Introducing Mass Transit in Gothenburg

Relationships Between Travel Time and Mode Choice

Master’s thesis in Infrastructure and Environmental Engineering

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ABSTRACT

Transport is a vital service that allows us to move between places we need to be and makes our daily life puzzles possible. Transport planning has for a long time focused on car travel which is coupled with both congestion and environmental issues. It is necessary to promote a more sustainable mobility and one way to do that is to make better use of transit. To achieve a shift from car towards transit it must be a competitive alternative. One of the most influential factors on individuals' choice of transport mode is travel time. Reduce a modes travel time and the utility of that mode will increase, and so will its market share. This thesis aims to investigate the relationship between travel time and mode choice by quantifying the effects of transit travel time through a meta-analysis approach. The literature search focus on, but is not limited to, studies of mode choice taking a multinomial logit (MNL) approach for reasons of interpretability. Elasticities derived from a sample of 16 studies conclude that a reduction by transit travel time by 1% can be expected to bring an increase of the transit mode share by 1.29%. Further, a 1% reduction in in-vehicle times of bus and metro are found to increase their shares by 0.59% and 0.33% respectively. The acquired elasticities are applied on a sketch complement to the transit network in Gothenburg, Sweden, to see what changes in mode split that can be expected if it were to be implemented. The potential travel time savings brought about by the proposed service are estimated between twelve activity centres in the city. The service is one of metro-standard and configurated based on a combination of local knowledge and transit ridership data provided by the local transit agengy. Results show an expected increase of the transit mode share in the range of 4.9-18.8 percentage units in the affected area and an increase of daily transit trips by as much as 20 000 (8%), perhaps even more. Ideally a meta-analysis gathers all previous studies of a certain topic. Although that is rarely a possibility, a larger sample of studies would have enabled more accurate and more diverse results to be derived. The decision to focus on MNL mode choice models might have impeded the final sample size and also the occurring modal distinctions through its inherent IIA assumption.

Key words: *Mode choice, travel time, meta-analysis, elasticity, transit, network design*

Införande av stadsbana i Göteborg
Relationer mellan restid och färdmedelsval

Examensarbete inom masterprogrammet Infrastructure and Environmental Engineering

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SAMMANFATTNING

Transporter är vitala tjänster som tillåter oss att resa mellan platser vi behöver besöka och som gör vårt dagliga livspussel möjligt. Transportplanering har under lång tid varit inriktad mot bilresande som är förenat med både trängsel och miljöproblem. Det är därför nödvändigt att främja ett mer hållbart resande och ett sätt att göra det är att utnyttja kollektivtrafik bättre. För att uppnå ett skifte från bil till kollektivtrafik måste det senare vara ett konkurrenskraftigt alternativ. En av de mest inflytelserika faktorerna på en individs färdmedelsval är restid. Genom att minska restiden för ett färdmedel ökar dess attraktivitet, och i förlängningen dess marknadsandel. Detta examensarbete syftar till att undersöka relationen mellan restid och färdmedelsval och effekterna av restid med kollektivtrafik kvantifieras genom en metaanalys. Av tolkningsskäl fokuserar litteratursökningen på, men är inte avgränsad till, studier över färdmedelsval vars strategi bygger på användandet av en multinomial logit-modell (MNL). Genom elasticiteter erhållna från 16 olika studier dras slutsatsen att en restidsminskning för kollektivtrafik med 1% kan förväntas orsaka en ökning av densammas färdmedelsandel med 1,29%. Vidare kan en minskning av restid på buss eller tunnelbana med 1% förväntas orsaka en ökning av deras marknadsandelar på 0,59% respektive 0,33%. De förvärvade elasticiteterna appliceras på ett förslag till kollektivtrafikutbyggnad i Göteborg för att se vilken förändring i färdmedelsfördelning som kan förväntas om utbyggnaden skulle bli verklighet. De potentiella restidsbesparingarna som den föreslagna utbyggnaden medför uppskattas mellan tolv aktivitetscentra i staden. Utbyggnaden förutsätts vara av en standard som motsvarar tunnelbana och konfigureras genom en kombination av lokalkännedom och resdata från det lokala kollektivtrafikbolaget. Resultatet visar en förväntad ökning av kollektivtrafikandelen på 4,9-18,8 procentenheter i det berörda området samt en ökning av det dagliga kollektivtrafikresandet med så mycket som 20 000 resor (8%), kanske ännu mer. Helst samlar en metaanalys all tidigare forskning inom ett visst ämne. Även om detta är sällan är möjlighet så skulle ett större urval av studier ha möjliggjort ett mer tillförlitligt och diversifierat resultat. Beslutet att fokusera på färdmedelsvalsstudier som använde MNL-modeller kan ha hämmat storleken på det slutliga urvalet samt den ingående färdmedelsuppdelningen genom dess inneboende IIA-antagande.

Nyckelord: *Färdmedelsval, restid, metaanalys, elasticitet, kollektivtrafik, nätverksdesign*

Contents

Preface

The idea for this thesis has emerged during the numerous early mornings spent on the tram, travelling from my home up to the university. Trams have always fascinated me. When I was little my parents could keep me perfectly pleased just by taking me on a ride from one end station to the other. That feeling of pleasantness remains with me still today in my adult life, although now I like to spend my ride-time re-visualizing the cityscape as it passes by outside the window glass. That of course requires a seat to be available, which unfortunately too often is not the case. Instead you might find yourself standing the entire trip, feeling the discomfort of being squeezed in together with too many people, not even having enough space between your feet to allow your bag to be put down on the floor. The air is thick with the breath of others. Could someone open a window? Like grass in the wind, people swing in tandem, back and forth, to compensate for the intermittent acceleration and deceleration activities of the metal vehicle. The journey is not long, it only takes minutes, but the squeaking experience seem to never end. Once again, the mind drifts away. There must be a better way. Travel should not be this discomforting. What could be done? What would it look like?

The previously depicted experience occasionally takes place in Gothenburg, my hometown.

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I wish to send my sincere thanks to all who have been involved in this project and all of you who have supported me along the way, you know who you are. Special thanks to Västtrafik whom shared their data with me and PTV Group for providing me access to Visum. Although I was compelled to change the initial approach, I still got an opportunity to learn a lot for the duration. A most profound thank you also to my supervisor, Ivana Tasic, for your excellent guidance and the many fruitful discussions during this time.

Gustav Blomgren, May 2020

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1. Introduction

Transport is but one of many services being offered in cities. It can be argued, however, that it is among the more important ones. It allows us to reach our jobs or schools, places we need to visit almost every day, and therefore allows us to live further away from those locations. It also provides access to, and thus enables the utilization of, desired services such as healthcare, leisure activities, social interactions, and other matters of interest in our everyday lives.

This study is partly set in Gothenburg, a Swedish city of 580 000 people in its municipal area according to Statistics Sweden, SCB (2020). It is sometimes nicknamed the Los Angeles of Sweden due to a car-centred focus in its historic transport planning. The truth in the previous statement can be debated. True is, however, that the city also offers an intricate public transit network, the core part being a tram network supplemented by trunk bus lines (Västtrafik, 2020). Tramways have been part of the city's transport system since 1879 and have expanded over the years since (Göteborgs Spårvägar, 2020a). Nevertheless, the system suffers from congestion and low speeds due to a combination of frequent stop spacing and the fact that almost every line is routed through the same point in the very centre of town (Västsvenska Handelskammaren, 2015).

