the model to study different scenarios. This can provide an opportunity to try different interventions and see how the result (i.e., effect, etc.) changes. Alternatively, can several models be used where one intervention is tested, which enables comparison of the effects (Pyddoke 2023). However, there are also overall disadvantages of using models, like uncertainties and inaccuracies in the model's assumptions, algorithms, data, etc., which may affect the results and their reliability. There are also difficulties in generalizing the model, to be able to apply for other regions with other conditions.

1.5 Delimitations

For the scope of this master thesis, it is important to specify the limitations of this work. For example, this master thesis will not analyze in detail every existing intervention for car use reduction. Instead, this thesis will identify different interventions and only the effective ones will be analyzed in detail. This thesis will briefly go through the stakeholders involved in the different interventions, thus there will not be an extensive stakeholder analysis (e.g., core, primary, and secondary). Furthermore, this thesis will not state/calculate the intervention efficiency in terms of obtained effect per invested cost.

1.6 Outline

Chapter 2 will provide the methodology of this thesis, for example explaining how certain articles were selected. Information about how the systematic literature and document review will be provided in this Chapter. Further information about the categorization of the interventions will also be given, as well as giving a brief description of effect. Chapter 3 will provide a theoretical background for the reader to understand concepts that will be used throughout the study, such as effect, interventions, etc. Chapter 4 will provide the empirics, and information about results from all the selected articles will be provided. Here will the list of identified interventions be presented. Chapter 5 will provide a comparison of the interventions provided in Chapter 4. Furthermore, an analysis of the intervention effect. Chapter 6 will provide a discussion of the results provided in Chapter 5, providing different aspects than what was presented in the analysis. Chapter 7 will provide the conclusion of this study and answers to the research questions. As well as future work within this framework.

2 Methodology

This chapter gives an overview of the methodology in this master thesis.

2.1 Systematic literature review

To identify interventions to reduce the share of car use, a systematic review of peer-reviewed articles and grey literature was conducted. Booth et al. (2021) mention that the use of a systematic literature review is appropriate when identifying characteristics between concepts from already established studies that are related to the chosen topic. Aromataris and Pearson (2014) supplement and elucidates the simple steps toward a systematic review, which includes clear objectives and questions that are going to be addressed; criteria to control the eligibility of the study; a widespread search to identify relevant literature; an assessment of research results, in terms of validity. Henceforth, these steps were applied in this systematic literature review.

The identification of relevant articles in this study started by identifying relevant search terms. Examples of search terms that were used are *car restrictive policy, change car use habits*, *reduce car use*, etc. These search terms were randomly picked and did not have any search order, the search terms were added gradually. To control the eligibility of the literature, a criteria was created, that specified what the articles should contain. For instance, quantified evidence of the result demonstration, including an intervention that reduces the share of car use. The purpose of the criteria is to be precise in the article selection and to ensure that the selected articles had reliable results to answer the search questions for this study.

Furthermore, the selection of relevant articles was carried out in *Scopus, ScienceDirect*, and *Google Scholar* which provided peer-reviewed articles. These databases were chosen due to the reliability and validity of the search findings, ensuring that the articles selected for this thesis have gone through a rigorous review process and have been assessed by experts that are transparent. James et al. (2016) describes that it is of importance to balance the findings of all relevant articles and find articles that meet the criteria for relevance. Databases like Scopus have the option to adjust the search limit, for example, the year of publication and the document type. This type of adjustment was used to further adjust the search results to better match the criteria. However, the selection of articles was based on screening the titles, abstracts, methods, and results to assess their relevance. Graham-Rowe et al. (2011) mention that it is common to find a smaller number of suitable documents than what exists. The authors have reviewed 3 486 articles that focused on reduced private car use with interventions, and yet were able to retain 69 relevant ones. The authors describe that their inclusion criteria were based on the publishing year, that the literature should be in English, present car-use reduction data, and that the paper was available to the public.

Further search for articles was through backward snowballing, which refers to looking into the found articles' references and identifying further relevant articles. This method enabled finding

new articles that are relevant by shorter time. However, this process followed the same steps as the previous search (e.g., screening against the criteria and reading relevant parts of the document).

2.2 Systematic document review

This study conducted a systematic document review of case-study reports to capture those evaluations of interventions to reduce car use. However, the difference to the systematic literature review is that the documents will not be published in peer-reviewed (Kuss et al. 2022). The systematic document review enables finding case-studies that has not been published in scientific perspective, but are still reliable. Therefore, document review was chosen to be able to identify more interventions to reduce car use. This search had the same technique as a systematic literature review to narrow the search, where related search terms like *reduce car use, reduce vehicles*, etc., were used. The search terms are mainly aimed at discovering literature related to car use reduction and regulations in cities.

Furthermore, the databases that were used for this search were *Elits* (Mobility Solutions) and *CIVITAS* (Resource Library and Mobility Solutions). The chosen databases are appropriate because they both are extensive databases of reports including transport interventions in cities (European Commission 2017). Furthermore, the database Elits offers filters like *urban vehicle access regulations*, *mobility management*, *traffic, and demand management*, etc., which was used to find studies related to this study.

2.3 Categorization and classification of interventions

The next step in the methodology was to categorize the different interventions into different classes, which enabled a clearer identification of the selected interventions and to further compare the interventions. Overall, the application of categories of the interventions facilitated the recognize of which intervention types that achieves higher effect addressing specific transport problems. This categorization also helps decisionmakers as well as planners to select the best intervention type. Therefore, the different interventions were categorized into intervention category, ex-ante/ex-post, policy measure, intervention type, and intervention approach. The first class is the *intervention type*, which describes the type of the intervention, provided that every intervention type was derived from the references. The same applies to intervention types that use different measures, such as congestion charge combined with improvements in public transport, where the majority of the derived effect is from the cordon scheme and therefore is categorized as congestion charge. This class was chosen to specify the studied intervention and to give a brief insight into what comes next. The second class is exante/ex-post, which indicates if the studied intervention is based on a before/after (ex-post) study or a model-based (ex-ante) study. The third class is intervention category, which describes the category of the intervention in terms of physical change, legal policies, economic policies, and information & education. This class was categorized according to the definition of these categories given by Fan and Chen (2020), see the definition in Chapter 3.4. This class

is necessary to include because this information elaborates on the previous classes and makes a good transition into the next class. The fourth class is *policy measure*, which identified if the intervention is soft or hard, which is based on the definition given by Bamberg et al. (2011). The fifth class is the *intervention approach*, which describes if the intervention has a push-and/or pull approach. For instance, if the intervention was based on a push approach, then it would mean that charges and regulations were used, while if it was based on a pull approach then it could for example refer to an improvement of public transport. This class was categorized in a similar way as the previous ones, given the definition by Hrejla and Rye (2022) and Kuss et al. (2022). Hence, the classes: intervention type, intervention category, policy measure, and intervention approach, were formed by previous definitions of the presented authors above.

Further information about the different interventions is given later in the report. For example, information about the city where the intervention was implemented or aimed to be placed; further explanation of the intervention (e.g., congestion charging was based on time-dependent charges); the effect of the interventions given by car use reduction in percent; the stakeholders involved. Additional information that was specific to ex-ante studies specific, was provided to understand the content and results, information such as model type was provided that states the utilized model.

Furthermore, building a better understanding of the presented classes, a fundamental basis of what the different intervention types implies was stated. Therefore, an overview presentation of the intervention types was provided in the frame of refences. However, this overview presentation was conducted after selecting the literature, which enabled to present a more focused presentation of information regarding intervention types that will be given later on in the report (i.e., in the literature search outcomes). The presentation stated for example information about the main purpose of the intervention type, and further knowledge about how these interventions could be utilized. The overview presentation of intervention types in the frame of refences was further categorized according to the measure type, for instance, all interventions that considered taxation, payment, etc., were presented in the subchapter *charging based intervention*. Hence, the sub-chapters charging-based intervention, access limitation-based intervention, parking management-based intervention, mobility service-based intervention, shared mobility-based intervention, and travel planning-based intervention will provide a fundamental basis of what the different intervention types implies.

2.4 Effect of intervention

A part of the information provided about the interventions is their effect, which is interpreted as the share of car use reduction. Hence, each individual intervention for each city case was presented by their effect that was obtained from the corresponding reference. The intervention effect could be utilized to measure the efficiency, in terms of intervention effect per invested cost. However, the efficiency measure was not analyzed/calculated in this study, instead a brief evaluation of the intervention effect was provided. It is also unfair to only compare the

intervention types based on their effect because the interventions are implemented in different locations throughout the world, where the state before implementing the intervention, traffic conditions, utilized method to measure the effect, and many other factors differ. The effect, share of car use reduction, is utilized as an indicator of the intervention reachability in each city case to determine the influence.

Furthermore, the effect of different intervention types have been conducted in different ways, however, the majority could be divided into three phases: the first is before intervention implementation, the second is during, and the third is after implementation of intervention. These three phases include statistical measurement expressing the difference between the phases and baseline data. This method of measuring the effect of interventions has the main drawback of misleading the results, due to the subject interpreting the response level differently in each phase (Karltun 2006). This could be interpreted as a risk where travelers could evaluate a certain circumstance differently before and after the intervention. Therefore, it is not trustworthy to draw conclusions based only on the results from the measures (compare numbers). Modijefsky (2021) describes the method used to obtain the effect of parking management, these effects seen from intervention application were based on yearly evaluations, comparing results with the "baseline situation" at the beginning of the project. The results were based on traffic data collected during the project since it is difficult to state an effect based on random individual measures. In addition, qualitative data is also collected before, during, and after the implementation, such as surveys and interviews to evaluate the effect of the intervention. Hence, quantitative (i.e., traffic data, traffic counts) and qualitative (i.e., survey and interview) are used to assess the effect of intervention types.

Börjesson and Kristoffersson (2015) describe that the assessment of reduced traffic size from congestion charge was based on traffic count from selected streets and compared to a baseline scenario, and used qualitative data. While Wall (2011) describes the evaluation of the effect of parking charges, which was carried out by collecting data from the City Council, such as the number of drivers participating in the intervention, as well as ticket sales data. This type of data collection enables to understand and detect behavioral patterns in parking, and then determine the effect as the pattern seen after the implementation of intervention. Furthermore, surveys were used to evaluate awareness and behavioral change in terms of intervention acceptance. Similar to Börjesson and Kristoffersson (2015) describes Köllinger (2022) that the measurement of the effect of access limitation was determined based on traffic count, survey, and interview, to assess the traffic volumes. Meanwhile, Thøgersen (2009) describes that evaluating the effect of mobility service in terms of picking random car owners in Copenhagen to receive a free public transport pass, was based on pre-intervention and post-intervention measurement in terms of telephone interviews. The assessment of the intervention effect of mobility service for employees according to Stumpel-Vos et al. (2013) was based on an online survey to collect data among the users. Inturri (2019) describes that the assessment of the intervention effect from mobility service for university was based on survey. Glotz-Richter (2016) describes that the assessment of the effect from shared mobility was derived from many quantitative and qualitative parameters such as monthly monitoring of the service, market analysis, surveys, and customer satisfaction report (CIVITAS 2013b). Buliung et al. (2011) describe the assessment of the effect from travel planning, which is based on survey data. ITL (2018) describes that the assessment of the effect seen from this intervention was based on the data collected through the application and further assessment based on survey and interviews.

2.5 Evaluation of intervention effect

The evaluation and comparison of intervention effect was provided to elaborate on the achieved effect from the intervention types to certain factors, such factors that can provide a better idea of the intervention success. Therefore, the intervention effect could be evaluated in terms of factors like location and the extent of effect to achieve car use reduction. However, there are multiple other aspects that could be considered when evaluating the effect, such as costs but that was not considered in this thesis. Evaluating the effect of the interventions provided a better understanding the importance of the intervention effect, rather than just comparing numbers that will not provide any useful information. The previous mentioned factors were selected based on their importance for the assessment of the obtained effect. For example, the location is important to consider due to the fact that it is easier to achieve higher effect in reducing car use in more populated cities where reaching travelers is easier. Other characteristics related to location, such as transport mode availability, the placement of attractive destinations, etc., has an impact on intervention effect. Therefore, evaluating the intervention location allows to determine if there are any disparities in the effect related to geographic. The extent of achieved effect is also central to the effect, because reducing 50% in certain road does not account for a whole city's traffic. That would rather be an incorrect way of presenting the share of car use reduction. Hence, determining the extent of intervention effect would elaborate the understanding of the intervention effect.

3 Frame of references

This chapter gives a brief explanation of what transportation is, and how and what can affect a travel choice. Furthermore, this chapter provides a description of intervention types and policy measures that affect travel behavior, and how such mean can be modeled.

3.1Transportation

Transport denotes the movement of resources and services from an origin to a destination by a given travel mode for a purpose, which is employed the concept of a "trip" (Fox 2002). Transportation arises due to the constant improvements in society, where transportation is a spatial interaction between economic and social activities. Immers and Stada (1998) explain that there are three types of changes that will impact the transportation system. First, "change in the demand for transport" which was explained to be all the changes related to population, income, and land-use. Second, referred to as "change in transport technology" which included new transport concepts like special lanes for certain travelers, information systems for travelers, road pricing, etc. Third, referred to as "change in value judgments" which means that people value time, environmental impact, and money differently when choosing travel mode.

Immers and Stada (1998) explain further that travel options for every user create the demand i.e., the option of traveling or not, the mode chosen for the travel, the route, and the time of departure. There are further factors that affect the transportation demand, for example, social and economic factors which will determine the level of economic activity, and the location of travelers (e.g., place of work, home etc.). Koppelman and Bhat (2006) agree and argue further that travel choice is also influenced by accessibility. For example, the extent of transport options from the origin to the destination and also the quality of the transport mode. As there are various means of transportation (e.g., car, bus, train, tram etc.) the decision maker will choose the most appropriate travel mode. However, there are natural limitations regarding the accessibility of travel modes for some travelers, one such is that high-speed rail will only exist if the origin and the destination are connected by the rail system. Koppelman and Bhat (2006) mean that every traveler does not have the same possibility of choosing different transport modes.

3.1.1 Sustainable and efficient passenger transport

Gudmundsson (2015) defines that a sustainable transportation system should enable people and society to meet their needs without harming the environment and human health. The sustainable transportation system should limit emissions, offer a choice of travel mode and operate efficiently. The author explains further the importance of achieving efficiency in transportation for reaching the greater perspective which is sustainable transportation. Sustainable transportation can be expressed in terms of environmentally friendly, safe, and affordable transportation, that could at the same time improve social equity, productivity of rural areas, and health. Correspondingly Schiller et al. (2018) express that to consider transportation to be sustainable then transportation needs to be considered as green (e.g., has a low impact on the

environment). Examples of such transportation are walking, cycling, public transport, carpooling, and car sharing.

Gudmundsson (2015) mentions that achieving sustainable transport requires efficiency, which is defined as the ability to do things well, without waste, and successfully. For instance, the ability to utilize time, space, vehicles, and fuel in the movement without any waste. The benefits of making the transportation system more efficient are for example to reduce emissions, congestion, infrastructure damage and increase safety, etc., which will benefit the involved stakeholders and society (Lumsden 2019). Hence, efficient transportation could be interpreted as a way of increasing the benefits for a certain organization, or in a bigger context efficient transportation leads to a sustainable society. However, efficiency in transportation does not refer to eliminating all travel for example, because there remain needed journeys for the development of society. Efficiency refers rather to reducing unnecessary journeys that do not benefit the individual and society with inefficient transportation modes, for example using the car to drive to the market for purchasing milk. Likewise, efficiency does not refer to removing all car travel, because that will lead to an increase in other means of transport demand causing congestion. This then will force the expansion of public transportation, leading to more greenhouse gas emissions, costs, resources utilizations, etc., to cover the demand.