Public transit is widely debated in the city. There is a consensus around the fact that it is necessary to increase the share of trips made with public transit at the expense of those made by car, not least from an environmental perspective. What is less agreed upon is how to get there. In the book 'Modelling Transport' by Ortúzar and Willumsen (2001), the authors begin by proclaiming that:

> *... old problems do not fade away under the pressure of mild attempts to reduce them through better traffic management; old problems reappear with even greater vigour, pervading wider areas, and in their new form they seem more complex and difficult to handle. (p. 1)*

In spirit with the quotation above, one eventually passes the point where minor adjustments, attunements and alterations no longer are enough to keep advancing challenges at bay. Instead, new efforts, and even entirely new solutions, may be required. At the same time, it is important to remember that the provision of transport infrastructure is an extensive and demanding business. Ortúzar & Willumsen (2001) points out the difficulty of transport investments in the sense that they most often require a lot to be done at once in order for them to be beneficial. Constructing parts of a railway simply will not work. As a result, transport projects are typically large, time consuming and expensive. Therefore, a thorough planning process is essential before any larger transport investment to make sure that what is to come, with the greatest possible probability, provides the desired effects.

This thesis reviews the foundations for creating effective public transit networks as well as desirable characteristics that makes them attractive to users. A meta-analysis is conducted concerning the role of travel time in the mode choice process. Based on this knowledge, further attention is given to the specific case of Gothenburg where a sketch complement to the existing transit system will be outlined, consisting of a circular mass transit line around the downtown area. This central service is subject to further analysis through application of the meta-analysis findings.

1.1 Purpose and aim

The purpose of this work is to investigate the effects of travel time on travel mode choice and then to apply those findings on a proposed mass transit development in the form of a new transit line in Gothenburg, Sweden. The impacts of said hypothetical new transit implementation will then be evaluated. While those may be many and diverse, the focus will be on two of them, namely travel time and modal split. The aim is subsequently to evaluate whether the new addition is viable in this sense, or if it is not.

1.2 Scope

The study is oriented towards transport supply in the perspective of the quality of service provided. The level of quality is valued through the potential savings in travel time the service can provide compared to the existing situation. Expected future environmental impacts from construction or operation phases of the service are not considered or quantified further, neither are economic aspects (finance and funding) nor the possible occurrence of modal preference based on anything other than total travel time a subject of this study.

1.3 Social and ethical aspects

The study, and the work put into it, has no implication on social or ethical aspects in itself, but it deals with features that indeed would have, provided the evaluated object of study, or something similar, would be realised in the future. Implementing a new public mass transit service would inevitably affect people's ability to reach the served destinations, both in terms of travel time and capacity. A shorter travel time to reach a destination, and a greater capability of transporting larger amounts of people to it, increases its accessibility. That in turn could contribute to rising land value. While that also may be desirable, it could also potentially have a negative impact on previous occupants in the area as rental expenses probably would increase as well. Another accessibility-related aspect could also be to the service itself. Stop and vehicle configurations would need to be designed in such a way that all potential users recieve unobstructed access.

All data used in this research is non-confidential and used with permission.

This study only provides an initial step in the process of evaluating the feasibility of a proposed transport service. If considered beneficial enough, more studies regarding other aspects would have to be carried out. The possible influence on sustainability, including the social and ethical aspects, would have to be further investigated in those.

2. Background

It can be said that cities, from the very beginning, have been a spatial relationship between mainly buildings and surfaces dedicated for transport. Over time those surfaces, i.e. the infrastructure, have developed in tandem with the technological advancement, adopting new forms and shapes, allowing for new means and modes of transport. The world has seen a rapid urbanization process ever since the industrial age when machines and factories created job opportunities in cities, and new inventions made farming much more efficient. This trend has been particularly strong since the 1950s during which time the urban population has increased about fifty percent faster than the global population (United Nations, 2019a). In 2007, a symbolic shift occurred when the world's urban population surpassed the rural. Today 55 percent of the population are urban dwellers. The urbanisation trend is not only due to cities being centres of human activity in general, but also because modern transport systems allows them to be (Vuchic, 2007). When a city grows, the need for transport grows with it. Somewhat simplified this relationship becomes stronger the larger the city becomes, since the distances will become greater, and more people need to travel. Without sufficient means of transport, increased areal size would inevitably act as a growth restraint.

Transport, although crucial for city functionality, does not come without its problems. And despite the advancement and technological leaps our society has taken during the past century, the issues in the field remain much the same in our days as in the past, in particular problems regarding pollution, congestion and safety (Ortúzar & Willumsen, 2001). According to the European Environment Agency, EEA, the transport sector was responsible for 27% of the total greenhouse gas emissions of the European Union member states in 2017, the largest part caused by road transport (EEA, 2019a). Cars exclusively represent about 12% of the total greenhouse gas emissions in the region. Perhaps even more problematic are local effects caused by transport such as noise and air pollution. Those are considered among the largest health risks in Europe (EEA, 2019b), (EEA, 2019c). Health impacts include annoyance, sleep deprivation, stress, and disease, but they are also estimated to be responsible for many thousands of premature deaths every year.

For reasons just mentioned it is highly desirable to increase the public transit ride share. During many years, the focus of transport planning was on forecasting future demand to estimate necessary capacity increases (Rodrigue, 2017). This led to an extensive highway construction which only strengthened the car as the dominating mode for transport. One must remember that this was a time when environmental concerns had not yet gained much notice. Nonetheless, the legacy of this era is what it is, and in order to increase public transport it needs to be a competitive alternative to the car (Daganzo, 2010).

2.1 Benefits of transit

Unlike the early days of transit when most services were founded on private icentives and motivated by the potential to make profit, the bulk of all transit systems of today are instead publicly owned, hence the common denomination public transit (Rodrigue, 2017). As such its operation and development are subject to political motives. The change was driven by the increasing availability of the car from the 1950s and onwards which brought both lower ridership figures and caused cities to develop in a less transit-friendly manner, i.e. they became more spread out. Deteriorating and no longer self-sustaining transit systems were then taken over by authorities to sustain some mobility, almost as a social service. The financially troublematic situation of transit systems are thus most often supported by subsidies. The subsidy rate of Swedish transit was 43% on average in 2016 but the figure varies a lot between different regions (Swedish Competition Authority, 2018). The lack of financial stability is in part because transit is viewed as a service designated towards taxpayers rather than potential customers (Rodrigue, 2017). As a result, transit systems are developed in areas where the customer base is not large enough to sustain it. Another issue is that the utilized transit technology may not be suitable for the area that it serves, e.g. high-cost rail systems in low-density neighbourhoods. Stjernborg and Mattisson (2016) has investigated the societal role of public transit in Sweden. Transit is viewed as vital in the planning process towards meeting different societal goals and, in addition to achieving better mobility, promotes economic growth, regional development, accessibility, and environmental sustainability. Environmental gains are in the form of reduced air pollution and emissions, mostly related to reduced car use through a presumed modal shift towards transit. Reduced car use may also have implications on safety due to less traffic. In the policy documents reviewed by the authors, a well-functioning transit system is considered to boost regional attractiveness and to facilitate for people in their everyday lives. Yet another benefit of transit is the increased amount of land that is available for development (Ortúzar & Willumsen, 2001). It is known that, whatever form it may take, transit make more efficient use of space than private vehicles. All in all, the benefits of transit are numerous and despite its economic disability, transit is key to urban sustainability.