Ogryzek et al. (2020) describe efficient transportation as minimizing the harmful impact of vehicles on the environment and promoting sustainable means of transport, such as public transport, cycling, walking, car sharing, etc. Witzell et al. (2021) agree on the definition of efficient transport and develop it by describing that efficient transport refers to replacing a part or entire trip that is made by car with cycle, walking, or public transport, where the chosen mode of transport would reduce emissions. While Aronsson and Huge Brodin (2006) interpretates transport efficiency as producing a service with less resource consumption and without reducing the service performance. There are various ways of defining efficient transport, therefore there is no unequivocal definition of what efficient transport is. In a similar manner, the measure of efficiency is expressed in different dimensions depending on the subject.

Schiller et al. (2018) describes that when people choose to leave their car at home and instead take a sustainable mode of transport, the effect is reduced congestion, pollution, greenhouse gas emissions, transportation costs etc. Gudmundsson (2015) states that to promote efficient transportation, an approach to policymaking is needed at local, regional, and global level. By this approach more people can be influenced to choose sustainable transport mode rather than cars.

3.1.2 Transport effect measure

Kuss et al. (2022) describe that there are different methods used to measure transport effect, which means that the study's used effect (i.e., car use reduction) could be measured in several ways. For example, vehicle kilometer travelled, traffic count, share of car journeys, travel time, queue length, reduced fuel consumption, public feedback, etc., are all measures that describe

car use reduction. Whereas vehicle kilometer travelled denotes the total kilometers travelled by car on road during a time period. Traffic count refers to counting the number of vehicles passing through a certain area. Share of car journeys denotes to the percentage of car travel as a transport mode of available modes. Travel time describes the time it takes to drive from a certain location to another. Queue length is similar to the pervious measure which refers to time on the road. Public feedback refers to surveys, where people can provide information about their travel mode choice. Reduced fuel consumption refers to measuring reduced car travel. However, even though these described measure account for car use reduction, yet they account for different dimensions of reducing the car use, and each everyone depends on different aspects. For example, vehicle kilometer travelled depend on how long the journeys are, while traffic count depend on how many cars pass a certain point and does not justify for traffic states outside the specified area. Furthermore, measuring the share of car journeys is dependent on how the total number is affected. Schiller et al. (2018) meant that these dimensions of reducing car use would rather be described as a quantitative assessment of the impact of an intervention, and do not need to be compared to each other due to the fact that different methods were used to obtained. However, a combination of different dimensions of car use reduction would be better fit to describe, for example, the effect of an intervention.

Two general methods that can be used to measure the transport effect and are ex-post and exante. To understand what the difference between an ex-post and an ex-ante studies are, a definition of both is needed. Fleurbaey and Peragine (2012) expresses that the ex-ante perspective is about evaluating scenarios through the circumstances and the outcome possibilities for different levels. Meanwhile, the ex-post perspective describes the actual level of effort when evaluating uneven accomplishments. Henceforth, ex-post studies express the actual outcome of an intervention that has taken place, while ex-ante expresses the outcome of intervention from models based on simulations and predictions. The main difference between the two perspectives is that ex-ante describes circumstances that are determined by forecast and the use of models, while ex-post states the outcome of intervention from real calculations based on, among other methods, observations. In this framework the meaning of ex-post is looking at numerical results of an action after it has occurred and exploit the likelihood of future returns. Therefore, it is important to consider the baseline situation before the intervention, and the values after the intervention implementation to determine the effect. Meanwhile, ex-ante looks at financial and other results through forecasting or predictions of future events, where models are commonly used tools.

Furthermore, Graham-Rowe et al. (2011) describes that there are different methods to evaluate the effect of interventions for ex-post studies. Three methods often utilized to evaluate the intervention effect are experimental design, quasi-experimental design, and cohort-analytic. First, experimental design, which describes collecting data through randomized controlled trails utilizing people. Second, quasi-experimental design, which denotes utilizing matched control groups that are not randomly allocated. Third, cohort-analytic, which refers to comparing a group of people before and after they have experienced an intervention. The similarity between many methods is the common examination of mean shifts, changes in trend, and variability. Examining the mean shifts denote attending to stability of baseline data, controlling overlap

between different phases. The changes in trends, as well as variability data refers to evaluating trends and data within the phase and adjacent phases. In addition, collected data in each phase is compared to each other to evaluate the overall data and pattern.

Meanwhile, Graham-Rowe et al. (2011) expresses that it is common to use indicators to evaluate the effect of the intervention in ex-ante studies, which is based on an extensive data collection (i.e., traffic flows, travel times, travel patterns, etc.). Indicators provided from the model outcome could be distance travelled, number of trips made by car or car trip frequency, time consumed in a car, and measures of modal shift. Further evaluation methods of intervention effects could be using multivariate analysis of covariance, linear regression analyses, conditional logistic regression, structural equation model, mixed logit models, etc.

3.1.3 Efficient passenger transport measure

Gudmundsson (2015) describes that the importance besides the approach choice lies on measuring the progress of transport efficiency with indicators. Indicators that express the effect of transport mode, which could be congestion, national security, safety, transportation patterns and traffic flows. Congestion refers to a situation where a place is too overcrowded. National security refers to the dependency on oil usage. Furthermore, safety refers to a decrease in traffic accidents, achieved through reduced vehicles on the road. The transportation patterns refer to the share of transport mode usage, the share of choosing public transport or the car as a transport mode. The traffic flows denote the number of vehicles on the road. In addition, there are measures related to vehicle efficiency, such as the vehicle's fuel consumption per kilometer.

Gudmundsson (2015) describes further about transport efficiency, for example, the filling rate, which refers to the number of utilized seats in the vehicle when driving. Jonsson and Mattson (2014) describe the filling rate as the utilized share of the available loading volume, measured in the percentage of goods transport. To develop this meaning in passenger transport then it would mean the utilized share of available seats. In other context the filling rate could be described as load volume and load weight which is more accurate in freight transport, where the volume and weight of the vehicle is measured. The filling rate is important to measure during the trip because a trip with 100% filling rate to a location and empty on the way back will give a total filling rate of 50%. Considering this in passenger transport, can the filling rate enhance Lumsden (2019) meaning of utilizing the time, space, vehicle and fuel in the movement. For instance, car-sharing could increase the filling rate from 40% to 60% by sharing a five-seat vehicle with the driver, and another traveler, given 3 utilized seats out of 5.

Robertson et al. (2015) argues that the efficiency of a transport mode could be measured by carbon dioxide emissions, which is measured by the amount emissions per kilometer, emissions per unit transported, and emissions per distance or number of trips. The measure *emissions per kilometer*, is appropriate to use when considering technology and vehicle change due to the fact that this measure considers the distance the vehicle drives. Meanwhile, *emissions per unit transported*, is appropriate to use when considering mode switch for passenger transport as this measure considers the amount transported. *Emissions per distance or number of trips*, this

measure is appropriate when considering project that aim to reduce the distances or number of trips.

Chen et al. (2022) argues that measuring carbon dioxide is important when evaluating efficient passenger transport due to the fact that vehicles exhausts pollutions. The author described further that burning fossil fuel is one of the main contributions to climate change and affects human health. Hence, transportation is not the only contributing element in increasing carbon dioxide emissions, other activities like deforestation, degradation of soils and land clearing for agriculture contribute to carbon dioxide emissions as well. Similarly, car-related improvements (i.e., improving engine, car model etc.), improvements in infrastructure, the way of driving, and fuel type could affect the amount of carbon dioxide emissions. Arvidsson et al. (2013) enlightens about how eco-driving (i.e., maintaining suitable speed, right tire pressure etc.) could reduce fuel consumption and reduce environmental impact by reduced emissions.

Comparatively, a measure that could be utilized for evaluating car use reduction is the reduced share of car use as a transport mode (Kuss et al. 2022). This measure allows to understand the magnitude of a change in transport mode. The reduced share of car use is measured in percentages, where the outcome indicates the effect of an intervention or transport efficiency. For instance, the use of public transport decreases the share of car use and at the same time contributes to reduced emissions in the cities.

3.2 Traffic models

Immers and Stad (1998) expresses that traffic models are essential tools for planning and operating interventions, traffic, behavior etc. Through modeling a traffic system, it creates knowledge in understanding and predicting traffic. For instance, modelling enables understanding of the aggregated phenomena occurring from complex interactions in traffic, and to predict future behavior of traffic system. Hence, it is important to estimate the consequences of, for example, an intervention to estimate the profit of a solution to a problem. Thus, a traffic model allows for a systematic comparison between alternatives. Treiber and Kesting (2013) describe that traffic models could be macroscopic where larger amount of traffic is studied, or microscopic where smaller amount of traffic is studied. In the microscopic model the traffic flows are studied on the single vehicle level presented in a dynamic simulation (time-dependent), where properties such as position and speed are captured. Meanwhile, in the macroscopic model the traffic data is aggregated over a fixed time interval given by static simulation (flows are constant over a time period).

Forthwith, Immers and Stad (1998) expresses that there are different types of models that could be utilized to model the consequences of the interventions. Example of such models are demand model, supply model, equilibrium model and impact model. The demand models define the size of demand given by a function of the service of level, which is considered in many sub models such as, production (number of trips created per zone), attraction model (expect the number of trips attracted to a zone), distribution model and mode choice model. The supply model defines

the level of service as a function of network load affected by the measures to be taken. This model type is appropriate to describe the relationship of time, cost and flow on a road section. Furthermore, the equilibrium models describe that every traveler chooses a route with the least travel time, and when such routes are found between every pair of origin and destination then the equilibrium condition is obtained. The impact models indicate environmental impacts, social effects, safety, etc., that are included in the provision of enhanced service level.

Immers and Stad (1998) states that a more commonly used model for real transport calculations is the so-called traditional traffic demand model. This model consists of sub-models, like production/attraction model, distribution/mode choice model, assignment model. The production model defines the number of trips that are generated in a zone as a function of characteristics of both personal and environmental. The number of trips produced is not affected by the destination of these journeys, instead they are specified as to point of time (i.e., peak-off or peak). Furthermore, a zone does also attract trips. The attraction model denotes the total number of attractive trips, where the attraction is not bound to the origin, given by a function of characteristics (i.e., employment rate, retail area etc.). The distribution model distributes the number of trips originated in zone i over destinations j, obtained through the production model. The trips provided from the attraction model with zone j as the desired destination, are spread over the point of origin i. The relationship between the points of origin and destination is expressed as a function of the distance between i and j. The model provides one or several origin-destination tables (OD-matrix). The OD-matrix presents the origins in rows and destination in columns, and the entries represent the number of journeys from an origin and a destination.

Furthermore, Immers and Stad (1998) describes that the mode choice model calculates the mode choice for the travelers, given by a function of the transport modes and personal characteristics. This results in a so-called modal split, the calculated distribution of transport modes. There are different routes from an origin to a destination for all types of transport modes. The traffic assignment model (which also employed the concept of a route choice model) assigns the routes between the origins and destination according to characteristics of the routes, one such characteristic could be the distance. The assignment is completed individually for each transportation mode, where the results give the traffic flows on the links of the network that also define the duration times. The duration time is compared with those used in the distribution/mode choice model, to decide if an iteration step is necessary (i.e., go back to distribution/transport mode and start again). Figure 1 illustrates the sub-models that consist of the traditional traffic demand model.

Immers and Stad (1998) describes that in view of the five previously described models above a parallel is found with the traditional traffic demand model. The demand models emerge in the traditional traffic demand sub-models, like in production/attraction model, distribution model and mode choice model. The supply models are imitated in the time-loss functions that indicate the relation between travel cost or time and the flow rate. The equilibrium models are utilized in the assignment model to determine the routes, which describes the routes in a network by considering the traffic flows themselves affect the travel times on the links. The impact models

calculate the effect of traffic, for instance, effects such as air pollution, safety, and noise could be estimated by the impact models.

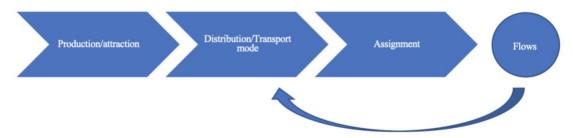


Figure 1: The traditional traffic demand model. Inspired by (Immers and Stad 1998)

3.2.1 Behavioral theories of transport mode choice

Koppelman and Bhat (2006) describe that people make decisions constantly, where the majority of the decisions follow a process the individual use to reach the choice. For instance, a choice regarding college, career, travel mode, house location, and destination. However, a usual characteristic that applies when studying choice is that people have different evaluations (e.g., the value attributes are different). The authors elaborate further by explaining that two people would have different sets of mode to choose from because these two people has different income and residential location where the attributes of travel time, and travel cost will be weighed differently. There are also other factors influencing the choice, such example is legal regulations (e.g., a person without a driving license cannot drive a car alone). However, the value indicator for an individual, the so-called utility, could not be measured, instead, could the characteristics of the alternative be measured. This could be considered as a chance variable, that a person is choosing an alternative (Immers and Stad 1998). Thus, many choice models generate the probability of choosing an alternative (Koppelman and Bhat 2006). Immers and Stad (1998) mention that the logit model (or logistic model) is a commonly used model to calculate the probability of an event happening, or more specific for mode choice is the probability of choosing a transport mode out of a all modes. This model utilizes case-specific data, referring to independent variables that use a different value for each case. The authors explain the usage of nested logit model to enable dependence through the responses, this is obtained through grouping alternatives into nests. Hence, the difference is that a nested logit model allows to accommodate varying interdependence (i.e., similarity) between subsets of options in a choice set. However, before defining the logit model in mathematical terms, a definition of the utility is needed. Calculating the utility for a specific individual is an average allowing more room for variation. The utility for alternative a is expressed as a stochastic variable U_a , which contains a systematic (non-stochastic) component V_a, which represents observed portion of utility, and stochastic component ea also called the error term. This error term uses a probability distribution with an expected mean value set to be equal to zero, which indicates that utility U_a has a probability distribution according to V_a .

$$U_a = V_a + \varepsilon_a$$

Immers and Stad (1998) expresses that the decision maker will maximize the utility of the alternative, while Koppelman and Bhat (2006) explain that utility maximizing includes also measures like uncertainty. For example, if the travel time for the bus is not the same every time (e.g., no delays), then the utility of this transportation mode will be influenced by travel time and measures of uncertainty. However, the traveler try to maximize the utility, expressing this mathematically as the probability Pr(a) of a person choosing an alternative a is equal to the probability that the utility of alternative a is greater than all other alternatives.

$$Pr(a) = Pr(U_a > U_k) K \neq a$$

Koppelman and Bhat (2006) explain further about "trade-offs" which occur when deciding on an alternative, one such could be about choosing an expensive mode of transportations because the travel time is lower than the cheap travel mode. Thus, the observable portion of utility could be expressed as a function of attributes of alternative a and characteristics of the decision maker. The systematic portion of utility $V_{t,a}$ for alternative a and individual t. The portion of utility related to alternative attributes is $V(X_a)$, and $V(S_t, X_a)$ describes the portion of utility from the interaction between attributes of alternative a and characteristics of individual t.

$$V_{t,a} = V(S_t) + V(X_a) + V(S_t, X_a)$$

The definition of logit model is defined as below, where μ refers to the dispersion given an arbitrary value (1 or 0).

$$\Pr(a) = \frac{e^{\mu V_a}}{\sum_{k=1}^K e^{\mu V_k}}$$

Furthermore, there is a general framework for decision making (e.g., travel behavior), which includes environmental factors, socio-demographic and situational factors (Bamberg et al. 2011). The influence on travel choice starts by implementing a policy measure that will affect the traveler's perception of objective environment. Furthermore, will the perception of an objective environment affect trip attributes such as purpose, departure times, travel times, and monetary costs. Additional factors such as socio-demographic and situational factors which refer to family structure, income, employment, weather, time pressure, weekday, and time of the day, will affect the trip attributes. However, the socio-demographic and situational factors will also affect decision making. Further, the decision-making will result in travel choice which then will result in the system effect.