2.2 How do people choose transit?

The choice of transportation mode depends on many different factors. One important factor is the purpose of the trip; is it the daily commute to or from work, is it shopping, or is it a social trip? Car travel seems to be more convenient for social trips and shopping while transit is more commonly utilized for leisure and longer trips (Shmid et al., 2019). For the individual, time and costs are significant aspects. One can imagine other factors of importance to be distance to nearest transit stop and service frequency. For elderly people it is likely that seat availability is of greater importance. To use the car (presuming car is an available option) instead of public transit is both comfortable and convenient (Lundin, 2014), and during the early years of automobile use when car ownership became more and more frequent, there was a significant decrease in public transit ridership (Vuchic, 2007). The balance between public and private transport depend on city characteristics such as physical form and density alongside the quality offered by the existing transit system, the distribution of streets and freeways, and the eventual plans for future transit improvements.

2.3 Report outline

The remaining chapters are organised as follows. The following section provide a general overview of the subject transit, what it is and what it implies, what one should keep in mind when configuring a network, and what makes it attractive to riders. Attention will also be given to common methods used to model travel demand. Section 4 then presents the methodology behind the meta-analysis approach and the design of the new transit service. Results and subsequent analysis are presented in Section 5 followed by a discussion around the findings in Section 6.

3. Structure and Implications of Transit

When faced with a problem in need of fixing, it helps to know which tools are available, what to make use of where, and when to use it. Understanding public transit, and its different components, is thus of great importance in order to promote a more sustainable mobility.

First, there are different terms used to describe transit, and sometimes they have different meanings. Other occurring terms include public transit, public transport, mass transportation, mass transit, or just transit, plain and simple. Henceforth, transit will be used as a joint term for all different modes of publicly provided transport, while mass transit will be used when addressing high-performance modes, most notably metro systems. As will later be made clear, these are modes which are both faster and have higher capacity than other public transit modes and they have in common that they exclusively utilize guided technology.

3.1 Transit network design

Transit network design rest on three fundamental objectives, namely to maximise ridership, maximise economic and operational efficiency, and maximise positive impact on the area of implementation (Meyer & ITE, 2016). From a rider's point of view, it means the network should provide an attractive service in terms of speed, reliability and frequency. Stops need to be both reachable and convenient for as many riders as possible, and well-integrated with other transport services to facilitate necessary transfers. Positive impacts on the area could be for example an increased public transit mode share, less congestion and pollution, and desirable urban development.

3.1.1 Line alignment

The building blocks of transit are lines and stops. It is the alignment and interrelation of different lines that creates and defines a transit network (Meyer & ITE, 2016). The most common type of line alignment are radial lines which extend from the city center out into more peripheral areas. These lines typically experience increasing passenger loads as the distance to the centre decreases. A related alignment configuration are diametrical lines that basically are two radial lines coupled together making it possible travel from one side of a city to the other without transfer, in contrast to only reaching the centre. Diametrical lines are not necessarily straight, L-shapes are also frequent and even U-shapes exist. An important aspect to consider when designing diametrical lines is to strive for balance between the two arms. If the travel demand on one arm were to differ substantially from the other, one of those would inevitably be underutilized. One way to account for varying demand along a transit path is to integrate several lines at sections with high demand. Line integration implies a sectional overlapping caused by lines merging and diverging at different locations. These so-called trunk lines have the benefit of increased frequency at the overlapping sections, thus providing higher frequency and capacity, while they in more peripheral areas branch out to instead provide better coverage, but with lower frequency and reduced capacity. For example, a trunk line with three branches, each with a frequency of twelve minutes, would ideally operate with a four-minute headway in the overlapping section. Concurrently, the capacity at the branches would only be one third of the capacity at the overlap. The remaining alignment types have in common that they avoid serving the city centre. Tangential lines provide perpendicular connections between radial lines, and circle lines literally forms a complete circle, interacting with all existing radial lines. Lines forming part of a circle are denoted circumferential. Unlike the other alignment types, circle lines are continuous and thus more sensitive to delays since there are no end-stop intermissions to make up for lost time.

3.1.2 Urban form

To fully understand transit network design, one must also be familiar with urban form as those two features are closely intertwined (Rodrigue, 2017). Rodrigue (2017) describes how the urbanization process has progressed hand in hand with transport development and this has influenced the spatial organization of growing cities. This can be seen in older cities which often display a dense mixed-use core reminiscent of a time when urban mobility was restricted to mainly walking. As you move further out from the core, the spatial structure changes following the evolution of transport technology. This evolutionary process is also visible through the land use of more modern cities (Rodrigue, 2017). While the walking city only dedicated about 10% of the land for transport infrastructure, a motorized city could easily see a share of 30% with an additional 20% dedicated to parking. However, the average in Western Europe is that roads account for 15-20% of the land use.

Increased mobility has transformed many cities into more polycentric arrangements in contrast to the previous monocentric form, especially in the post-car era. The opportunities the car offered when it became available to ordinary people inspired the development of suburbs far away from the city centre (Lundin, 2014). The car became a symbol of freedom as it allowed one to go almost anywhere at a time of your choosing. This is closely related with the phenomenon of urban sprawl which describes the extensive geographic expansion of cities. Between the years 2000 and 2014, the global urban expansion of cities was 1.28 times larger than their population increase, by consequence leading to lower population density (United Nations, 2019b). Low-density development and car use are strongly related (Rodrigue, 2017). The provision of public transit depends on the number of potential users since fares help make up for operation costs. When people are more spread out, more infrastructure per unit area is required to serve the same number of people as in a denser area. It is also harder to make the transit service attractive when the travel demand may be too low to motivate a decent service frequency. All in all, this may leave the car as the only viable option. To oppose this a new form of managed growth has been suggested, called transit-oriented development (Meyer & ITE, 2016). The strategy centres around the transit facility itself and build upon the idea of providing great connectivity both locally, to nearby neighbourhoods, and to more remote areas through a variety of different transit services. A pedestrian-oriented environment is promoted by high-density and mixed-use developments and parking limitations.

Different cities exhibit different street patterns depending on their geography, topography, and general planning history. Many cities either have the predominant part of their streets organised in a grid pattern or in a ring-radial pattern circulating the city center. This has implications on transit network design since many transit systems utilize those streets, and thus the same street pattern, for their operation. Walker (2010) view the grid pattern as ideal for transit systems in denser cities, especially if they are of more polycentric character. The grid is efficient is terms of stop distribution and will allow any kind of trip to be made with one transfer only. However, Chen, Gu, Cassidy and Daganzo (2015) do not reach the same conclusion. According to their models which aim at developing a city-wide transit network to the lowest cost, considering both grid and ring-radial street distributions, they find the ring-radial pattern to be more beneficial to transit. The main reason for this its ability to concentrate travel demand, which from a transit perspective is favourable since concentrated demand increases service efficiency, and by that lowers cost. Trips are also more direct in general.

3.1.3 Area coverge

A fundamental part of a transit networks is the area coverage since it forms the basis for the potential number of travellers the system can attract (Meyer & ITE, 2016). Transit services should be offered at places where people start their trips, an allow them to reach their desired destinations. It is commonly assumed that people access transit stops on foot and thus the area covered by a transit stop is limited by a certain distance that a typical person is prepared to walk. The United Nations (2019b) considers a distance up to 500m to the nearest (bus) stop as good coverage. In practice, however, a stop might have a much larger coverage than that although that also imply other means, for example cycling, to access the stop (Meyer & ITE, 2016). If the provided transit service is of high quality, people are willing to travel longer to access the stop, sometimes even by car. One form of this is called park-and-ride which means that one uses the car to reach a suitable transit stop and then use the transit service for the rest of the trip (Vuchic, 2007). It is most often used as a substitute for car commute from suburban areas. Kiss-and-ride imply a similar trip configuration with the only difference of being dropped of at the transit stop by someone else rather than parking your own car. This form of multimodal transport is one way to alleviate congestion and to make travel more sustainable, given necessary transit facilities are established. In more central areas, however, walking is the utterly dominant form of accessing transit stops, thus relying on relative stop-spacing for good coverage (Meyer & ITE, 2016).

3.1.4 Marchetti’s constant

Apart from offering the trip relations desired by travellers, a well-performing transit network should also do so in a limited amount of time. There is a concept describing the amount of time an individual is supposedly willing to spend on one-way commuting trips (Rodrigue, 2017). This has become known as Marchetti’s Constant and is generally considered to be around 30 minutes. The constant is derived from the apparent instinctual behaviour of humans (Marchetti, 1994). Without going into more detail about the theory behind this concept, the behaviour demonstrated by Marchetti’s Constant raises questions about optimal city size and could potentially serve as a framework when planning new developments.

3.2 Transit modes

Vuchic (2007) considers three typical characteristics when defining public transit modes, namely right-of-way (ROW), system technology, and type of service. The ROW describes the separation relative other traffic and is categorized into three levels, A, B, and C. Category A in this division means that the mode in question is fully separated from other traffic by either grade separation or extensive signal priority to such a degree that eventual crossings do not influence the performance. Category C is the opposite and implies a high level of on-street use where the mode shares the space with other types of traffic. Modes that enjoy partial separation are assigned category B. The second characteristic, system technology, describes modal structure and mechanics such as how it is supported with regard to the riding surface, if it is steered or guided, how it is propelled, and to what level it is controlled, i.e. manually or automatic. Lastly, the type of service characteristic hold information on route design and operation time and type. Differentiation into separate modes are made if at least one of these characteristics exhibits a clear distinction.

3.2.1 Mode classification

Attributes on speed, capacity, reliability and safety are used to define the performance of public transit modes (Vuchic, 2007). The larger or higher these get, the better the performance. ROW has a large influence over the performance of different modes. For example, the absolute separation provided by ROW A takes away the restraining effects caused by intersections and other traffic, enabling both higher speeds and better safety due to fewer intermodal conflicts. Fewer conflicts and better safety in turn reduce the risk for disruptions leading to better reliability as well. Vehicle and operational configuration can also be freer when less attention is needed towards other modes, thus allowing larger or longer vehicles with increased capacity. Performance measures are commonly used to categorize public transit modes into street transit, semirapid transit and rapid transit (Meyer & ITE, 2016). Because ROW has a substantial impact on modal performance, this classification system closely resembles how modes would be distinguished just based on that trait. Below follows a short description of each category and a selection of modes belonging to them based on the work of Vuchic (2007).

Street transit: Street transit utilizes surface modes and primarily operates under ROW category C, i.e. they share space with other traffic. As such, the performance is tied to traffic conditions which lower the modal reliability. Buses are the predominant form of street transit, but this category also include trams and trolleybuses. The fact that traffic flow is acts as a determinant for speed most often makes street transit slower than cars because they also make frequent stops to let people on and off. However, the performance of both buses and trams can be increased significantly by providing them with preferential treatment, thus qualifying them for the definition of semirapid transit.

Semirapid transit: This category implies an increased level of attractiveness among passengers due to better service characteristics regarding speed, reliability and capacity. The improvements are conditioned a ROW B operation. Minor sections of ROW A or C can also exist in semirapid transit systems. Most tramways fall under this category although in this case they are more commonly denoted as light rail transit to differentiate them from lower-performing tramways. Light rail, however, use the same technology as trams and is often sprung from those older systems. Some defining features are increased separation and signal priority in line with ROW B, longer and articulated vehicles, lower flooring that improves vehicle accessibility, and larger stop spacing. Semirapid transit also include, despite its name, bus rapid transit, which can be described as a heavily prioritized form of bus transit. Besides the obvious difference in system technology, its service characteristics are similar to that of light rail, but vehicular capacity is much lower.

Rapid transit: Metros, or rail rapid transit, is the most widely used mode of rapid transit. It is the superior mode considering capacity, speed, reliability and safety. Similar performance is offered by the more uncommon modes of rubber-tired rapid transit and monorails. Light rail rapid transit is yet another mode in this category which only differs in relation to the other three in terms of capacity, which is lower. All rapid transit systems are guided and operate exclusively on ROW A. In addition, they can more easily be designed as fully automated systems. When referring to mass transit in this thesis, those are the modes inferred.

Paratransit: Some transport modes show similarities with public transit but not enough to be classified as one. Paratransit is a concept that collects modes that are difficult to categorize as either strictly public or strictly private (Vuchic, 2007). These modes are demand-responsive in the sense that routes and schedule are adapted to the individual user in contrast to usual public transit modes which run on fixed routes and schedules. The most common example of this semi-public form of transport is the taxi. Two other paratransit modes are the intermediate between taxi and private car, car sharing, and dial-a-ride between taxi and bus. Dial-a-ride differs from regular bus services in that they need to be called in advance. Desired time, pick-up site and destination are usual specifications and operators typically try to plan the route to serve several users with the same vehicle. Paratransit might grow in importance in the future given the development of autonomous vehicles. The potential on-demand services they offer may pose a new competitor to public transit given the convenience and attractive door-to-door service (Rodrigue, 2017). Autonomous vehicles are also considered to offer more environmentally friendly driving patterns and increase traffic safety (RISE, 2020). Given the vehicles are shared, as would be a prerequisite for inclusion in the paratransit family, the need for parking will also be reduced.

The previous categorization allows for the inclusion of most frequently used public transit modes. Exceptions are modes that are customised for certain natural or topographical conditions such as ferryboats, ropeways and others.

3.3 Factors of transit mode choice

There are many reasons behind an individual’s mode choice for a certain trip, but to state the obvious, a mode must first and foremost be available before it can be considered (Meyer & ITE, 2016). The more available, both in spatial and temporal terms, the more attractive it will be. Hollevoet, De Witte and Macharis (2011) has reviewed which factors play in during the decision process between different transport options. Most studies concerning mode choice are found to take a rationalistic approach where the travellers’ decision ultimately comes down to maximizing utility by minimizing travel time and travel cost. However, other studies occur that take on the problem from either a socio-geographical or psychological approach, thereby introducing spatial and psychological components to the issue. The authors categorize the modal determinants into spatial, socio-demographic, journey, and psychological determinants. Spatial determinants include urban population density and proximity to both public transit and road infrastructure. Parking, public transit frequency, land use diversity and the possible need for transfers are others. Transfers avert people from using public transit and guaranteed free parking promote car use regardless if public transit is faster. Increasing density typically increases proximity to infrastructure, thus increasing its availability. In addition, it reduces parking space and works as a driver for walking and cycling by reducing trip distances. Among socio-demographic determinants, car availability is the most influential. It is in turn interrelated with income, education, and employment. Having children is also an important car-favouring factor. Another determinant is lifestyle. Certain lifestyles can influence mode choice both in itself and by extension through other determinants. What type of trip, when it is made (peak or off-peak), and whether it is direct or part of a chain are determinants related to journey characteristics. In particular trip chains are sensible to infrastructure coverage to impede complexity. Other important and more well-known journey determinants are travel time, distance, and cost which are all related to each other. Finally, psychological determinants of interest are experience, modal perception, and habits. Past experiences affect travellers' attitudes towards different modes, and thus their perception of them. Similarly, habitual behaviour may unconsciously prevent travellers from taking available information under consideration in the modal decision process.

Although Hollevoet et al. (2011) do not present details on the relative importance of each determinant, it is still an interesting enumeration of relevant factors in need of consideration. They manage to highlight the complexity involved in mode choice underlining the interrelation of different factors and the involvement of both subjectivity and unawareness in the decision process.