3.3.1 Behavioural change

Bamberg et al. (2011) states, to achieve a behavioral change such as changing the choice of transport mode, then a theory is needed: the theory of planned behavior and the norm-activation theory. According to the theory of planned behavior, subjective norms, attitudes, perceived behavioral control, and subjective norms influence a person's behavioral goals. The norm-

activation theory describes that moral norms control individuals believe and behavior. These two theories are the underlying base for Bamberg's et al. (2011) four stages of behavioral change, which includes a pre-decisional stage, pre- actional stage, actional stage, and post-actional stage, which are briefly described in the following. Prochaska and DiClemente (1982) describe that voluntarily behavior change is time-ordered sequence of transition stages, where the stages reflect the motivational and cognitive obstacles humans face when trying to change the behavior.

In the first, pre-decisional stage, describes Bamberg et al. (2011) it is assumed that people become conscious of consequences that are caused of their current behavior, this then leads to acceptance and taking personal responsibility for the consequences of the action, a state of self-awareness. A part of self-awareness is comparing current behavior with personal standards, such as reflection on caring for the environment. This comparison may elicit a negative effect, in terms of anxiety or guilt, that increases the need to follow personal standards (personal norms). For instance, fear and social dissatisfaction trigger personal norms. At the same time, perceived social norms affect personal norms, such as expectations of what people might expect from one. However, when one becomes in line with personal norms, it activates positive feelings such as pride and satisfaction, this will provide incentive to form a goal intention.

In the second, pre-actional stage, Bamberg et al. (2011) show that the assumption of goal intention is based on two factors that affect the creation of behavioral intention. These two factors are formation of attitude toward behavioral alternatives and perceived behavioral control over behavioral strategies, which is the personal consequences related to the perceived difficulty of performing them (perceived behavioral control).

In the third, actional stage, expresses Bamberg et al. (2011) is when the plan for implementation of the behavioral intention occurs, which refers to action planning, coping planning, and maintenance of self-efficacy. The action planning denotes the order of actions needed to precede the new behavior implementation. Coping planning denotes preparation for handling challenges that will hinder to perform of the new intended behavior. Coping self-efficacy refers to the self-confidence of remaining with difficult behavior.

The fourth, post-actional stage, describes Bamberg et al. (2011) as sustaining the new applied behavior that has been implemented successfully.

3.4 Transport intervention

Transport interventions aim to facilitate sustainable travel behavior and affect travel perception throughout influencing travel choice (Bamberg et al. 2011). Fan and Chen (2020) describes that transport intervention is considered to be soft policy measure, hard policy measure or a combination of both, where the soft policy measure denote the use of techniques of information persuasion and dissemination to influence travelers to choose sustainable travel mode, and the hard policy measure include for instance, improvement of infrastructure for public transport.

However, the purpose of both interventions is to facilitate travel mode choice change, departure time, etc., which in turn affects the travel choice. Semenescu et al. (2020) declares that a soft policy measure could reduce around 5% of traffic, while a combination of soft and hard could result in 10-15% of traffic reduction on a national level. Along the same line describes Möser and Bamber (2007) that in the last decades local authorities have explored the implementation of hard policy measures such as physical improvements to transport infrastructure, control of road space, and changes in prices. Despite these hard Policy measures the desired share of reduced car use was not obtained.

The relationship between hard and soft policy measure and the behavior theories expressed by Bamberg et al. (2011), is that hard transport policy measure adjusts the environmental factors, that travelers may change their travel mode if the environment is changed. For example, if a lane is blocked, which would cause a delay if the travel were done by car, but if the travel is done by other transport mode, then the delay could be avoided. Meanwhile, if soft transport policy measures were used then that would mean influencing the travelers by altering their perceptions of the consequences related to the different travel modes. Hence, lead to empower the decision maker to choose an efficient travel mode, and minimize the consequences related to the transport mode.

Furthermore, Fan and Chen (2020) express four different intervention categories: physical change, legal policies, economic policies, information and education. These categories can describe the intervention, where some can be a combination of two or more categories. These intervention categories can be further described as soft and hard policy measures. For instance, physical change and economic policies can be both soft and hard policy measures. While legal policies are mainly described as hard policy measure. Whereas the information and education category is described to be a soft policy measure.

Fan and Chen (2020) describes that the hard policy measure within the category of physical change could be related to interventions that consider vehicles with high occupancy, adding speed ramps and removing parking places. Meanwhile, the soft policy measure considers intervention that is about public transport service improvement as well as for walking and cycling environment, and shared mobility (e.g., shared minibus). Leading those physical changes emphases, the attractiveness of another transport mode. The authors describe further that hard policy measures within the category of legal policies can be for example, license-plate restriction, access limitation, parking limitations, and decreasing the speed. Whereas the desired effect of legal policies is that travelers will comply with these policies, and in the long-term lead to social norms change. Thereupon, hard policy measures within the category of economic policies can for example be, congestion pricing, taxation of car fuel etc. Meanwhile, the soft policy measure relates to offering travelers discounted travel, and fare-free public transport service. For the purpose of making car use as travel mode more expensive. The assumption is that people will choose a cheaper travel mode dependent on cost-benefit analyses. Furthermore, the authors mentions that soft policy measure within the category of information and education is based on sharing information about the negative and the positive effects of car use, giving feedback about the environmental impact, promoting alternative travel modes, and personalized marketing about travel alternatives. These measures focus on travelers' attitude, perceptions, values, beliefs, and personal norms.

Hrejla and Rye (2022) state that regardless of the type of intervention, they will have a pushor pull effect or a combination. A push approach will push travelers to choose other modes of transportation, and a pull approach will influence people to walk, cycle, and public transport. Kuss et al. (2022) discuss that the push-approach is likely to use charges, fees, taxes, regulations, etc., to drive people toward other modes of transport, whereas the pull approach is likely to use monetary incentives to influence people to choose low-carbon or non-motorized modes of transportation. Hrejla and Rye (2022) express further that through integrated transport and land use planning, a pull effect can be achieved, where people will decrease the need of cars and make it easier to cycle and walk for short-distance trips.

3.4.1 Charging-based Intervention

Börjesson and Kristoffersson (2015) describe that the implementation of road user charging aim to reduce congestion and affect the travel mode choice, at a regional level. Pyddoke (2023) describes that car users are rather underpriced, as cost related to car usage is not high enough to make the car user to consider other transport modes. Therefore, a charging based intervention aim at charging vehicles in the network, but the cost has to be carefully determined in order for this intervention to be successful. Because a too low cost will not lead to reduced congestion and achieve a travel mode switch, while too high cost will result in negative economic impact. The importance of an efficient charging scheme is that being able to use the revenues to fund the charging scheme itself and also improve the road quality. Hence, the charging schemes should not be perceived as "tax". Cottingham et al. (2007) describes that the charging could be implemented through satellite-based positioning which captures the traveled distance of a vehicle through a receiver; cellular network which refers to capturing the location of a vehicle through smart devices such as smartphones; automatic number plate recognition uses sensors and cameras to discover vehicles when passing a zone (e.g., entrance and exit points); dedicated short-range communication uses tag and beacon technology to detect and identify vehicles; microwave & infrared refers to detecting vehicles through placing microwave tag on the vehicle that gets detected when passing a gantry.

Cottingham et al. (2007) describes further seven types of charging. First, is the point charging, which refers to vehicles being charged when passing a given point (e.g., toll booth). Second, is the cordon charging which denotes vehicle being charged when driving through a border or cordon. Third, is the zone charging which refers to vehicles being charged for driving in or out of a zone. Fourth, is the distance-based charging which signifies that the vehicle is charged permile traveled. Fifth, is the time-based charging that symbolizes the vehicle is charged for travelling during a certain time. Sixth, is the time- and distance-based charging which uses permile rate with time variation. Seventh is the parking charges, which refers to charging for parking.

Litman (2021) describes that charging-based interventions involve parking charges, example of such is street wise charging schemes, site-based solutions, and paid parking zones. The author expressed that the streetwise schemes and paid parking zones use different charging models, example of such is residential parking, visitor parking, or company- linked parking. This type of measure addresses different users within the same area. Meanwhile, the site-related parking charges are associated with companies, hospitals, schools or universities and suggest differentiating between permanent users like employees, and guests. This type of measure pushes organizations to finance alternatives for car trips, such as sustainable transportation (i.e., public transport).

3.4.2 Access limitation-based intervention

Kuss et al. (2022) describes that access limitation was used for vehicles to not be able to drive through a certain zone during specific hours. The access limitation could be used for example in low emission zones, where only certain vehicles are allowed or in some cases no motorized vehicles are allowed. Vehicles that are more heavily polluting are usually those that are not allowed to enter low emission zones. Such limitation could be formulated in a criteria where motorized vehicles or the vehicle fuel used (i.e., petrol- and diesel-driven vehicles). Further access limitation could involve heavy vehicles (e.g., busses, trucks, etc.) to not enter city areas to protect infrastructure. Such regulation could be formulated in a criteria about the allowed tonnage. Hence, access limitations could be used for different vehicle types (i.e., cars, motorbikes, vans etc.).

3.4.3 Parking management-based intervention

Litman (2021) describes parking management includes different measures regarding parking, such as parking limitation and removal or reallocation of parking spaces. Parking limitation could be associated with allowed parking time, this will limit the maximum duration of parking. Those limitations are allocated in shopping areas, city centers and transport hubs. This parking limitation decreases the need of more parking spaces to cover the need. This measure could be also combined with parking charges, where the users are allowed to park for a certain amount of time for a certain cost.

Furthermore, Litman (2021) defines that the removal or reallocating of parking spaces aims to reuse the space for sustainable transport or for non-transport users. The reallocation of parking spaces aims to reallocate parking spaces toward the border of the city to encourage more people to plan their travel or switch to public transport. The removal of parking could apply for on street and off-street parking, where the traffic flow is shifted to other transportation modes.

3.4.4 Mobility service-based intervention

Stumpel-Vos et al. (2013) describes mobility service as an innovative technology- enabled service, which includes multiple approaches. Mobility service signifies providing service

through a joint digital channel, which lets its users plan, book, and pay for their single mobility service. The aim of mobility service is to shift away from personally owned transportation modes and lean toward transportations modes that are provided as a service. The providers of such transportation means are a combination of public and private transportation providers by a unified access, which creates as well as manages the trip. The purpose of mobility service is to provide mobility alternatives based on the traveler's needs, where the traveler can choose to pay per trip or pay a monthly fee, making it easier to choose other transport modes than car. Hence, provided all the mobility alternatives traveler then can choose their preferred trip based on time, cost and convenience. The author expresses further that mobility service could be provided for employees, which could include shuttle bus used as a transport mode between transfer locations such as public transport hubs, park and ride locations, and train stations and the local companies. Inturri (2019) describes that mobility service can be provided for students, which could include bus rapid transit line that served campus site and outside the city center, enabling students and teachers to take the bus instead of car. Thøgersen (2009) expresses mobility service could mean offering employees public transport pass, this will enable employees to shift away from single car travel. This intervention type decreases the number of single car travel through focusing on single mobility service, leading to fewer single cars on the road.

3.4.5 Shared mobility-based intervention

Glotz-Richter (2016) defines that shared mobility aims to maximize the utilization of mobility resources and be an alternative transport. The author argues that car-ownership could be decreased through car sharing (also called carpooling). Car sharing could be applied in three different approaches, where all three approaches denote car rental (car-club). First, is the station-based car sharing that included reserving cars through electric access at stations and that had to be returned to the same station. This approach covers a wide range of car selection that could meet different needs. Second, is the one-way car sharing that could be expressed as cars were accessed through smart phone reservation that were found on public streets. This approach enables customers to return the car within a defined area, and not exactly to the same place as it was picked up. Third, is peer-to-peer car sharing that denotes sharing cars that are privately owned. Privately owned cars were announced as available on the internet platforms (i.e., Tamyca in Germany) or within cooperative systems (Autopia in Flanders, Belgium).

Furthermore, shared mobility could also be considered sharing micromobility means of transport, such as bike, electric bikes and electric scooters sharing (Shaheen et al. 2018). Bikes and electric bikes and scooters are rented to be utilized for shorter trips. This measure uses the same technique as the three approaches from car sharing (i.e., accessing the bikes could be carried out through applications on smart phones for on-way sharing). This measure enables travelers to use bikes/electric bikes to and from public transport for longer trips.

Shared mobility could be perceived to be similar to mobility service (Glotz-Richter 2016; Stumpel-Vos et al. 2013). However, the difference is that shared mobility focuses on

maximizing the filling rate of transport means, providing joint transport modes for travelers. This intervention type does initially not include the distance from home to the car rental station, as it only considers the journey when the car rental has started. Meanwhile, mobility service focuses on the single mobility providing a digital channel for travelers to plan, book and pay for their trips. Therefore, shared mobility refers to the shared use of a vehicle, such as carpooling or bike sharing. While mobility service refers to a platform that integrates various modes of transportation, such as public transit, ride-sharing, and bike sharing, into a single service considering the whole journey.

3.4.6 Travel planning-based intervention

Kuss et al. (2022) describes several travel planning measures that included workplace, school, university, and personalized travel planning. This intervention focuses on changing commuting behavior, which is achieved through various targeted measures that encourage and support the traveler to shift from passive (e.g., car) to active transport (e.g., walking or cycling). A measure could, for example, be installing sidewalks, bicycle lanes, etc., to increase accessibility. While other measures could be awareness campaigns to educate and remind people of all ages to choose sustainable transportation. However, in the end the result of this intervention type is governed by traveler's behavior, and their response of the implemented measure. Therefore, the mutual aim of using travel planning is to encourage all types of travelers to shift to sustainable transport modes, encouraging travelers to plan their trip. The concept of travel planning in an organization could be to provide a strategy for the organization, to decrease the travel impacts through influencing the travel behavior. Influencing incentives such as offering shuttle buses, discounted passes for public transport, and improvements of infrastructure for bikes could encourage employees to choose un-motorized transport modes. Other measures could be considering departure time, trying to avoid peak hours, to reduce congestion. All the previousmentioned incentives as part of travel planning could be implemented in workplaces, schools, and universities. While personalized travel planning involves personal travel suggestions to reconsider the transport mode choice, route, time of departure, etc. Additionally, could discounted public transport (i.e., discounted transport for certain time and weekday) promotes people to choose sustainable transport and avoid peak hours for travel.

3.4.7 Similarities and differences between intervention types

There are multiple similarities and differences in the presented intervention types, as well as advantages and disadvantages. Table 1 presents a summary of the intervention types, giving an idea of how different intervention types are similar and different from each other.

Table 1: Similarities and differences between intervention types.

Interven	Description	Implementa	Intervention	Extent of	Advantage and Disadvantage
tion type	•	tion time	category	effect	5

Charging	Use charging methods to target less important car trips. Decrease the number of trips into the city center by car.	Mid/Long	Physical change, Economic policies	Regional/ local	+Infrastructure improvements through profit +Decreases travel through city boarders -Does not affect time-sensitive travelers -Costly/require maintenance
Parking managem ent	Use parking limitation and removal or reallocation of parking spaces to decrease all car travel.	Mid	Physical change, Economic policies	Regional	+Reuse the land +Decreases car travels into city center -Requires a lot of planning for it to be efficienct - Require multiple stakeholders from authorities
Access limitation	Use legal policies to limit all car travel into city center/ old town, and certain zones. Decrease emissions in the zones.	Mid	Legal policies, Physical change	Local	 + Preserve zones from increased emissions +Decreases the noise level - Requires a lot of planning for it to be efficient -Require multiple stakeholders from authorities
Mobility service	Provide mobility alternatives based on the traveler's need to decrease the single car travel and car ownership.	Mid/Long	Economic policies, Physical change, Information & Education	Regional	+ Single mobility service +Decreases car ownership -Require multiple stakeholder to be cost-efficient - Require maintenance of the mobility means
Shared mobility	Use of shared transport modes. Decreasing car ownership and single car travel.	Mid/Long	Physical change, Information & Education	Regional	+ Reduce the number of cars on road +Maximizing filling rate -Less convenient - Require maintenance of the mobility means
Travel planning	Helping people to plan their trip, in terms of using different travel mode, avoiding peak periods, etc.	Short	Physical change, Information & Education	Local	+Encourage all travelers +Sustainable thinking for young travelers -Is not as effectual in long term -The effect does not reach widely
App for Sustainab le Mobility	Using application to use un-motorized transport modes, through awarding systems.	Short	Information & Education, Economic policies	Local	+ Encourage all travelers +popular among younger travelers - Not as effectual in long term - The application does not reach older people

3.5 Transport intervention efficiency

Coelli (2003) describes intervention efficiency as the effectiveness and cost-effectiveness of actions taken to encourage people to use alternative modes of transportation such as walking, cycling, public transport or car sharing, and reduce their reliance on cars. Intervention efficiency is often considered as a core responsibility allocated to decision makers, regulators (i.e.,

government agencies), etc., when implementing an intervention. Hence, intervention efficiency is an important aspect to consider when evaluating different interventions. However, intervention efficiency could be measured in regard to many aspects and be set in relation to the intervention effect, for example cost, time, reduction in car trips, decrease in carbon emissions, increase in physical activity levels, and economic benefits such as reduced expenditure on transportation, healthcare and environmental impacts. The author expresses that each aspect of the intervention efficiency evaluation could be divided up into several dimensions. For instance, if considering only the cost, then it could be divided into agency costs, user costs, life cycle cost impact of agency and users. The agency costs consider the construction costs, such as labor, equipment, materials, contract engineering, etc. The user cost denotes work zone user costs, such as delay costs, crash costs, fuel consumption, etc. Whereas the agency life cycle costs impact denotes the maintenance expenditure over the implementation time span, interest rate, maintenance costs, etc. The user life cycle costs impact refers to the incurred costs by the user, saved costs for the user due to improved infrastructure conditions. Henceforth, it is of importance to consider the intervention efficiency; for example, an intervention that takes a long time to implement, with high costs and high energy consumption but that has low effect, then the intervention is perceived as not being efficient. Meanwhile, an intervention with high effect and reasonable time, cost and energy consumption is perceived as efficient. Hence, measuring intervention efficiency is an appropriate way to compare different interventions based on their presentation.

4 Literature search outcomes

This chapter will give a description of the literature finding based on the Method.

4.1 Results from systematic literature and document review

The first step in the systematic literature review started by forming a criterion to determine which literature will be included and to assess the quality of the literature. Therefore, the criteria in Table 2 were created, and additional specifications will be presented below. Criteria number one state the year of publication, to ensure that the literature is current to infrastructure, society, etc. Criteria number two is relevant to include due to the subject of this thesis. This will also reduce irrelevant topics that also consider other types of interventions (i.e., that do not reduce car use). Criteria number three is necessary to include because the results from the literature should be reliable, in terms of measurable results or based on model simulation/analysis outcome. Hence, data samples, calculations for the derived results, model output/input etc., should be presented. Henceforth, literature should not include assumptions of intervention effect, and that is the main reason to include this criterion. Criteria number four is used to collect reliable output, where the sample size of data reflects the reliability of the output. This criteria states that the data samples should be motivated by the author/authors in the literature to argue for the reliability in the results. Criteria number five describes that the literature selections was based on the location of the interventions, such that different interventions should not only be placed in capital cities but also in smaller cities. Through specifying the location of the intervention, an equitable analysis of the intervention effect will be provided because similar interventions located in different cities with different sizes will provide different results. Criteria number six describes that interventions should regard car use reduction in the city center. Criteria number seven excludes studies that include a single unsuccessful intervention to reduce the share of car use. Criteria number eight the literature shall also state the effect of the intervention in percent of car use reduction.

Table 2: Criteria for literature.

Criteria (The article should):

- 1. Be published the year 2005 and after
- 2. Include an intervention that reduce car use
- 3. Be based on quantified evidence of the result demonstration (i.e., methodological description of data generation, calculations, outcome of calculations, model calculations, model outcome in numerical form, etc.)
- 4. Be based on reliable data size (e.g., sufficient sample size for the car use group), where the data size should be further motivated by the author/authors for reliability
- 5. Intervention types should not only be placed in capital cities but also in smaller cities
- 6. Contain intervention type that focus on reducing car use in the city center
- 7. Should not include a single unsuccessful intervention to reduce the share of car use
- 8. Present the effect of the intervention in percent of car use reduction

Going forward, the main search terms used to find the literature are emission, intervention,

policies, sustainable travel, efficient travel, car use, restriction, ex-ante, ex-post, model, cities, estimation, prediction and reduction. However, there have been some inflections of these terms, for instance, the word *restriction* could be substituted for *limitation* etc., a small part of all used search terms and number of hits in the selected databases is shown in Table 3. The focus of these search terms are aspects of reducing car use with policy interventions obtained through ex-post and ex-ante studies.

Furthermore, the search in Scopus and ScienceDirect was refined according to specified year of publication (from 2005 and above) limit, to match the criteria in line one. The criteria were used further to review relevant literature for this study through scanning the titles, abstracts, methods, and results to the criteria. The majority of scanned and yet not included articles did not meet the criteria in Table 2. Such that some articles studied very similar intervention located near each other, while other articles did not have reliable data in terms of size of data sample. Meanwhile, other articles could have fulfilled criteria one to seven but missed criteria eight, which resulted in that the study was excluded. Overall, criteria number three and four is a little harder to examine in some articles, because some articles provide a clear presentation of calculations and data size. While, other articles provide some limited information about the calculations and data size, which means that the assessment of whether these criteria are met depends a little on how clear information is provided in the articles. Meanwhile, the rest of the criteria are easier to assess of whether they are met or not, such as scanning for effect of the intervention in percent, etc. A small section of all used search terms and the number of hits from the systematic document review presented are in Table 3. This search also relied on a filter that was available in Elits database to obtain more accurate results, and to exclude documents that are not relevant to the search term (filter).

Table 3: Search terms and number of hits from systematic document review.

Database	Search term	Number of hits
ScienceDirect	Parking policies to reduce car use	18 549
	Car use reduction AND estimation	43 288
	Car restrictive policy to car reduce	9 528
	Intervention for car use reduction	62 993
Scopus	Parking policies to reduce car use	179
	Car use reduction AND estimation	702
	Car restrictive policy to car reduce	24
	Intervention for car use reduction	664
CIVITAS Resource Library	Reduce car use	8
	Vehicle access limitation	11
	Parking restriction	75
CIVITAS Mobility Solutions	Reduce car use	324
	Mobility service	949
	Travel planning	286
Eltis	Filter	
	Urban vehicle access regulations	25
	Urban mobility planning	
	Mobility management	41

The steps conducted for the systematic literature and document review are shown in Figure 2.

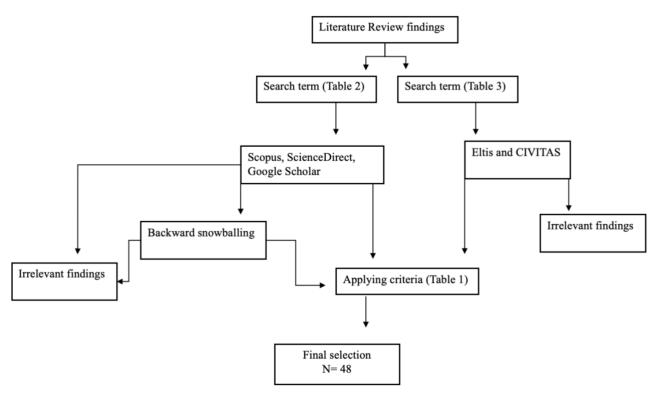


Figure 2:Steps used for the systematic literature and document revie.

4.2 Presentation of selected literature

The interventions identified in the literature search are presented in Table 4, including both the ex-post and ex-ante studies. Furthermore, the interventions are categorized in 12 intervention types: congestion charging, parking charging, access limitation, parking management, mobility service for University, mobility service for commuters, shared mobility, school travel planning, workplace travel planning, University travel planning, personalized travel planning, and app for sustainable mobility competition. Additionally, the categorization is based on ex-ante or expost studies, intervention category, policy measure and intervention approach derived from 48 city cases.

Table 4: Interventions shown to reduce car use, that are identified from the selected scientific articles and case documents. The interventions are grouped in 12 intervention types, which are further grouped in intervention category, policy measure and intervention approach derived from 48 different city cases presenting both ex-ante and ex-post studies.

Intervention type	Ex-ante/ Ex-post	Intervention category	Policy measure	Intervent ion approach	Measure type/ Model type	City	Car use reduction [%]	Stakeholders Involved	References
[1] Congestion charging	Ex-post	Physical change, Economic policies	Hard	Push &Pull	Charges dependent on time- and day for cars in defined zones (i.e., city borders)	[1]Stockholm [2]Gothenburg [3]London [4]Milan	[1]22% [2]12% [3]33% [4]31%	Civil Society, Public Transport Provider, National Government, Regional	[1](Eliasson et al. 2013) [2](Börjesson and Kristoffersson 2015) [3](Metz 2018)
	Ex-post	Physical change, Economic policies	Hard	Pull	Improvements in public transport from the revenues of congestion charging	[5]Singapore	[5]15%	Government	[4](Beria 2016) [5](Glaister and Graham 2006)
	Ex-ante	Physical change, Economic policies	Hard	Push &Pull	Nested logit demand model linked to the network assignment model EMME/2	[6]Stockholm	[6]16%	Not specified	[6](Eliasson et al. 2013)
	Ex-ante	Physical change, Economic policies	Hard	Push &Pull	Nested logit demand model linked to the network assignment model EMME/3	[7]Gothenburg	[7]11%	Not specified	[7](West et al. 2016)
	Ex-ante	Physical change, Economic policies	Hard	Push &Pull	Logit model, multifactor analysis of variance (MANOVA) and vehicle emissions model	[8]Beijing	[8]16%	Not specified	[8](Wu et al. 2017)
[2] Parking charge	Ex-post	Physical change, Economic policies	Hard	Push &Pull	Workplace parking fee for employees that is dependent on arrival time and the distance from home to workplace	[9]Rotterdam [10]Nottingham [11]Winchester	[9]25% [10]9% [11]12%	Local Government, Civil Society, Private	[9](Strompen et al. 2012) [10](Dale et al. 2019) [11](Wall 2011)
	Ex-post	Economic policies	Soft	Pull	Employees will collect credits for not traveling to work with car, credited for every km	[12]Rotterdam	[12]25%	Private	[12](Strompen et al. 2012)
	Ex-ante	Legal policies, Economic policies	Hard	Push &Pull	Logit model (SPSS software)	[13]Belgrade	[13]16%	Not specified	[13](Vidovic and Simicevic 2023)

[3] Access Limitation	Ex-post	Legal policies, Physical change	Hard	Push &Pull	Limitation regarding city center access dependent on weekday, time of day, tire- and vehicle type. Introduction of low emission zones	[14]Rome [15]Bielefeld [16]Stockholm	[14]20% [15]26% [16]25%	Municipality, Transport Authority	[14](CIVITAS 2013a) [15](Köllinger 2022) [16]](Twisse, 2019)
[4] Parking management	Ex-post	Legal policies, Physical change	Hard	Push &Pull	Removing parking spaces around and in city centers, and introducing parking restriction	[17]Oslo [18]Amsterdam [19]Madeira	[17]19% [18]16% [19]10%	Civil society, private, Municipality	[17](Modijefsky 2021) [18](Van Der Pas 2014) [19](CIVITAS 2016)
[5] Mobility service for commuters	Ex-post	Economic policies, Physical change, Information & Education	Soft & Hard	Pull	Offering public transport pass for employees and commuters, and providing rides with shuttle buses	[20]Utrecht [21]Copenhagen	[20]37% [21]7%-10%	Car-sharing-providers, public transport companies, local, national, and regional government	[20](Stumpel-Vos et al. 2013) [21](Thøgersen 2009)
	Ex-ante	Economic policies, Physical change, Information &Education	Soft & Hard	Pull	Linear regression model	[22]Umeå	[22]41%	Not specified	[22](Van Der Pas 2015)
[6] Mobility service for University	Ex-post	Physical change, Economic policies	Soft& Hard	Pull	Free pass for public transport and providing bus rapid transit for students and employees	[23]Catania [24]Bristol	[23]24% [24]24-27%	Educational Institution, Local Government, Public Transport Provider	[23](Inturri 2019) [24](University of Bristol 2018)
	Ex-ante	Physical change, Economic policies	Soft	Pull	Logit model	[25] Varese, Como, and Milan	[25]20-45%	Not specified	[25](Grotti et al. 2022)
	Ex-ante	Physical change, Economic policies	Soft	Pull	Scenario-based analysis	[26]Ten Swedish cities	[26]9-24%	Not specified	[26](Kenworthy and Svensson 2022)
[7] Shared mobility	Ex-post	Physical change, Information & Education	Soft & Hard	Push & Pull	Introduce car-sharing service for employees, car-club, and promoting sustainable transportation	[27]Bremen [28]Genoa [29]Bristol	[27]35% [28]15% [29]25%	National Government, local Government	[27](Glotz-Richter 2016) [28](CIVITAS 2013b) [29](University of Bristol 2018)

	Ex-ante	Legal policies, Economic policies	Hard	Push & Pull	Agent-based simulation model	[30]Lisbon	[30]9%	Not specified	[30](Manuel Viegas et al. 2014)
	Ex-ante	Legal policies, Economic policies	Hard	Push & Pull	Simulation travel demand model	[31]Atlanta	[31]14–18%	_	[31](Agatz et al. 2011)
[8] School travel planning	Ex-post	Physical change, Information & Education	Soft	Pull	Promoting walking, cycling and car sharing for pupils and their parents with buddies through awareness/safety events	[32]Brighton & Hove [33]Norwich [34]Alberta	[32]5% [33]11% [34]13%	local Government, Public Transport Provider, private	[32](CIVITAS 2013c) [33](CIVITAS 2014) [34](Buliung et al. 2011)
[9] Workplace travel planning	Ex-post	Physical change, Information & Education	Soft & Hard	Push &Pull	Promoting public transport through discounted travel pass for employees.	[35]Brighton & Hove [36]Graz [37]Nantes [38]Norwich [39]20 Swedish cities	[35] 5% [36]12-14% [37]12% [38]18% [39]18%	local and national Government, civil society	[35](CIVITAS 2013c) [36](ITL 2018) [37](CIVITAS 2013d) [38](CIVITAS 2014) [39](Cairns et al. 2010)
[10] University travel planning	Ex-post	Physical change, Information & Education, Legal policies, Economic policies	Soft & Hard	Push &Pull	Parking management around and on campus, further advice for using public transport, walking, cycling and walking.	[40]Bristol [41]San Sebastian	[40]27% [41]8-12%	local and national Government, private, educational institution	[40](University of Bristol 2018) [41](CIVITAS2013e)
[11] Personalized travel planning	Ex-post	Information & Education, Economic policies	Soft	pull	Personal plans for travel and public transport discount offers.	[42]Marseille [43]Munich [44]Maastricht [45]San Sebastian	[42]6% [43]6% [44]5% [45]8-12%	Local, national, regional government	[42](Thaler et al. 2018) [43](Bamberg and Rees 2017) [44](Modijefsky 2019) [45](CIVITAS 2013f)
	Ex-ante	Information & Education	Soft	Pull	MANCOVA in combination with linear regression	[46]Berlin	[46]51%	Not specified	[46](Bamberg 2013)
[12] App for Sustainable Mobility Competition	Ex-post	Information & Education, Economic policies	Soft	Pull	Obtain points when using sustainable transport through an application on smart phone (BetterPoints)	[47]Bologna	[47]73%	Local government, private	[47](ITL 2018)
	Ex-post	Information & Education, Economic policies	Soft	Pull	Giving eco-feedback by tracking the mobility of the individual (GoEco)	[48]Ticino & Zurich	[48]31%	Local government, private	[48](Cellina et al. 2019)

4.2.1 Congestion charging

Congestion charges placed in Stockholm with 22% reduced car use, Gothenburg with 12% reduced car use, London with 33% reduced car use, Milan with 31% reduced car use, and Singapore with 15% reduced car use was based on ex-post studies. Eliasson et al. (2013) expressed the cordonbased congestion charge scheme in Stockholm was placed around the inner city, aiming to reduce the traffic into and through the city center by blocking the arterials leading into the inner city. The author further expressed that this scheme started with a trial in 2006, which then resulted in permanent placement in 2007. The following schemes in Gothenburg in 2013, London in 2003, Milan in 2008, and Singapore in 1975, have similar characteristics in that they cover the city borders and are cordon-based (Börjesson and Kristoffersson 2015; Beria 2016; Metz 2018). The common thing about these charging schemes is that they are time-of-day dependent charges, where the price could vary from €0.9 to €14.50 on weekdays between 6:00-18:30. However, the difference is that the charging scheme in London charges all vehicles driving in, driving out, or parking on a public road inside the zone (Metz 2018), while in Stockholm, Gothenburg, Milan, and Singapore charged for passing each direction of the cordon. Furthermore, Beria (2016) stated that the charging scheme in Milan banned older vehicles from entering the zone, while low-emission vehicles were able to pass through without any charge. Metz (2018) described further that Singapore utilized the system to maintain a consistent speed in the area, where vehicles were charged if the speed was not maintained to a certain threshold. Further common detail in the defined schemes is that they used automatic number plate recognition (Börjesson and Kristoffersson 2015; Beria 2016; Metz 2018; Eliasson et al. 2013), except the Singapore scheme which utilized the dedicated short-range communication (Metz 2018).