3.3.1 Crowding

A traveller's perception of a mode is ultimately derived from its provided level of service. Some aspects of this are already mentioned, such as travel time and cost. However, reliability, safety and comfort are other relevant aspects (Vuchic, 2007). Comfort variables are for example in-vehicle climate, cleanliness, impressions of vehicle movement and presence of information systems (Meyer & ITE, 2016). But perhaps an even more important aspect of comfort is crowding, i.e. how many other people one is sharing ride with. There is no fixed measure of what crowding really is although a common definition is the relation between the number of passengers and the number of seats, called load factor (Tirachini, Hensher and Rose, 2013). Sometimes, however, the concept is also used to denote the number of passengers in relation to the total vehicle capacity, including both seated and standing riders. A third occurring measure of crowding is density of standees per square meter. Just like with the measure itself there is no consensus around at what point crowding comes into effect. Nonetheless, increased levels of crowding acts as a deterrent in transit attractiveness and evidence points towards travellers being willing to spend extra time waiting if they think it will increase their chance of being able to get a seat. Consequently, increasing the number of seats acts positively on transit comfort, but at the same time it lowers the overall capacity since seated passengers occupy more space than standees (Meyer & ITE, 2016).

3.3.2 Transit travel time and reliability

The travel time of a trip is not limited to the time one stays on a vehicle. There is also time spent on accessing the transit stop, time spent waiting for the vehicle to arrive, time spent during transfers, and time spent reaching the destination from the alighting stop. Door-to-door travel time is one of the most important factors of transit attractiveness according to Meyer and ITE (2016). In a survey with 3001 respondents conducted in the Swedish region of Västra Götaland, people were asked about their travel behaviour and opinions about transport (Västtrafik, 2019). When respondents are asked what would make them travel more sustainable, 43% answers better public transit followed by cheaper at 22%. 83% agree with the statement that travel time is a decisive factor behind their choice of travel followed by price at 65% and the environment at 48%. Reducing travel time is thus a key part in the endeavour to promote the use of transit over the car.

Crowding, as recently discussed, do not only act negatively on comfort, it also has implications on transit operations affecting both travel time and reliability (Tirachini et al. 2013). At some point the available seats will run out and travellers are compelled to stand. An increasing number of standees may hinder movement inside the vehicle, obstructing the boarding and alighting procedure at stops and thus leading to longer dwell times. People standing at or near doors are found to have a larger impact on this effect than people standing in the aisles, but the manner in which people choose to distribute themselves onboard a vehicle can to some degree be influenced by vehicle design. A similarly delaying effect is caused by crowding at stop platforms which can be obstructing for people trying to leave or enter a vehicle. High occupancy further increases the risk for bunching. Bunching is when, for example a bus, experience unexpectedly long dwell time at a stop (or ride time due to e.g. traffic conditions) and as a result it falls behind schedule. By being late it is likely to encounter a larger demand than planned at the next stop, and thus falling even further behind schedule. The effect is amplified along the bus route eventually causing the bus behind it, which on the contrary will meet a lower passenger demand, to catch up.

Ultimately, in the worst case, crowding may cause the vehicle to reach its occupancy limit, forcing it to leave passengers behind, resulting in longer waiting times and higher experienced travel discomfort (Tirachini et al. 2013). Delays are always undesirable and the risk of facing longer travel times than expected lowers service reliability in the eyes of the affected traveller. As such, reliability can be defined as the probability of the service reaching its destination on schedule. However, operators might define what is on schedule slightly different. As an example, Swedish passenger trains are considered on time if they arrive at their end station within five minutes after the scheduled time (Transport Analysis, 2020). On the other hand, the public transit operator in Gothenburg define on time as not arriving at a stop more than half a minute early or three minutes late (Göteborgs Stad, 2020a). However, reliability is not always a measure of punctuality, although it is the traditional meaning of it (Cevallos, 2016). From a traveller's point of view, it can also be a measure of whether the trip lives up to the expected level of service regarding for example comfort and seat availability.

3.3.3 Value of time

Time it seems, is not a fixed entity. At least not from a subjective point of view. In fact, people value time differently depending on situation. For transit, that implies a distinction between different parts of the trip. For example, Abrantes and Wardman (2011) finds that time spent walking and waiting during journeys in the UK is valued 1.65 and 1.70 times higher compared to time spent in-vehicle. Supposedly the ratios reflect a greater discomfort for those parts of the trip, causing travellers to perceive them as longer. According to Litman (2017) It could also be an effect of the fact that time in-vehicle allows for one to use that time in a more productive manner, e.g. to work or read for the duration. The value of time can be used to estimate the willingness to pay for various network or service improvements. Björklund and Swärd (2015) investigated Swedish transit users' willingness to pay for reduced discomfort and found that standing travellers were willing to pay 30-37 SEK per hour to get a seat. They also estimated a value of hourly transit travel time savings of 54 SEK. Willingness to pay measures are useful in cost-benefit analyses conducted to check the economic viability of transport projects. The value of travel time varies greatly depending on both trip characteristics and those of the individual traveller (Börjesson & Eliasson, 2014). As a result, a reduction in travel time will undoubtably also be valued differently depending on who is asked.

3.3.4 The necessity of transfers

The necessity to make transfers to reach a desired destination can be hard to avoid in many transit networks. It is well-known that transfers discourage people from using transit and the negative impact on commute satisfaction grows stronger when waiting times are longer (Lunke, 2020). According to Gong, Currie, Liu and Gou (2017) the waiting time and eventual walk time required at transfers are but one of two negative components of transfers. The second component is a subjective penalty caused by the transfer event itself. They also find this penalty to vary dependent on outside effects such as weather, direction of travel, and modes between which the transfer occurs. The disutility of transfers sometimes makes travellers take detours just to avoid them (Litman, 2017). In consideration of the negative attitude towards transfers, direct trips are always ideal. Although this is an impossible objective there are ways to reduce the need for transfers, for example through trunk lines with branches which increase the availability of direct lines, albeit at the prize of reduced frequency. When transfers cannot be avoided it is still possible to reduce the disutility by making them as convenient as possible by coordinating schedules and minimising the distance required to move at transfer locations (Meyer & ITE, 2016).

3.4 Designing a mass transit system

Mass transit, metro systems in particular, are the most effective and high-performance means of transit that are available to date (Vuchic, 2007). They are also the most expensive to construct. A common question that arises is what size of a city is required for a metro system to be feasible. Unfortunately, there is no straight answer. For a long time, one million inhabitants were considered a benchmark for constructing metro systems but several cities, e.g. Stockholm and Lisbon, had a population in the range of 700,000 when their systems were first inaugurated. Oslo had not even reached half a million when their system opened. Instead of population it is more relevant to consider density when planning for new metro systems, since spread out low-density development lack support for more high-performing services.

Transport investments are often motivated by their ability to stimulate new development due to the increased accessibility they provide (Meyer & ITE, 2016). The primary objective for a mass transit service is typically to reduce the travel times as much as possible for as many as possible, and that requires good coverage (Laporte, Mesa, Ortega, & Sevillano, 2005). However, there is a constant trade-off between these two goals since more stations will provide better coverage, but also contribute to increasing travel times due to more frequent stops. Instead the service needs to be allocated to places with significant travel demand, ideally featuring a stop spacing between 500 and 2000 meters. Deciding upon suitable locations on where to place the service is the initial step of mass transit design (Cadarso & Marín, 2015). One can argue that capacity is not a relevant aspect to consider at this stage since it is more of a strategic decision. Unlike busses or trams, metro systems do not suffer the same constraints regarding vehicle length. Their capacity is instead mainly determined by the lengths of the stations which in turn determine how many cars each platform may accommodate. In contrast, a bus can only be so lengthy as traffic regulation allows it to. Length may also be of additional concern in central areas where intersections are frequent and stop area limited. The same applies to tram systems, although to a varying degree. Newer tram systems are designed to allow for longer vehicles, but older tram systems typically were not. These are more inclined to include sharp turns and to larger degree make use of on-street operation together with other traffic. Many of them were originally operated by horse-drawn carriages (omnibuses) and are not well-suited for more modern tram operation unless they are dramatically reconfigured.

3.4.1 Alignment geometry

The performance of mass transit is related to its horizontal and vertical alignment (Vuchic, 2007). The curvature on a line influence the speed by which a curve can be traversed, and the gradient affect the technological capabilities that the service must possess. It is unusual for newer systems to feature curve radii below 120 meters and many standards set the bar even higher. Although greater radii benefit performance it is important to note that it also might imply design difficulties, especially in dense urban areas, resulting in rising costs. Cost is also associated with the gradient since a higher gradient will require a higher power-to-weight ratio of the operating vehicles. Brussels currently feature the steepest mass transit service. It operates with a maximum gradient of 6.25% and approaches the practical limit for mass transit systems. Steeper grades of up to 8% are physically possible, but only under special circumstances which makes it unsuitable for regular operation. A recommended extreme value for new lines is 6% even though most systems today seldom exceed gradients of 4%.

3.4.2 Further considerations

Transit design in general is troublesome because of the scale and diversity of the problem (Bruno, Gendreau, & Laporte, 2002). Most methods deal with the allocation of single lines, as opposite to entire networks, and tentative approaches focusing on downtown activity centres and arteries are common. Another challenge is the fact that the proposed transport service does not yet exist since it is difficult to predict the attitudes of travellers towards new and different options that they have no previous experience of (Ortúzar & Willumsen, 2001). The reason for this is because it is common for the modelled demand to be based upon observed behaviour, i.e. revealed preference. When this is not possible, surveys on stated preference could be useful, in which respondents are faced with hypothetical choices. It is important, however, to account for an eventual exaggerated enthusiasm, which is not an uncommon feature when people are asked about how they feel about future solutions. In the end, transit is about taking people where they need to go. Having access to information on where people come from and where they intend on travelling, so-called origin-destination data, would be ideal in the case of transit network design (Bruno, Gendreau, & Laporte, 2002). Such data can however be both hard and costly to get hold of. Another issue is that the demand after implementation might differ from the demand observed beforehand.

Depending on city typologies different modes will be more or less well-suited in certain situations (Vuchic, 2007). Large transit cities typically offer a wide variety of transit alternatives tailored to specific conditions. For example, high-quality modes are superior at transporting many people fast across long distances, but their coverage is significantly inferior to that of a regular bus. Multimodal networks commonly allow for better integration in the urban landscape but at the same time emphasizes the requirement for smooth and efficient transfers between different modes. To achiev that is not seldom costly and perhaps also difficult in terms of scheduling, but cities who offer such services are often rewarded with higher ridership per capita (Vuchic, 2007). Excellent modal networks but poor integration between them may lead to underutilization of both modes. It is important to have the interest of the transit users, present and future, in mind when planning new developments and a long-term planning horizon rather than minimising short-term costs.

Public transit is highly demand dependent (Rodrigue, 2017). With increased demand, transit grows in efficiency while it is the other way around if the demand is reduced. Poorly planned transit increases the risk of underutilization which may have severe economic implications. The same result can be achieved by oversized dimensioning. While underutilization a serious issue, overutilization is less of a problem. If demand increases, this can often be met by increased frequency, longer vehicles, or both.

3.5 Models of travel demand and mode choice

Travel demand is derived from a need for mobility across a certain space which is both time- and purpose-specific (Ortúzar & Willumsen, 2001). As such, travel is a service which will only be demanded if it matches the need at present and similarly travel services are only beneficial if provided when and where there is a need for them. This makes estimation of travel demand highly relevant in the context of transport planning. It also helps to explain the attractiveness of the private car, which after all, always stand ready and available to those who own them. If the car in addition enable a smoother trip, perhaps both faster and cheaper than transit, then the reasons for not taking it might weigh light in contest to the alternatives.

Transport planning, of which demand estimation is a vital part, commonly involves making use of different models to predict future scenarios and through that provide support for necessary strategic decisions. A model in its simplest form can be conceptually represented by a response variable Y, as a function of a set of variables X of some relative strength given by coefficients θ:

$$Y = f(X, \theta) \tag{1}$$

Before a model can be used it must be calibrated and estimated which mean finding parameters relevant for the desired outcome and to determine their values. A widely known model for travel demand estimation is the classic transport model, also called the Four-Step Model, which consist of four steps: trip generation, trip distribution, mode choice and trip assignment (Metropolitan Washington Council of Governments, 2020). In the first step, trip generation, the study area is divided spatially into zones, commonly denoted traffic analysis zones (TAZs), which are connected to each other by the transport network. The purpose of the zones is to make means for possible travel movements, acting either as an origin or as a destination for a trip. Each zone will yield a certain number of both generated and attracted trips respectively based on a model including for example population level and composition, social characteristics, economic activity, and land use for a base year. For example, a zone with a large share of residential development will see more trips being produced while an employment-heavy zone will see more trips being attracted. Since the conditions will vary between zones, so will the amount of produced and attracted trips. The second step, trip distribution, distributes the generated trips between the TAZs, matching the respective number of trip attractions and productions, resulting in a flow-matrix between the included zones. The distribution process is reliant on the assumption that travel time is perceived negatively. Mathematically it is represented by a friction factor that increase the burden of travel the farther away (measured in time) the trip end lies. As such, a larger share of trips produced in a zone will have their ends in nearby zones rather than in zones situated far away from origin. In the third step, mode choice, trips are divided across different modes through a function considering the availability and relative attractiveness of the mode alternatives. This can then be converted into values of probability for choosing a particular mode. The fourth and last step then consist of assigning the trips to their respective modal networks, visualising the flows. Which route a trip is assigned to take is a question of minimising impedance for the path. For road links the impedance is given by volume-delay functions which describe the effective travel speed on the link as an effect of the traffic flow. By scaling up the base-year conditions, future travel demand can also be estimated.

3.5.1 Discrete choice

Mode choice is commonly modelled as a discrete choice problem, i.e. when an individual is compelled to choose only one option out of a finite set of alternatives. What choice is made depends on how attractive the option is and on the socioeconomic characteristics of the individual that is faced with the choice (Ortúzar & Willumsen, 2001). These factors are accounted for by the utility of each choice, a theoretical construct which the chooser is presumed to maximise. The framework of random utility theory states that individuals of a population, Q, possess perfect information and act rationally in the sense that they will always choose the option that maximises their own personal net utility. The utility of an option, j, for an individual, q, is given by the following formula:

$$U_{jq} = V_{jq} + \varepsilon_{jq} \tag{2}$$

The first term, V_{jq}, is the measureable part of the utility and is a function of different attributes related to the alternative and the individual. The second term, ε_{jq}, is an error, or disturbance, term to weigh up the fact that the modeller does not have complete knowledge of every single element involved in an individual's decision-making. Since it is practically impossible for the researcher to capture every single aspect of utility, the error term is used to represent the unobserved part. It is treated randomly and is assumed to follow a specified probability distribution function. The measurable, or observed, part of the utility function usually takes a linear form according to the formula below, but other forms are also occurring. The attributes related to the individual and the alternative are given by X_k, and the coefficients, β_k, represent the relative strength of the different factors involved.