A model-based study on Stockholm's congestion charge was carried out. Eliasson et al. (2013) described the utilized model to forecast the congestion charge scheme in Stockholm and the data set obtained from Swedish national travel survey Riks-RVU 1994–2001. The used model, Sampers, consists of nested logit demand model that is associated with network assignment model EMME/2. The demand model compares varieties of trip rate, destination and mode choices, with separate sub-models for various trip purposes, and comparing mode of transport. The demand data are divided into time-of-day matrices, which then are assigned to road and transit networks utilizing the network assignment model. The authors expressed further that the travel times and costs from the assignment model are given back as feedback into the demand model to reach the desired convergence. Furthermore, there was some adaptation to the demand model, such as letting the total number of work trips end per zone to be equal to the number of workplaces in the zone. This interprets that switching workplace as a response to the charging scheme is unlikely to happen. The authors further explained the disadvantage of using static assignment models, for example spillback queues, blocking of intersections/ ramps, and dynamic congestion are not reflected fairly in the model. In addition, this model excludes activity-based travel demand and simulation-based network assignment. The result of this model provided a 16% reduction in car use, 10-15% reduction in vehicle kilometers travelled and emissions somewhat less.

Likewise, a model-based study was carried out on the congestion charge in Gothenburg with 11% reduced car use. Börjesson and Kristoffersson (2015) described the model utilized for this scheme, which is similar to the one used in Stockholm. Hence, differences in the modelling will be presented. The authors described that the topography of Gothenburg had a big effect on the designed cordon in comparison to the Stockholm cordon. For instance, the cordon in Stockholm covers the bottleneck of the inner city and cuts through the water which also works as a natural barrier. The design of Stockholm cordon charge does not result in undesirable blockages in the network; while in Gothenburg the topography is different, where natural barriers around the bottleneck does not exist leading to unwanted barriers within residential areas. However, there were possibilities to avoid the charging scheme through alternative routes in many OD-pairs with longer travel time. Hence, the traffic effects obtained from the model were sensitive to the assignment parameters (i.e., distance, travel time and cost). West et al. (2016) expressed that due to having the

ability of choosing charged and uncharged routes in Gothenburg a multi-passenger rule was needed in the model. The multi-passenger rule denotes a hierarchical route choice algorithm including upper and lower level that was added to the model from Stockholm' congestion charge. However, the upper level expressed if the drivers are paying or not, and the lower level expressed the distribution of drivers to the network. The lower level therefore expressed if the drivers had full access to the network (the paying drivers) or limited to the routes that without charges. The multi-passenger rule enables to simulate the differences in the topography.

Furthermore, a single ex-ante study about congestion charge with no connation with any ex-post study presented in the city case of Beijing. This study showed that the probability Pr(car) of a person choosing car as a transport mode was reduced by 16%. Wu et al. (2017) defined the congestion charge in central area of Beijing, utilizing logit model, multifactor analysis of variance (MANOVA) and vehicle emissions model. The authors described that they did not only focus on cordon-based charging scheme but also a distance-based scheme. The distance-based charge considers vehicle travel distance within a zone and is more complex to implement than cordonbased. However, the advantage of modelling distance-based charging scheme is that it gives more precis output. The selection of charging zone in the model is based on traffic performance index, which considers network congestion, congestion share on road type and the length of congested road. Furthermore, the macroscopic model assumes that the trip generation and trip distribution to not be associated with the congestion charge. In addition, the model considers that the charging scheme affects private vehicles used in the charging zone, and that it has an impact on mode choice and trip assignment. The authors further explained that the simulation was implemented in VISUM, which provided travel activity inputs for emissions estimation. Moreover, the result of modelling congestion charge in Beijing both cordon- and distance-based resulted in similar results, which is 60-70% reduction in carbon monoxide, 35-45% nitrogen oxides, vehicle kilometers travelled was reduced by 35-50%.

4.2.2 Parking charging

The next intervention type is parking charge introduced in Nottingham in 2012 with 25% reduced car use, Rotterdam in 2004 with 9% reduced car use, and Winchester in 2002 with 12% reduced car use, was based on ex-post studies. Dale et al. (2019) described that Nottingham considered workplace parking spaces used by employees allocated around the city boundaries with 2500 survey commuters covers the period 2010 to 2016. The cost for utilizing these parking spaces was increased, and the revenues from the parking charge was used to part-fund the expansion of tram lines. Meanwhile, Strompen et al. (2012) explained that Rotterdam studied employee parking space placed near a medical center with around 10 000 employees. The parking charge (€1.5- €4) was based on arrival time and distance from home to the medical center (work), this is due to the fact that the majority of employees drove to work by car even if they lived nearby. Furthermore, to encourage more employees to travel with sustainable transport modes they introduced a cash-outscheme achieving 25% reduced car use. The cash-out-scheme is referred to as an awarding system, where employees were credited €0.10 for every km not travelled by private car. Further initiative describes by Wall (2011), was in Winchester included a discount of 50% to 75% on annual parking permit holders for low emission vehicles and offered free annual permits for electric or hybrid vehicles. This measure ran from 2002 to 2006 with sample size of 3102, where the measures included a variable tariff for annual parking permits holder around and in the city center. Further, the prices were increased for parking spaces near the city center and cheaper for park and ride.

Vidovic and Simicevic (2023) modelled an intervention based on parking charge, utilizing a multinomial logit model to evaluate parking charge and its impact on travelers' transport mode choice. This model is an extension of logit model with more than two possible outcomes of dependent variables, given a set of independent variables. The setup for this model is like the logit model, but the only difference is that there are *K* possible outcomes than just two. The multinomial logit model used statistically relevant variables that had an influence on the decision makers utility,

like socio-economic and trip characteristics. The variables were collected through a survey to collect information about the variables, such as engine size, walking distance, trip purpose, parking duration, arrival period and parking price. Furthermore, this model consists of sub-models, like production/attraction model, distribution/mode choice model, assignment model. The results obtained from the model indicated that when increasing the walking distance, parking price and reducing parking duration the probability of changing from car to public transport is increased. Consequently, the authors estimated a 16% of car use in the modal split can be reduced when increasing walking distance, parking duration and parking price.

4.2.3 Parking management

Further interventions that had effect on car use reduction is the use of parking management, which was defined in Oslo with 19% reduced car use, Amsterdam with 16% reduced car use, and Madeira with 10 % reduced car use. Modijefsky (2021) describes that Oslo removed on-street parking spaces around and inside the city center in 2009, aiming to encourage more people to use sustainable transport and to achieve streets that are car free. Further initiative to encourage nonmotorized transport modes was building new bicycle lanes and pedestrian network, terraces, playground etc. Similar initiative describes by Van Der Pas (2014) was introduced in Amsterdam, where parking spaces were reduced to achieve clearer air quality and to reduce the time cars spend on streets. The city-owned garages were held up and other commercial garages were removed creating 3 300 additional spaces. Furthermore, Amsterdam introduced park and ride facilities around the city center to enable more people to park outside the city center. However, the latter would achieve higher effect if it was combined with financial ingenuity, which involves earning a small amount of money when a parking permit holder stays parked for over 24 hours. This system used automatic number plate recognition to monitor the cars, to encourage more people to take sustainable transport modes. The Madeira case integrated low emission zones and parking restrictions similar to in Oslo and Amsterdam, and additional initiative regarding walkability for the disabilities to achieve an attractive city center for all types of people (CIVITAS 2016). To further encourage these initiatives Madeira used billboards to influence more people and at the same time prevent illegal parking.

4.2.4 Access limitation

The following intervention type based on ex-post study is access limitation, that was used in Rome with 20 % reduced car use, Bielefeld with 26% reduced car, use and Stockholm with 25 % reduced car use. Access limitation was introduced in 2001 and expanded in 2007 in Rome, which involved vehicles restriction to enter the city center through introducing electric gates at entry points area of 4.8 km² with 5 000 population (CIVITAS 2013a). The limitation regarding access during certain times of day and weekdays for instance, 6:30-18:00 on weekdays and 14:00-18:00 on Sundays was the entrance possible for users who pay annual fee for the entre permit. The revenues from violation of this restriction and from the entrance fee was invested in public transport service. Köllinger (2022) enlightens about the access limitation in Bielefeld with 5 140 people participating in survey, which regarded car access into the old town area, aiming to reach an emission free inner city. The author further emphasizes that the entries into the old town were blocked for cars to pass through, however one entrance was recreated for drop-off point for pupils and car sharing services. The streets were converted into cycling paths and several parking lots were built for bicycles to encourage more to cycle into this area. Meanwhile, Twisse (2019) describes that Stockholm introduced a low emission zone aiming to improve air quality in the city center. The regulation involved access limitation for heavy vehicles, older vehicles, vehicle tires and fuel types of dependent on weekday and time of day, which resulted in 30% carbon dioxide reduction in the area.

4.2.5 Mobility service

An additional intervention identified was mobility service, which could be aimed at commuters and universities. Thøgersen (2009) describes that the mobility service for commuters could include free public transport pass, which included free transport by local buses, trams, rental bikes and electronic scooters in the region. This transport pass was also able to be used for other trips than to work, therefore car ownership could also be decreased. This intervention have achieved 7%-10% in reducing car use. The data was collected through telephone interviews of 1071 participants, where people with car ownership were randomly picked. Stumpel-Vos et al. (2013) explains a similar approach as Thøgersen (2009) with 19 120 urban public transport passes sold and was evaluated through survey. Stumpel-Vos et al. (2013) explains further that several workplaces offered shuttle buses that transferred employees between train stations and park and ride facilities achieving 37% reduced car use. This intervention is also advertised by marketing events and communication plans to increase the awareness of urban mobility. Inturri (2019) described comparable approach that was taken for universities, which involved providing free bus rapid transit to campus, and free access to all public transport for students, and trainees with approximately 40 000 students, and 1000 professors and researchers. Comparable mobility service was presented by Van Der Pas (2015), that described the green parking purchase model used in Umeå achieving 41% in reduced car use. The aim was to increase the share of public transport use through 20% discount on the monthly tickets. Further incentive was to upgrade the bicycle parking spaces, such as including heated garages, dressing rooms and stations for bike repair. In addition, an on-site car sharing facility was also offered.

Furthermore, Grotti et al. (2022) estimated the effect of three policy measures within mobility service. These three policies included (1) car sharing, (2) public transport and other sustainable transport modes, and (3) public transport with other sustainable transport mode paired with promotion of cycling. These policy measures were estimated by multinomial logit model to have 20%, 35% and 45% effect on reducing single car. The probability of a person i choose a policy option j is expressed as below.

$$P_{ij} = \Pr(U_{ij} > U_{iy}) \ y \neq j$$

The data input for the multinomial logit model were based on personal attributes, trip characteristics, psychological factors, and mode specific factors collected from a survey in Uninsubria campus in Varese. The authors used this campus because of students living outside the campus, in Varese, Como, and Milan, to be able to capture different opinions of car commuters. The results of the estimation indicated that parking management measures had higher effect on female car commuters, employees and students that were in the science department. Furthermore, the authors indicated that faculty staff would rather leave their car at home and use bikes as an alternative travel mode, and that people are more likely to do so if no other sustainable transport mode were within a reasonable reach. Nevertheless, the authors further expressed that applying these policy measures alone will not provide the same effect, because the perception of policy measures depend on public transport and built in environmental conditions where the users live. Furthermore, the author explained about these policy measures could achieve a reduction of greenhouse gas emissions by 40% by 2030.

Kenworthy and Svensson (2022) used scenario-based analysis to study five different scenarios: (1) to increase the seat occupancy in public transport; (2) double the seat in public transport; (3) increase car occupancy by 10%; (4) decrease energy use per car (vehicle kilometer travelled) by 15%; (5) increase the share of non-motorized trips to 50%. The authors explained that the first scenario would lead to 9% reduction in private transport energy; the second scenario would mean a reduction in private transport energy by 24%; the third scenario would lead to 10% reduction; scenario four would mean 15% reduction; the fifth scenario would lead to 12% reduction. The authors calculated scenario 2 and 5 to have the best effect on decreasing car use and emissions. Therefore, they created a sixth scenario which was a combination of scenario 2 and 5, resulting in

60% reduction in passenger transport energy use. These five scenarios were tested in larger Swedish cities, such as Stockholm, Malmö, Göteborg, Linköping, Helsingborg, Uppsala, Västerås, Örebro, Jönköping and Umeå. However, the data to create these scenarios were based on four years research (2016-2019), collecting data directly from the primary sources, such as regions, Swedish municipalities, or national datasets that are available for the analyzed city. For instance, data about public transport energy use were collected through consulting the publisher of the source in form of mail conversations and phone calls. This data was then used to calculate the effect, for example, the authors calculated the reduced car passenger kilometers per capita. This was calculated through multiplying new boardings in public transport by average car journeys length in these ten Swedish cities. The result is a new car passenger kilometer per capita which then was multiplied by the energy consumption per car passenger kilometer to achieve the total transport energy per capita.

4.2.6 Shared mobility

The following intervention type is shared mobility which denotes sharing means of transport modes with other people to make more use of a vehicle and to reduce ownership. For instance, Bremen with 11 00 users have achieved 35% reduced car use, and Genoa with 2000 users have achieved 15% reduced car use. This intervention type have increased the car sharing itself and the stations where such means could be found in both city center and in residential areas (Glotz-Richter 2016; CIVITAS 2013b). Glotz-Richter (2016) stated that shared mobility was promoted through billboards, media reports, campaigns etc., to employees and students. To increase the attractiveness of this initiative in Bremen, travelers were able to combine a season ticket for public transport and optimized the placement of car sharing stations (e.g., close to public transport). A similar initiative was introduced in Bristol University provided for 24 048 students and 8552 staff members, where they built a private car sharing scheme in campus providing a guaranteed parking space and emergence ride home (University of Bristol 2018).