$$V = \beta_1 X_1 + \beta_2 X_2 + \ \dots \ + \beta_k X_k$$

$$V_{jq} = \sum_k \beta_{jk} X_{jkq} \tag{3}$$

Utility-values are used in discrete choice models to predict the probability of an individual to select a certain mode of transport. Wittink (2011) provides an example where the choice-maker has three alternatives to go to work, either by taking the car, the bus, or to walk. The observed utilities are found to be $V_{Car} = 4$, $V_{Bus} = 3$ and $V_{Walk} = 3$. Because of the unobserved part of the utility function, this does not mean that going by car will always be the best option, only that it seems more likely. If the unobserved utility regarding for example walk were to be significantly better than the corresponding unobserved utility for the car alternative, then walking would be chosen instead. The probability for this to happen is the same as the probability for the difference between the unobserved utility of walk and car to be larger than the difference between their observed portions. According to Wittink (2011), this can be expressed generally as:

$$P_{in} = Pr\left(\varepsilon_{jn} - \varepsilon_{in} < V_{in} - V_{jn}\ \forall j \neq i\right) = \int_{\varepsilon} I\left(\varepsilon_{jn} - \varepsilon_{in} < V_{in} - V_{jn}\ \forall j \neq i\right) f(\varepsilon_n) d\varepsilon_n \qquad (4)$$

The first part of the integral is an indicator function taking the value 1 granted the statement inside the parenthesis holds, or 0 if it does not. Depending on the assumption about the density function used to distribute ε, the integral will take either an open or a closed form. The specification of $f(\varepsilon_n)$ also defines the type of the discrete choice model. Probit, and logit are two common families among discrete choice models (Wittink, 2011). In probit models the disturbances are normally distributed and the integral above takes an open form. In logit models the integral instead has a closed form thanks to the disturbances being logistically distributed. The estimation of the parameters β_k are usually carried out by means of maximum likelihood for both logit and probit models, however, the open integral form of probit models make those analytically less convenient due to the increased complexity it infers. As a result, probit models are problematic when datasets are large. This limitation is not shared with logit models and for that reason they are used much more often.

Discrete choice theory consists of a diverse and manifold group of models. Only a few of them will be mentioned here. The multinomial logit model (MNL) is one of the most frequently used (Ortúzar and Willumsen, 2001). In the model the disturbances are assumed to follow an IID (independent and identically distributed) Gumbel distribution which allows the model to be written as:

$$P_{iq} = \frac{e^{V_{iq}}}{\sum_{A_j \in A(q)} e^{V_{jq}}} \qquad (5)$$

The model tells the probability of an individual q to select mode i from a predetermined set of j alternatives. It is expressed as the natural logarithm raised to the power of the selected mode's observed utility divided by the full set of alternatives expressed in the same manner. The MNL model gained popularity due to being able to predict multiple choices from larger datasets (Ortúzar and Willumsen, 2001). The computational power required is relatively low compared to other models which also has contributed to make estimation software widely accessible. Further, the model's simple formulation makes it easy to interpret and thus it is also easier to extract behavioural implications from it. A disadvantage of the MNL is that it cannot account for eventual taste variations among individuals, i.e. when the perceptions of different attributes vary. However, the biggest limitation of the MNL is the independence of irrelevant alternatives (IIA) assumption which basically states that the relative probability of choosing one alternative over the other remain unaffected by the eventual inclusion or exclusion of some other alternative (Ortúzar and Willumsen, 2001). The ratio between two choice alternatives, P_1 and P_2, in the equation above rewritten such that:

$$\frac{P_1}{P_2} = \frac{e^{V_1}}{\sum_{A_j \in A(q)} e^{V_{jq}}} \Big/ \frac{e^{V_2}}{\sum_{A_j \in A(q)} e^{V_{jq}}} = \frac{e^{V_1}}{e^{V_2}} = e^{(V_1 - V_2)} \tag{6}$$

It becomes clear that the relationship is a fixed constant. A famous example which often occurs in literature that illustrates this is the red bus blue bus paradox. Consider initially a case where the mode split is divided equally between private car and blue buses, i.e. their respective utilities are equal and $P(Car) = P(Blue\ Bus) = 0.5$. Suppose a new bus service is introduced with exactly the same level of service as the previous one, i.e. the same utility, but with a different colour, red instead of blue, then the IIA assumption states that $P(Car) = P(Blue\ Bus) = P(Red\ Bus) = 0.33$. Since introducing the red buses does not contribute to increase the bus utility, it would be a more realistic scenario if the proportion of car users remain at 50% while the bus users split equally between the two bus alternatives. It is thus important that alternatives included in multinomial discrete choice models are not mutually correlated.

The IIA disadvantage of the MNL can be mitigated by instead using a nested logit (NL) model structure (Elshiewy, Guhl, & Boztug, 2017). The NL model is similar to the MNL but in contrast it has different levels which allows similar alternatives to be grouped in different nests. Regarding mode choice it enables separation of for example private modes from public at one level, and specific modes at the next. A schematic example of such a structure, containing two levels and three nests, is shown in Figure 1.

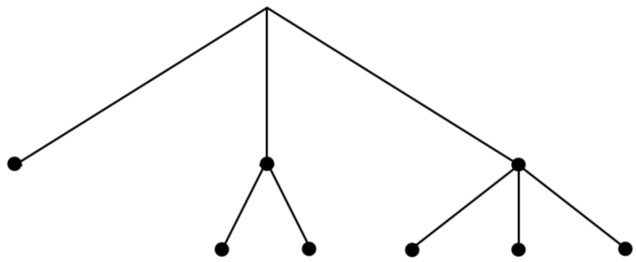


Figure 1. Example schematic structure of an NL model.

In general, the NL contain k nests and the number of levels may also vary from two and upwards. The probability for an individual n to choose an alternative i from nest B_k is expressed in the equation below. The correlation between alternatives within a nest is captured by the parameter λ_k (*k=1, … ,K*) which if estimated to 1 collapses the structure into an MNL form.

$$P_{ni} = \frac{e^{\frac{V_{ni}}{\lambda_k}} \left(\sum_{j \in B_k} e^{\frac{V_{nj}}{\lambda_k}} \right)^{\lambda_k - 1}}{\sum_{l=1}^{K} \left(\sum_{j = B_l} e^{\frac{V_{nj}}{\lambda_l}} \right)^{\lambda_l}} \tag{7}$$

For better interpretability it can be divided in two parts where the probability of choosing an alternative i in nest B_k is expressed as the product of first choosing the nest, and then the specific alternative within it (Wittink, 2011). This is achieved by distinguishing the part of the observed utility which is mutual within a nest from the part which varies between the included alternatives:

$$U_{ni} = V_{ni} + \varepsilon_{ni} \rightarrow U_{ni} = W_{nk} + Y_{ni} + \varepsilon_{ni} \tag{8}$$

Here W_{nk} represent the utility of the variables describing nest k and Y_{ni} represent the utility of variables which are tied to the specific alternatives. Y_{ni} is in turn formulated as the observed utility V_{ni} subtracted by the utility that is mutual in the nest, i.e. W_{nk}. The probabilities for an individual n to choose the nest P_{nB_k}, and specific alternative in that nest $P_{ni|B_k}$, are given by the following expressions:

$$P_{ni} = P_{ni|B_k} \times P_{nB_k} \tag{9}$$

$$P_{nB_k} = \frac{e^{W_{nk}+\lambda_k I_{nk}}}{\sum_{l=1}^{K} e^{W_{nl}+\lambda_l I_{nl}}} \tag{10}$$

$$P_{ni|B_k} = \frac{e^{\frac{Y_{ni}}{\lambda_k}}}{\sum_{j \in B_k} e^{\frac{Y_{nj}}{\lambda_k}}} \tag{11}$$

$$I_{nk} = ln \sum_{i \in B_k} e^{\frac{Y_{in}}{\lambda_k}} \tag{12}$$

The term I_{nk} defines the inclusive utility which the choice-maker always can expect from choosing an alternative from within the nest B_k.