Manuel Viegas et al. (2014) described a shared taxi system implemented in an agent-based simulation model achieving 9% reduced car use. The model itself uses rules and algorithms to present the interaction of agents over time. The authors emphasized that this system considered taxis and clients as agents that made decisions based on their interests. The system acted on clients sharing taxi rides with other compatible clients in terms of well-suited time and space, in exchange the clients were offered lower prices. Furthermore, the agent-based simulation model considered that the client is willing to accept a maximum deviation from the client's direct route. The model input, such as demand was obtained through survey for Lisbon. However, the model output i.e., the share of shared-trips was used to compare to a base scenario without this system, in order to determine the achieved effect. Agatz et al. (2011) carried out a similar study achieving 14%-18% of reduced kilometer travelled, where the study included dynamic ride-sharing based on smartphone technology. This system is based on bringing travelers with similar itineraries and time schedules to share the ride. Hence, this system provides matching drivers and riders on short notice, contrary to what Manuel Viegas et al. (2014) presented. The system was based on optimization approaches that minimized the total travelled vehicle kilometers by the members of this shared mobility service, and a simulation travel demand model developed by Atlanta Regional Commission (ARC). The result of this study indicated that ride-sharing systems would contribute to the sustainability perspective of travels when comparing to a base case i.e., without the system. The authors enhanced that the use of sophisticated optimization methods improved the performance of the ride-sharing system. The study indicated that even with few participants in the system (i.e., in urban areas), an effect of efficient mobility could be achieved.

4.2.7 Travel planning

The succeeding intervention type is travelling planning, which is aimed at school, workplace, university and individuals. The travel planning for school in Brighton & Hove (198 children) have achieved 5% in reducing car use, Norwich (40 294 children) have achieved 11% in reducing car

use, and Alberta (1489 children) have achieved 13% in reducing car use. These interventions promoted walking, biking and car sharing, and further improved school storage for such means of travel (CIVITAS 2013c; CIVITAS 2013d). Furthermore, they introduced workshops and events for walking to school, as well as adding flyers and newsletters to promote non-motorized travel to school. In addition, Norwich developed a website which provided step by step guidance to support travel plans (CIVITAS 2014). Buliung et al. (2011) describes that schools placed in older suburban neighborhoods were more likely to achieve higher effect through applying travel planning in terms of improvement project; while newer suburban neighborhoods increased the effect when using enforcement (i.e., parking restriction). However, parents found it more convenient to allow their children to walk, cycle, etc., if they had company on the way to school or home. This expressed Buliung et al. (2011) to be important to increase the effect of school travel plans. The same approach was taken for Universities travel planning as school, which included advertising for sustainable transport and improvement of lanes for non-motorized travel (CIVITAS 2013e).

Workplace travel planning involved companies creating travel plans, where promotion events and social media engagement on various platforms to encourage more people to take sustainable travel mode to work (Cairns et al. 2010). These intervention have achieved 5% reduced car use in Brighton & Hove, 12%-14% in Graz, 12% in Nantes, 18% in Norwich, and 18% in 20 Swedish cities. Further initiative regarding workplace travel planning is using monetary awards from municipality motivating companies to inspire their employees for sustainable transport (ITL 2018). Furthermore, in Nantes and Norwich an analysis is carried out of mobility needs, accessibility of public transport and advice for sustainable travel modes for companies (CIVITAS 2013d; CIVITAS 2014). Cairns et al. (2010) described that to aspire more people to choose public transport or non-motorized transport modes to work, introducing enforcement in parking spaces, provide company shuttle busses, and providing discounted public transport ticket would achieve higher effect. The interventions regarding university travel planning in Bristol with 27% reduced car use and San Sebastian with 8%-12%, utilized a combination of two measures. These measures regarded parking management around and on campus, and promotion of using public transport, walking and cycling instead of car use. Meanwhile, the personalized travel planning included mobility pass offers for different age groups and marketing for awareness raising achieving 5%-12% in reduced car use (Thaler et al. 2018; Bamberg and Rees 2017; Modijefsky 2019). The incentive in San Sebastián included providing a three-month free public transport pass to see if people were willing to switch to public transport from car.

Bamberg (2013) estimated the effect of personalized travel planning (i.e., dialog marketing intervention) through utilizing behavioral change theory based on the pre- decisional stage, pre- actional stage, actional stage, and post-actional stage. This study was carried out through using phone-based social marketing campaign i.e., dialog with random car owners through phone calls, to promote car use reduction through travel planning. A part of the dialog was to measure the effect, in terms of asking multiple questions in the begging and in the end of the phone call to determine change in behavior. Another approach was using interviews to collect information about the assessment of the intervention effect. In addition, a daily diary of information gathered during this trial was used. The author utilized Multivariate analysis of covariance (MANCOVA) to obtain the intervention effect and then used linear regression for postintervention of car use. The demonstrated results show that utilizing a stage-based intervention a 51% reduced car use can be achieved. The author explained further that this effect reflected travelers trying to be in line with their personal norms.

4.2.8 App for sustainable mobility competition

Furthermore, ITL (2018) and Cellina et al. (2019) evaluated applications that give scores for trips made with sustainable transport and non-motorized means of transport achieved effect between 31%-73%. ITL (2018) explains that the system enabled rewards for the users to spend when a threshold is reached. This facilitates mobility competitions between individuals and companies.

The data collected through the application could then be utilized further by public administration for planning purposes. ITL (2018) describes that the trial period of this application was between April and September in 2017 and included 15 000 active users from Bologna. Hence, the share of reduced car use was based on the app users and does not regard the whole population of Bologna. Cellina et al. (2019) explains that the GoEco was based on three tracking periods, the first period from March to April 2016 was used to collect baseline mobility data through the application. The second period October 2016 to January 2017 was used to collect persuaded mobility data. The third period was from Match to April 2017 which included post-intervention mobility data collection. The users were approximately 600 individuals distributed between Ticino and Zurich.

5 Comparing interventions

This chapter provides an analysis and a comparison of the identified interventions, and their effect based on the share of car use reduction.

5.1 Comparison of interventions from ex-post studies

An appropriate approach to evaluate the effect of the identified intervention is to compare the intervention types based on location of intervention and extent of intervention effect, etc. This is because the identified intervention types have used different methods to measure the intervention effect. The variances in intervention effect (presented in Table 4) could be seen in Figure 3, and shows how the different intervention types vary in their effect. Even within every intervention type the difference in effect between the cities are significant. For example, mobility service for commuters has two city cases, Utrecht shows much higher effect than Copenhagen. Meanwhile, in other intervention types one can observe a similarity, such as low intervention effect. For instance, personalized travel planning, that shows low effect in all four city cases. Conversely, access limitation has three city cases where all of these have high effect in reducing car use.

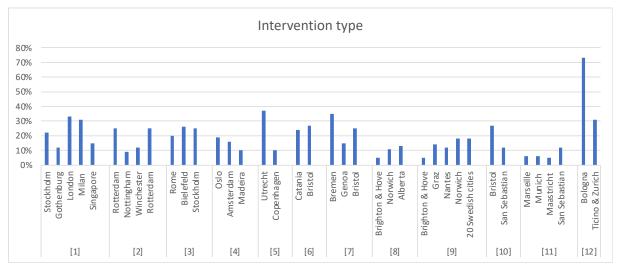


Figure 3: All identified intervention types in each city. [1]Congestion charge, [2] Parking charge, [3] Access Limitation, [4] Parking management, [5] Mobility service for commuters, [6] Mobility service for University, [7] Shared mobility, [8] School travel planning, [9] Workplace travel planning, [10] University travel planning, [11] Personalized travel planning, [12] App for Sustainable Mobility Competition.

Furthermore, presenting the intervention types based on their extent in terms of effect can give an indication of which intervention types have the highest effect (i.e., on regional or local level). A regional effect expresses a change in a specific region or geographical area, while local effect refers to a change in a specific place or a specific area in smaller scale than a regional effect. Hence, regional effect affects a larger geographic area, while local effect occur on a smaller scale. Important to keep in mind is that a regional effect is more difficult to achieve, refereeing to extensive behavioral change among the travelers. Meanwhile, a local effect could be obtained through minor changes, such as closing a road to avoid traffic and achieve 100% reduction in

car use for that specific area. Therefore, it is also unfair to compare intervention effect that has different extent. Figure 4 presents all interventions with an effect on the regional level. In Figure 5, all interventions with local intervention effect are presented. Figure 6 presents the average effect of all intervention types in an increasing order, to present intervention types with highest effect identified in this study based on the literature selection.

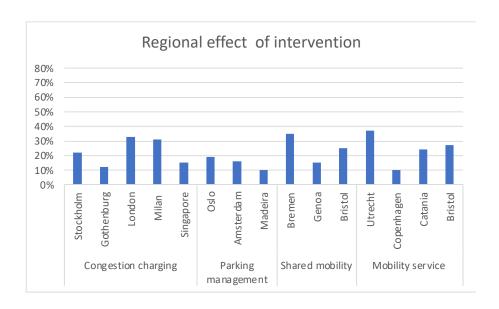


Figure 4: Interventions that has a regional effect.

Congestion charge, parking management, shared mobility, and mobility service are the intervention types considered to have regional effect, in terms of car use reduction. Congestion charge reduces all traffic across the cordon (i.e., through the city) covering larger geographical area, and therefore cannot be interpreted as a local. Parking management involves larger changes, which affects a larger geographical area. For example, removing parking spaces near the city center can lead to reduced car travel around as well as to the city center, which refers to as a larger change. The reduced parking spaces can also lead to reduced car travel to the city center or other geographical area, as there are no parking spaces available. Shared mobility and mobility service involves all types of travelers in the whole region, therefore the reduction in car use is on a regional level as the service offers unlimited travel. For example, two people from different neighborhoods can share the ride, leading to one less car on the road.

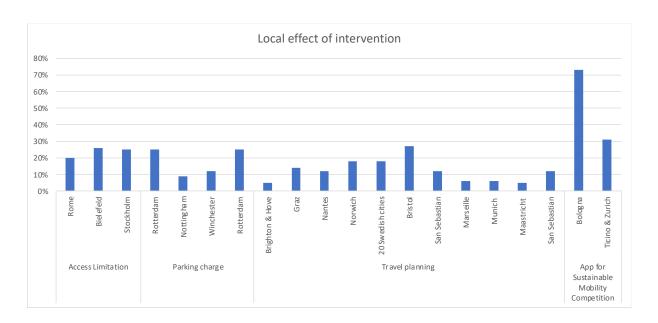


Figure 5: Interventions that have a local effect.

Access limitation, parking charge, travel planning, and app for sustainable mobility are the intervention types with a local effect in terms of car use reduction. This depends on the intervention extent and approach, for example, access limitation will only limit car travel in certain areas. Access limitation achieves only a local effect is also due to the fact that this intervention often regards certain entrances to specific areas, such as old towns. Travel planning and the app for sustainable mobility consider certain travelers, and not all types of travelers are involved, such as older people and disabled people. For example, older people do not have a good grip on the technology, and therefore to use an application would rather seem advanced and complicated. The same could be argued for travel planning, as it is very hard to change a very old habit voluntarily, such as travel mode choice. Furthermore, these intervention often regard certain travel purposes with the regard of a singular traveler (i.e., when travelling alone), because it is often harder to convince other to change their travel mode choice if the trip is made with a group of people. Hence, it is easier to choose walking to school alone than convincing other to also do so.

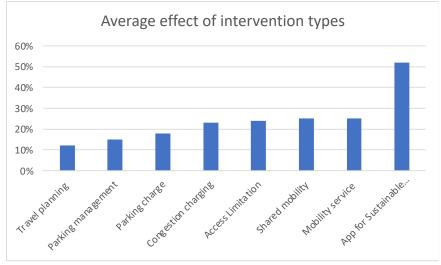


Figure 6: Average effect of all identified intervention types (both local and regional).

The intervention type congestion charging can be efficient to reduce car use and emissions. However, given by the examples above one can see that the cities have different sizes and are placed in different parts of Europe and one in Asia (the case of Singapore), which is crucial to the effect of the intervention. For instance, London has achieved 33% reduced car use, where this city is the largest in population and area of all the presented cities. Important to realize is that congestion charging is efficient in densely populated cities as well as high levels of car ownership (Börjesson and Kristoffersson 2015), which could be one of the many reasons to why the effect of congestion charge in London is the highest. Metz (2018) describes that there are other factors that will influence the effect of such intervention type, for example social and economic factors which will determine the level of economic activity, and the location of travelers. Further upon, cities share of cost-sensitive and time-sensitive travelers will also affect the intervention effect. Furthermore, congestion charge in Gothenburg has achieved the least effect of all identified city cases for congestion charge, where this city is relatively small, and the congestion is limited to a few highway junctions.

Congestion charges achieve the broader effect of reducing car use (i.e., to the extent of a region), in contrast to parking charges which mostly affect the extent of a local area. This is because parking charge often considers certain parking spaces in certain areas, therefore the traveler is still able to choose other parking spaces in another area. Hence, the effect from parking charge is rather limited to where the parking spaces are located, meanwhile congestion charge is harder to avoid when traveling from one side of town to the other. The identified interventions with the focus of parking charge were shown to have higher effect if the increase of parking price was combined with an awarding system. Such a system was presented by Strompen et al. (2012) in Rotterdam with a local effect of 25% in car use reduction. Additional aspects increasing the effect of these interventions are converting the prices of parking near workplaces to be individualized, as was done in Rotterdam. The prices were based on arrival time and the distance between home and workplace. Further applicable intervention was presented by Wall (2011), where the prices for annual parking permits were reduced for low emission vehicles, encouraging people to switch to environmentally friendly vehicles.

The intervention type access limitation considers the same extent as parking charges (i.e., affecting in the extent of a local area). However, access limitation shows to have on average a higher effect on reducing the share of car use from the cases in Rome, Bielefeld and Stockholm than parking charge. The access limitation uses legal policy, which forces drivers to follow rules, standards and prohibitions regarding where and when to drive in certain areas. Hence, drivers have to consider alternative roads, or other modes of transport if they are time-sensitive or consider making the trip when the regulations do not apply (i.e., outside the restricted time windows). Köllinger (2022) expresses that the effect from this type of intervention does not reach widely because the road network allows drivers to choose from different alternatives of accessing the restricted area, which are rather restricted by the road network itself.

Furthermore, parking management which denotes removing parking spaces near city center would achieve higher effect in reducing the share of car use. Modijefsky (2021) described removing on-street parking spaces around and inside the city center will achieve higher effect

in reducing the share of car use by 19% in the city center. This intervention type encourages the car use switch to other transport modes, due to reduced parking spaces. Travelers will weigh relevant factors associated with car travel (e.g., walking distance, parking duration, etc.) to consider the transport mode with maximized utility. Meanwhile, in Amsterdam a park and ride facilities around the city center were also introduced to enable more people to park outside the city borders. That would achieve a higher effect if it was combined with financial ingenuity, which involves earning a small amount of money when a parking permit holder stays parked for over 24 hours. The case in Amsterdam resulted in 16% reduced car use, while Oslo reduced 3.3% more in car use. The difference in the intervention effect achieved depends on the characteristic behavior of the population, and the differences in the supply of car alternatives and transport modes availability. However, this intervention type reaches a regional effect to reducing car use but is not as successful compared to the others presented in Figure 4. Comparing the average effect of respective intervention type with the presented city cases, shows that parking management has 15% on average effect, congestion charge has 23% and 25% for both shared mobility and mobility service. This indicates that parking management could have a limited effect on the regional level.

Interventions with the highest effect on a regional level are shared mobility, mobility service, and congestion charge to be more precise the cases of Bremen, Utrecht and London. The intervention mobility service enabled approximate 19120 employees to shift their most repeated trips (home to work) to public transport according to the study in Utrecht. This is due to the fact that employees were offered to save their expensive costs related to the car (e.g., fuel, insurance, etc.), with a more cost effective one as employees are offered public transport pass or rides with shuttle buses. Meanwhile, the intervention shared mobility was able to reach travelers that are rather car dependent, in terms of having poor connection to public transport near home. This intervention enabled 3 850 people to reduce their car use, and at the same time decrease their cost, as the cost of sharing a ride is cheaper than making it alone. For example, the fee from passing a congestion charge in such case, renting the car, fuel, etc., would be divided among the travelers. Furthermore, it became rather easier for travelers to choose shared mobility because the car sharing stationer were introduced near workplaces and other attractive destinations. These interventions have reached 33-37% in reducing car use through combining economic policies, physical change, information & education. These interventions are also based on a combination of soft and hard policy measures. Meanwhile, access limitation is the intervention with highest effect on a local level.

However, shared mobility, mobility service, and congestion charge will not be considered as having the highest average effect if the application for sustainable mobility is excluded. This is due to the fact that the measurement of this intervention effect is based on the participant of the app. For instance, the Bologna case had 15 000 active app users and the 73% regarded this group referring to 10 950 people that have reduced their car travel. Considering this number of people with the total of Bolognas population of 814 000 people (Macrotrends, 2023), then the share will rather be 0,0013%. Therefore, when comparing the car reduction in relation to the whole population of Bologna the effect will not be as high. In addition, the trail time of this

intervention is rather short, as similar intervention reaches higher effect in the beginning and will fade by time.

The rest of intervention types with local effect have a varying effect size, which could depend on the selection of the studies. Hence, selecting other studies may show other relationship of intervention effect, therefore it is of importance to keep this in mind.

Furthermore, if considering the intervention types based on the policy measure (i.e., Soft or Hard, or combined), then one can analyze the intervention effect based on the policy measure. Table 5 presents the average effect (i.e., the share of car use reduction) by study type (i.e., expost, ex-ante) of the identified intervention. The average effect from the identified ex-post studies is shown to be highest for soft & hard policy measures combined, which includes congestion charging, mobility service, shared mobility and travel planning. The second highest is soft, policy measure and finally comes hard policy measure. However, there are no major differences in average effect between these policy measures, where the effect differs from 1%-2%.

Table 5: Average effect o	of intervention hased on i	nalicy measure: Sa	ft & Hard Hard	I and Soft for the study	tune ex-nost
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Policy measure	Ex-post
Soft & Hard	21%
Hard	18%
Soft	19%

5.2 Comparison of interventions from ex-ante studies

Eliasson et al. (2013) and West et al. (2016) used a nested logit model to estimate the congestion charge of Stockholm and Gothenburg, which allows nests of outcomes to satisfy the independence of irrelevant alternatives property. Meanwhile, Wu et al. (2017) utilized a nested logit model for the case study of Beijing, but the outcomes of both model types predict similar effect of car use reduction (i.e., maximum effect of 16%). However, for the case of Stockholm the model predicts somewhat lower effect than measured effect provided from the ex-post studies. Former statement could be, explains the authors, a part among other things the disadvantage of using static assignment models. For example, spillback queues, blocking of intersections/ ramps, and dynamic congestion are not reflected fairly in the model. In addition, this model excludes activity-based travel demand and simulation-based network assignment. These drawbacks of the model led to underpredicted travel times, and off-peak traffic effects were underpredicted, because of underestimating the leisure trips. However, Eliasson et al. (2013) argue that the overall performance of the model result in comparison to actual effects of the Stockholm congestion charges, which indicated that the travel demand model forecasted accurately when comparing the forecasted results and the actual outcome. Meanwhile, the spillback queue in Gothenburg is not a large problem, and therefore a static model assignment could provide accurate prediction of travel time reduction. However, through having the possibility of avoiding the charging scheme in Gothenburg due to the topology, the model is instead more sensitive to travel time, distance and charge. The prediction of car use reduction of Stockholm is underpredicted in comparison to the ex-post measure with 6%, while Gothenburg is underpredicted with 1%, which shows that the spillback queue and other factors led to lower accuracy of model prediction. Wu et al. (2017) describes that utilizing the distance-based charging scheme increases the accuracy of measured output. The authors explain that the selection of charging zone in the model is based network congestion, congestion share on road type and the length of congested road. However, the results (i.e., car use reduction) from Wu et al. (2017) and Eliasson et al. (2013) models, although different models have been used, is the same 16%. On the other hand, 16% of car use reduction in Beijing's population is much more than Stockholm's, because the population differs significantly.

Furthermore, parking charges were modelled by Vidovic and Simicevic (2023) that showed when increasing the walking distance, parking price and reducing parking duration the probability of changing from car to public transport is increased. This study shows other perspectives than just increasing the cost of parking, the parking duration and walking distance are important aspects for travelers in which is a part of choosing to travel by the car over other transport modes. However, comparing Vidovic and Simicevic (2023) study to the ex-post studies in Nottingham and Winchester, indicates to be slightly over predicted but when comparing to Rotterdam then it has been under predicted. Regardless of the city cases studied a slightly different kind of parking charge (i.e., parking for employees), whereas Vidovic and Simicevic (2023) studied parking spaces in Belgrade's central areas. In addition, one difference is that the ex-post studies explored additional initiative rather than just increasing the cost for parking, such as offering discount for low emission vehicles, introducing cash-out-scheme to decrease the car travel. However, the predicted effect from Vidovic and Simicevic (2023) indicates that in order to decrease the parking demand and car travel, the walking distance, parking price and reducing parking duration could imply behavioral change in mode choice. Therefore, the model study could be better fit for new planning and improvement projects, while the effects of ex-post studies can be utilized for already existing parking places and future cases.

Van Der Pas (2015) studied mobility service in Umeå, where the aim was to increase the share of public transport use. This was applied through introducing a discounted public transport ticket (i.e., 20% discount). Furthermore, improvement to the bicycle parking space, and introducing an on-site car sharing facility was also offered. This mobility service accounted for a 41% decrease of the car travel, where the effect is a bit overpredicted in comparison to the ex-post studies, such as the case of Utrecht with 37% car use reduction. Stumpel-Vos et al. (2013) explains that free public transport passes and shuttle buses for employees were offered to decrease the need of car travel. The Utrecht ex-post study and Umeå's ex-ante study are comparable in the implemented initiatives to reach car use reduction, although reached different effect in reducing car use. This difference could be explained in many ways covering different parts of the traveler's perception, convenience, availability, etc., of choosing such transport means. At the same time one can argue that interventions could achieve different levels of effect depending on the location and the extent of the initiatives. Hence, implementing a simple car

sharing system in one city does not mean that the same effect could be achieved when implemented in another city.

Furthermore, mobility service for university in Catania and Bristol (from ex-post studies) shows to have achieved similar effect of reducing car use (24%-27%), while the ex-ante studies predict to achieve higher effect. However, it is important to keep in mind that the system of shared mobility can be implemented in various ways, and that may have an affecting role on the intervention effect. The difference in effect may also depend on the level of detail for the different system of shared mobility. For example, Grotti et al. (2022) estimated the effect of different interventions based on gender and faculty in the university. In addition, the authors further express that applying these policy measure alone will not provide the same effect, because the perception of policy measures depend on public transport and built in environmental conditions where the users live. Furthermore, ex-ante study by Kenworthy and Svensson (2022) of reducing car use predicted the effect to be at the highest 24% which is in line to the effect obtained from ex-post studies that has some differences in the intervention. Kenworthy and Svensson (2022) mentions that this study was based on ten Swedish cities, in which strengthens the effect size and the effect accuracy, also the ex-post studies, as mentioned earlier, achieved similar effect size.

Manuel Viegas et al. (2014) and Agatz et al. (2011) analyzed shared mobility systems, but their approach maintains a significant difference in the obtained effect of reducing private car use. Manuel Viegas et al. (2014) used agent-based simulation to analyze ride-sharing system, and Agatz et al. (2011) analyzed a similar system by using optimization methods to improve the performance of the ride-sharing system. Whereas Manuel Viegas et al. (2014) predicted to have reduced 9% of car users, while Agatz et al. (2011) predicted to reduce the car use by 14% to 18%. The former indicates that the use of optimization methods could improve the performance, leading to closer results (in terms of effect) to the ex-post studies.

An ex-ante study analyzing personalized travel planning by Bamber (2013) shows that utilizing a stage-based intervention utilizing dialog marketing could achieve behavioral change (i.e., change in transport mode choice), in which led to car use reduction and increased public transport. This study is unique where the intervention was developed as a part of the behavioral change theory (presented in subchapter 3.3.1), and demonstrated its effect. However, this 51% reduction was accounted from 720 participants from random addresses located in Berlin.

Furthermore, an analyses of intervention types regarding intervention effect based on the policy measure (i.e., soft or hard, or combined), can be carried out, see Table 6. The average effect from ex-ante studies indicates that the interventions with soft & hard policy measures have the highest effect. Besides that, one can see that hard policy measures within the two study types have the lowest average effect. Semenescu et al. (2020) reinforces former statement and claims that soft policy measure by itself can achieve high effect, but in many cases a combination of both soft and hard policy measure could increase the obtained effect of the intervention. Similar statement regarding hard policy measure defined by Möser and Bamber (2007), that local authorities have explored the implementation of hard policy measure such as physical

improvements to transport infrastructure, control of road space and changes in price. However, despite this hard policy measure the desired share of reduced car use was not obtained.

Table 6: Average effect of intervention based on policy measure: Soft & Hard, Hard, and Soft for the study type ex-ante.

Policy measure	Ex-ante
Soft & Hard	41%
Hard	14%
Soft	40%

5.3 Evaluation of interventions effect

Car use reduction could be achieved by implementing one or a combination of the interventions presented in Table 4. However, by just implementing the intervention will not guaranteed that the same effect can be achieved, this is due to the difference in the interventions effect in correlation to the location, and travelers where the intervention is implemented. For instance, topography of the cities, availability of public transport, travelers preferences, situational factors, social factors and economic factors which will determine the level of economic activity, and the location of travelers (e.g., place of work, home etc.). The former factors are somewhat a small collection of what actually could affect the intervention effect. Hence, it is rather the extent of the intervention effect and the evaluation of the effect that is more appropriate to consider when trying to implement an intervention that aims to reduce car use.

The intervention effect can be generally evaluated in relation to the intervention size in terms of the implementation phase, energy used, material, change in architecture, etc. For instance, some interventions with soft policy measure are less energy demanding in terms of implementing a change i.e., awareness event. Furthermore, comparing congestion charge in London (33% effect size), and mobility service in Utrecht (37% effect size), one can state that the latter is more efficient when considering the intervention size. Meanwhile, when considering the extent of the intervention effect, one can state that congestion charge is more efficient. This is because of congestion charge covers travelers on regional level, while the Utrecht case of mobility service involves travelers in a certain zone. Hence, congestion charge covers all type of car users in London, meanwhile the mobility service in Utrecht considers certain travelers (i.e., employees) in business areas. Furthermore, the effect from the intervention in Utrecht might not be the same when applying in other cities, for instance Copenhagen implemented similar approach but was able to achieve up to 10% in effect. Grotti et al. (2022) describes that applying an intervention alone will not provide the same effect, because the perception of interventions depend on public transport and built in environmental conditions where the users live. Therefore, it is also of interests to consider the size of the effect in terms of number of cars, to be able to compare the effect size in a simpler way. For example, travel planning in Norwich included 40 294 people in the trail and have achieved 11% in effect (reducing 4 432 people from using car), while travel planning in Alberta with 1 489 people have achieved 13% (reducing 194 people from using car) (CIVITAS 2014; Buliung et al. 2011).

Likewise, the app for sustainable mobility achieved 73%, which is the highest achieved effect of reducing car use of all presented interventions types. This intervention is based on a soft policy measure where the implementation is not as costly as the congestion charge. However, the effect from soft policy measure are more likely to evaporate with time, which is mainly due to people are more affected at the beginning of a process and it becomes harder to continue. Relating to the short period of trial time for this intervention type, that can have been one of the many other reasons to why they achieved high effect.

Furthermore, congestion charge, mobility service, and shared mobility are the intervention types that requires bigger changes in terms of implementation phase. Whereas the rest of the intervention types fall between small changes like introducing an app for sustainable mobility and medium sized like travel planning, parking management, and parking charges. However, each of these intervention types requires investment, with some requiring more while others less. Therefore, it is usual that multiple stakeholders are investing in a certain intervention to cover the costs, among other things. In Table 4, the stakeholder for each intervention is presented, showing that multiple stakeholders are involved in a single intervention. Consequently, investing in an intervention with high effect and high cost could still be possible when multiple stakeholders share the responsibility and costs to fund the intervention.

Reducing car use does not indicate that the trip itself will not be made, because some of the trips are necessary (i.e., work, home, etc.) to be made and therefore the demand could shift toward other transport modes. For instance, if public transport does not have enough capacity for the increased demand, then congestion will increase in these transport means. In addition, some cities could even consider expansion of alternative transport modes (e.g., public transport lines, vehicles, etc.), which itself will increase costs and increase greenhouse gas emissions. Therefore, dependent on the most successful intervention type for the specific city, the effect will then be evaluated based on cost.

Furthermore, the intervention effect could also be evaluated toward already existing measures in the specific city. For instance, access limitation in combination with parking removal could increase the effect of reducing car use, as the travelers does not have a parking space when entering an area during the unrestricted period. This will instead force the travelers to reconsider alternative transport mode to reach their destination. There are many ways of combining intervention types to obtain the desired effect in reducing car use. Contrariwise, an undesired effects could also be achieved if combining two un well-fitted intervention in the same place, creating resistance toward sustainable transport modes. Coelli (2003) discusses intervention effect in terms of life cycle and maintenance costs, which also is crucial when evaluating the intervention effect. With other words, evaluate the effect of an intervention to ascertain if the intervention is yielding its money worth in relation to the obtained effect. For instance, the intervention maintenance could in the case of shared mobility imply having cars, bikes, electric

scooters ready to be utilized and that the vehicles itself are regularly controlled for safety measures, etc.

Comparatively, the intervention effect could be evaluated in relation to other type of effect, such as greenhouse gas emissions. For instance, Köllinger (2022) describes that access limitation has greater effect in reducing greenhouse gas emissions, in terms of the emissions from the vehicle itself. Meanwhile, intervention that reduces car use does not necessarily mean a reduction in greenhouse gas emissions, especially if the alternative transport mode use fossil fuels. However, Twisse (2019) describes that the case of Stockholm has achieved 30% in carbon dioxide reduction while 25% in car use. Similar initiatives were implemented in Madeira integrating low emission zones, and in Bielefeld regarded car access into the old town area, aiming to reach an emission free inner city. Meanwhile, Eliasson et al. (2013) explained that the emission reduction of the congestion charge was somewhat around 10-15% and the car use 22%. Therefore, depending on which intervention type and desired effect, the effect of the intervention could shift, and the cost can be set in relation. Hence, what seems to be inefficient intervention to reduce car use, might be an efficient intervention to reduce greenhouse gas emission. Wall (2011) describes that in Winchester the parking charges are lower for low emission vehicles, electric or hybrid vehicles, which could encourage more people to invest in a more environmentally friendly vehicle. These initiatives will in the longer run reduce greenhouse gas emissions and improve the air quality. On the other hand, this initiative does not reduce the number of cars on the roads and the car travel itself, and therefore effects such as congestion are still remaining.

6 Discussion

This chapter will provide a discussion of the analysis.

6.1 Intervention effect

The identified interventions used to reduce the share of car use were identified from 48 city cases and were categorized into 12 intervention types. The majority of the intervention types entail multiple measures, and different combinations of intervention categories. Many of the intervention types apply a combination of push & pull approach, and the rest apply pull approach. Hence, there is no single intervention case that had only applied a push approach. Kuss et al. (2022) mean that combining policy instruments together could increase the effect in reducing car use.

The effect was used to evaluate the intervention in terms of extent of effect, policy measure, utilized approach, location, etc. Hence, depending on the desired effect some intervention types were more successful than others. For example, different interventions could be applied if the desired effect is to reduce the car use in a regional level or local level; overall reduction with the focus of the city center; reducing the share of greenhouse gas emissions; increasing the passenger transport efficiency. Congestion charge, mobility service, and shared mobility are appropriate intervention types to reduce car use in larger geographical area. However, Börjesson and Kristoffersson (2015) mean that congestion charge can reach its potential effect in densely populated cities as well as high levels of car ownership. In addition, the importance of an efficient charging scheme is that it will be able to use the revenues to fund the charging schemes itself and also reduce congestion. Meanwhile, if the desired effect of implementing an intervention is to reduce the share of car use but do not want to make bigger changes in the infrastructure, then shared mobility and mobility service would be appropriate. The difference between these two interventions is that mobility service focuses on the singular travelers need and travel convenience. While shared mobility considers maximizing filling rate and the utilization of already existing vehicles, and to decrease car ownership.

Furthermore, if the desired effect of implementing an intervention is to reduce the share of greenhouse gas emissions, then access limitation could better fit. This is because access limitation reaches greater effect in reducing emissions rather than reducing the car use. Köllinger (2022) expresses that access limitation have greater effect in reducing greenhouse gas emissions, through forcing car users to plan their trip with alternative transport mode or choosing other time windows. For instance, the case of Stockholm has achieved a 30% reduction in carbon dioxide (Twisse 2019). Other than reducing greenhouse gas emissions, the amount of congestion around and through the restricted area has also decreased, due to lack of accessibility in or through the restricted area. The authors Köllinger (2022) and Twisse (2019) have expressed that to increase the effect of such interventions, sufficient information or public engagement is required to provoke enthusiasm and avoid resistance.

Intervention types that aim to pull the single car users from choosing car as a transport and instead push toward an efficient transport mode, according to Koppelman and Bhat (2006) is dependent on several factors. Such factors could for example be accessibility, uncertainty, and quality of the transport mode choice. An equally important aspect of transport mode choice is the trade-offs, such as choosing an expensive mode of transportation because the travel time is lower than the cheap travel mode. These factors could be associated to the difference in why these interventions obtain different effect within the same intervention type. Likewise, adjacent aspects such as, environment factors, socio-demographic and situational factors affect the intervention effect.

Meanwhile, factors like intervention cost and the extent of the effect would rather influence the choice of the intervention type. For example, the intervention type travel planning does require high costs in the implementation and the extent of the intervention effect is limited to a certain area. Furthermore, travel planning often achieves higher effect in the beginning of the implementation phase where travelers are affected by the campaigns and the encouragement. However, this effect does not last for long until majority of the travelers chooses to go back to old habits (e.g., using car as travel mode). Therefore, travel planning have lower effect than the other intervention types. Bamberg (2011) explained that the affected share of travelers are rather self-aware in their transport choices and their impact on the environment. Meanwhile, other travelers are affected by workplace location, type of work, etc., which controls the modes choice and the utility maximization, in some cases it could rather be efficient to use a car instead of other transport mode.

Considering the intervention type mobility service which has achieved highest effect, is considered to focus on encouraging travelers at different ages to urban mobility. Thus, one obtained effect from this intervention is decreasing the share of car trips made to work, school, university, etc., and shifting the traffic toward public transport. With other words, provide efficient alternative travel mode for the most frequent and important trips for travelers. Stumpel-Vos et al. (2013) explained that the case in Utrecht involved free public transport passes, which included free transport by local buses, trams, rental bikes and electronic scooters in the region for employees. This transport pass was also able to be used for other trips than to work, therefore car ownership could also be decreased. In addition, several workplaces offered shuttle buses that transferred employees between train stations, park and ride facilities and business areas. This intervention resulted in 37% decrease in car use, while in Copenhagen the share of car reduction only reached up to 10%. The effect from the Copenhagen case was obtained in far lower period than Utrecht. Thøgersen (2009) explained that the case of Copenhagen included car owners receiving a free month travel pass to increase the commuting by public transport. The results showed that people were willing to switch their travel mode with a more efficient transport mode. Considering the trail time of this intervention, which is one month, the achieved effect may not be as high if the trial time were longer. However, Thøgersen (2009) described that the effect was still evident five month later. A comparable approach was introduced, Inturri (2019) described that free bus rapid transit to campus, and free access to all public transport for students, trainees, Ph.D., was provided to increase the urban mobility which resulted in at the highest 27% of car use reduction.

Furthermore, shared mobility has also achieved high effect in reducing the share of car use. However, some of the interventions presented above have achieved different effect, which could depend on the city with its transport network and at the same time the behavior of the population. Meanwhile, area and population size wise the cities are similar, apart from any differences in transport availability, topography, socio-demographic and situational factors, the interventions are slightly different in what is provided for the traveler. For instance, the case of Bremen enabled the travelers to combine a season ticket for public transport, and optimized the placement of car sharing stations. While in Bristol, the University of Bristol provided a private car sharing scheme in campus offering a guaranteed parking space and emergence ride home. These two city cases with their additional touch to car sharing (Bristol and Bremen) had greater effect in reducing the share of car use, than the case of Genoa. The shared mobility intervention in Genoa aimed mainly at increasing and improving the car sharing system with no further unique improvements as it was in Bristol and Bremen. Therefore, through optimizing the number of customers and vehicles, placements of service point, an increased effect could be achieved. As it could be seen that Bremen and Bristol have achieved higher effect than Genoa, which could stats that the latter has a decisive role for the traveler mode choice; this is once again apart from other affecting factors that is city and individual specific.

The intervention type travel planning is mainly a soft intervention, one can observe that the effect obtained from the city cases are not as high as the other intervention types. However, this has also to do with the fact that the travel planning concept is to provide a strategy for an organization or to an individual, to decrease the travel impacts through influencing the travel behavior. Hence, this intervention type is mostly affected by the socio-demographic and situational factors and other city specific factors, like transport mode alternatives and accessibility, location of various attractive destinations, etc. The obtained effect of this type of intervention is also crucial to the baseline situation, if there is already a high number of people traveling with public transport and non-motorized transport mode then the effect of such intervention will not drastically increase. The same applies for the app for sustainable mobility competition, where this intervention type depends on peoples preferences and other factors relating to the traveler. However, the advantage of this intervention type is the awarding system which encourages more people to use other transport alternatives than cars.

6.2 Efficient passenger transport

Each intervention type could be compared in terms of how efficient the passenger transport mode is, for example, reduced congestion and increased filling rate. Gudmundsson (2015) describes that transport efficiency could be evaluated by the transport modes filling rate, which in this study refers to the number of travelers in the vehicle. This measure fits well with the authors definition of efficient passenger transport "the ability to utilize time, space, vehicles and fuel in the movement without any waste", where the filling rate is equivalent to how the transport mode utilizes *time*, *space* and *fuel* in the movement. For instance, the intervention type shared mobility, mobility service and travel planning, aims to decrease singular drivers by

substituting to share the travel or use other travel mode (e.g., public transport). In addition, travel planning encourages more people to not travel during peak hours and to utilize non-motorized travel modes. For example, Buliung et al. (2011) mentions that more pupils are allowed to walk to school if they had friend. These type of interventions, increase the utilization of time, space and fuel in the movement, and are perceived as efficient passenger transport. Meanwhile, congestion charge, parking charge, access limitation, etc., does not directly impose an increase of efficient passenger transport. However, there is an indirect relationship to the former intervention types and efficient passenger transport (e.g., public transport, cycling, walking, shared mobility, etc.). Through introducing an additional cost for the car users, some of the car travelers are willing to switch the transport mode and even the departure time if possible.

6.2.1 Choose morally right intervention

The main focus of this discussion so far has been on the intervention itself, but a part of making an intervention successful is to maintain the inspiration and encouragement of people to choose efficient transport modes. A part of this is to choose morally right intervention, referring to not force the traveler to change workplace due to limited transportation modes that have reasonable time and cost. For example, it is not morally right to remove all parking spaces near workplaces, homes, etc., in order to force the traveler to reduce the car use, instead could some of the parking spaces be reduced to encourage for a voluntarily behavior change. Prochaska and DiClemente (1982) explains that voluntarily behavior change is time-ordered sequence of transitions stages, where the stages reflects the motivational and cognitive obstacles humans face when trying to change the behavior. In addition, some travelers do not have the same accessibility, a wide selection of transport modes; because some people live far away from the city center, where the frequency of public transport is low. Meanwhile, other people could have limited accessibility due to natural limitations, which Koppelman and Bhat (2006) mean to be affecting the transport mode choice. The traveler mode choice is not only dependent on the accessibility, but also on the uncertainty, and quality of the transport modes. For example, delay is one main factor that traveler focus on, because majority of the trips are made in connection with time pressure where people have to be at a certain place at a specific time. Several travelers plan their journey to have a good time margin, but there is still other travelers that don't, and thus car travel can be a more convenient choice. However, there is still uncertainty in car travel relating to time, such that there is a car accident on the road, or that the car breaks down, which will affect the travel time.

6.2.2 Travelers acceptance and perception

Travelers acceptance and perception of the intervention is also important because if more people reject an intervention, it can create a rebellion among the travelers. In some cases, the introduction of an intervention is central to what the travelers perception and behavior would be when the actual implementation takes places. Therefore, to prepare the travelers for how the things will change may increase the effect of an intervention, where people have more time to

think an evaluate how to proceed. Grotti et al. (2022) mentions that applying these policy measure alone will not provide the same effect, because the perception of policy measures depend on public transport, socio-demographic factors and situational factors. For instance, through campaigns and awareness event for how car travel impact the environment in universities with implementation and improvement of alternative transport modes may increase involvement and encouragement among people. For example, the parking charge in Rotterdam involved the parking price to be specific for the users, and also launched a cash-out-scheme to encourage the car owners in the area to decrease their car use. However, if this intervention was well prepared before implementing, in terms of an event to increase the awareness of car users impact on society and environment; share this in social media and flyers; engage more people to inform about the intervention and its benefits, would have encouraged more people, which could increase the intervention effect. Bamberg et al. (2011) expresses that influencing the travelers by altering their perceptions of the consequences related to the different travel modes, and empower the decision maker to choose an efficient travel mode. An applicable method is to utilize the four stages of behavioral change described by Bamberg et al. (2011), and shown to be successful of personalized travel planning based on ex-ante study. This study showed that the effect reflected travelers behavior where they tried to be in line with their personal norms.

6.2.3 Interventions affect younger peoples travel behavior

Thaler et al. (2018) explained that interventions that aim to reduce car use can also influence young people to decrease the uptake of car dependency as a transport mode. Hence, teaching young people that car travels could be substituted with other convenient transport modes. For example, travel planning for school and universities could stimulate a sustainable travel behavior, such as cycling and walking to school, to meet friends, etc., which could affect other travels than just school-home based. The same thing could be argued for the mobility service, where alterative transport modes and encouragement through providing discounted travels could inspire people in young age to use sustainable transport modes. Overall, while interventions to reduce car use have the potential to yield significant benefits for the environment, public health, and transportation infrastructure, they may also pose challenges in terms of access, convenience, and social equity. Therefore, it is important to carefully consider the potential impacts of such interventions on various stakeholders before implementing them.

7 Conclusion

The aim of this master thesis is to identify interventions that aimed at decreasing car usage in and around cities. To fulfill the aim, this thesis presents a comprehensive analysis of multiple methods for measuring and evaluating the impact of reducing car use. Therefore, understanding the different metrics to measure reduction in car use is crucial. This thesis identifies multiple intervention types that has reduced car use, focusing on strategies that decreases the overall share of car use. Additionally, the thesis emphasizes intervention types that have achieved high effect, to embrace how car usage could be reduced in the best way.

This thesis has identified interventions used to reduce the share of car use from 48 city cases, and was categorized into 12 intervention types. Many of the intervention types involved multiple measures, and different combination of intervention categories. The different interventions has applied a combination of push & pull approach, and some applied only a pull approach. The results of the analysis on ex-post studies was compared to the ex-ante studies, in terms of simulation results and real measured results. This comparison enabled to identify differences and similarities in the achieved effect from the interventions; as well as evaluate the intervention effect in terms of location and extent of effect to achieve car use reduction.

The effect of transport interventions can be identified in different ways, where the mutual definition is to express the effect as a measure to reduce the impact on society and environment caused through car transport. The effect of transport interventions utilized in this study is car use reduction, however, other definitions could be reduced congestion, reduced greenhouse gases, etc. However, these definitions of transport intervention effect are rather a small collection of many other that has not been presented in this thesis. Two general methods that can be used to measure the intervention effect in terms of measuring vehicle kilometer travelled, traffic count, share of car journeys, travel time, queue length, reduced fuel consumption, public feedback, etc., is through using ex-post or ex-ante approach. The ex-ante perspective is about evaluating scenarios through the circumstances and the outcome possibilities for different levels. Meanwhile, the ex-post perspective describes the actual level of effort when evaluating uneven accomplishments. However, in both methods an evaluation of the intervention effect is needed, such as using experimental design, quasi-experimental design, or cohort-analytic. These methods are used to determine

Transport interventions aim to facilitate a sustainable travel behavior, and affect travel perception throughout influencing travel choice. Transport intervention focuses on influencing travelers to switch from car to for instance public transport or non-motorized transport modes, as well as consider making the trip in the first place. Through establishing such travel behavior, the total car travel will be decreased, which decreases the share of car use. Therefore, to achieve a reduction in car use a behavioral change regarding mode choice is necessary. This could be achieved through soft policy measure, hard policy measure or a combination of both, where the soft policy measure refers to using techniques of information persuasion and dissemination to influence travelers to choose sustainable travel mode like public transport instead of car.

Meanwhile, hard transport policy measures refers to increased costs for car use, improvement of infrastructure for public transport, and rationing or prohibition of car use, to push travelers from not important car travels and replace car travel with sustainable transport modes. However, the purpose of both intervention measures is to facilitate travel mode change, encouraging travelers to choose travel modes that do not involve a single passenger travel. Instead, push the travelers toward travel modes that utilizes time, space, vehicles and fuel in the movement in a more efficient way. For instance, increasing the filling rate of a vehicle through sharing the ride, which will decrease the number of cars on the road.

Intervention types with the highest effect identified in this thesis and found in Figure 6, was mobility service, shared mobility, access limitation and congestion charge. These interventions has shown to have higher average effect in reducing car use than parking charge, parking management, travel planning and app for sustainable mobility. These intervention types have achieved different extent on their effect, mobility service, shared mobility and congestion charge are intervention types that has achieved a regional effect, while access limitation has achieved a local effect. These intervention types have also used different combinations of policy measures and intervention approaches. For example, mobility service have used a pull approach. Meanwhile, shared mobility, access limitation and congestion charge have used push and pull approach. However, mobility service and shared and shared mobility have used soft and hard policy measure, while access limitation and congestion charge have used only hard policy measure.

7.1 Future work

This thesis has studied a limited part of this subject, and therefore there are various ways to develop the search within this topic. For example, focus the study on the intervention effect and provide more details, as well as provide efficiency in terms of effect per invested cost. This will allow a more detailed comparison of different intervention types based on ex-post studies. Furthermore, identify more studies that has used similar method to measure their intervention effect, to enable a fair comparison in terms of achieved effect.

This thesis could be progressed through choosing intervention types that focuses on other types of effect (i.e., greenhouse gas emissions, safety and traffic flow) to obtain other perspectives that regard the intervention effect. For example, explore which interventions that have effectively reduced the previous mentioned effects, to further compare two effect types with each other to analyze differences and similarities.

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