Although partially relaxing the IIA assumption, the NL similarly to the MNL can not account for taste variations. One model that is unrestrained of both those assumptions is the mixed logit (ML) model (Wittink, 2011). The use of ML models offers increased flexibility and widened opportunities thanks to its ability to cope with panel data, but it is also more complex which has limited its applicability. Other advanced discrete choice models are for example machine-learning models (Zhao, Yan, Yu, & Van Hentenryck, 2020). Those models are generally considered superior as they are not bound to predetermined model structures and assumed disturbance distributions. Their predictive superiority, however, come at the cost of yet increased complexity which often makes them considered uninterpretable. Neither ML nor machine-learning models will be further covered in this paper.

3.5.2 The elasticity measure

The estimated parameters in discrete choice models do not provide much information other than their strength relative each other. Arguably it is more interesting to investigate their implications on individual behaviour and a common way to do that is to derive elasticities. Elasticities can be used to indicate the magnitude and direction of change in response given a change in a determinant variable (Balcombe et al, 2004). Applied in transportation that could be the modal shift resulting from a change in a mode choice variable. There are two distinct forms of elasticity. Own-elasticity refer to the change in probability of choosing a certain mode given a change in a variable associated with that mode, and cross-elasticity which refer to a probability change brought about by changes in attributes of other modal alternatives. Balcombe et al. (2004) defines elasticity as:

$$E_{x_i} = \frac{The\ proportional\ change\ in\ demand}{The\ proportional\ change\ in\ the\ explanatory\ variable} = \left(\frac{\Delta y}{y} \bigg/ \frac{\Delta x_i}{x_i}\right) \tag{13}$$

Here y is the response variable, i.e. the probability of choosing a particular mode, and x_i is the explanatory variable of interest for that choice. The effect change that x_i brings upon y can be described by a demand function and represented by a demand curve (Balcombe et al. 2004). When the change in x_i is extremely small, it becomes clear that the elasticity is represented by the slope of that curve multiplied by the ratio between the explanatory and response variable, at a specified point given by the value of x_i. This is referred to as the point elasticity.

$$E_{x_i}^{point} = \lim_{\Delta x_i \to 0} \left(\frac{\Delta y}{y} \bigg/ \frac{\Delta x_i}{x_i}\right) = \frac{x_i}{y}\left(\frac{\partial \mathrm{y}}{\partial \mathrm{x}_i}\right) \tag{14}$$

Because elasticity is a measure of percentage ratios it is dependent on where along the demand curve it is computed. Considering a hypothetical case where the demand behave linearly given unit changes in x_i the elasticity would be greater for larger values of x_i than for small values (since a one-unit change of x_i is proportionally smaller when x_i is large and thus the demand change relative the change in x_i will grow in proportion as well). If the change in x_i is large, it can be cumbersome to use this method of computing since the elasticity in another point on the demand curve is likely to be different (Balcombe et al. 2004). For that reason, large differences in x_i are better represented by computing arc elasticities which have the advantage of incorporating two points on the demand curve instead of only one. It is also reversible, i.e. if a variable x_i is increased by some amount, and then decreased by the same amount, the response variable will return to its original value. The arc elasticity is given by the following formula where y_1 is the original demand and y_2 the new demand given a change in the explanatory variable of interest from x_{i1} to x_{i2}:

$$E_{x_i}^{Arc} = \frac{\log y_2 - \log y_1}{\log x_{i2} - \log x_{i1}} = \frac{\Delta(\log y)}{\Delta(\log x_i)} \tag{15}$$

4. Method

The ultimate objective of the study is to evaluate the effects that a proposed mass transit addition would have on the transport system. Particularly the study aims to answer questions about changes in travel times and their impact on modal split. Ideally, the new addition would offer a service which in the end makes more people choose public transit over their own cars, thus increasing the transit market share. The sought-after effect will be derived through a meta-analysis approach where already existing studies of mode choice are evaluated with respect to the importance of travel time. A benefit of the travel time measure is that everyone can relate to it. Although just one attribute among many in the mode choice process, Meyer and ITE (2016) deem travel time to be among the most influential on transit attractiveness.

4.1 Meta-analysis

A meta-analysis is a statistical analysis of a number of already existing studies with the intent of derive findings from a wide spectrum of research (Glass, 1976). It can thus be said to be a study of studies. The name for the approach was originally minted by Gene Glass who saw a need for better utilization of a rapidly growing amount of research. The procedure of meta-analysis dates back to the late 1970s but has since gained in popularity, primarily in the field of medicine but to a lesser degree also in transport (Elvik, 2005). Ideally, a meta-analysis of a certain topic includes all studies ever made on that same topic, without geographical or language restrictions (Elvik, 2005). Such extensiveness, however, is practically impossible to achieve. Still, as many relevant studies as possible should be attained with respect to the scope of the study and other possible constrains for the researcher(s). Which studies are to be used in the analysis should be predetermined by detailed inclusion criteria, and how those studies are retrieved should also be reported. A meta-analysis approach is useful when there exist several similar studies within a field from which knowledge can be summarised. The aggregated result grows in significance as the amount of studies included in the meta-analysis increases.

A renowned meta-analysis within the transportation field was carried out by Ewing and Cervero (2010). They inspected over 200 studies dealing with effects of the built environment on travel behaviour (measured in vehicle-miles travelled) and computed effect sizes out of 50 of them. Those were then turned into elasticities for easy interpretation of the impact from various specific built environment characteristics. Elasticities commonly describe the relative effect of the response variable given a 1% increase of a specified explanatory variable. This kind of knowledge could be of great value to many practitioners of transport and urban planning.

The first step of the meta-analysis is to gather research relevant to the decided topic. By that standard and in this context, it is desirable to collect as many studies as possible that deal with travel mode choice and where travel time is included as an explanatory variable. Focus lies on mode choice in an urban context and both car and transit options must be present for inclusion in the analysis. How travel time is treated varies between studies. Some deal with it in an aggregated form, i.e. the total travel time for a trip, while others divide the measure into for example in-vehicle time, access time, and wait time. In order not to disqualify too many studies already from the beginning it is decided to include mode choice studies regardless if they treat travel time in an aggregate or disaggregate manner.

The search for literature was mainly conducted through the Chalmers Library to gain content access to various journals and databases such as Science Direct, Elsevier, JSTOR, and Scopus. Searching was also conducted through Google and Google Scholar. Relevant studies were found by using different forms and combinations of the following keywords: mode choice, public transit, public transport, travel time, elasticity, modal determinants, multinomial logit, and metro. Further, several studies were found using an ancestry approach, i.e. backtracking literature found in reference lists of reviewed literature.

Travel mode choice is a form of discrete choice in the sense that there exist a finite set of unordered alternatives (Ortúzar and Willumsen, 2001). Which alternative is chosen is a function of its relative attractiveness to the other alternatives and the choice-maker's socioeconomic characteristics, i.e. the alternative's utility. There are many types of discrete choice models, some more intricate than others. Especially logit models have been dominant within transport research for a long time (Zhao et al., 2020). The simplest multiple-choice model in the logit family, not counting the binary logit which only can account for two alternatives, is the multinomial logit (MNL). It is well-known that the MNL suffer from limitations, most notably the IIA assumption. This has led to the development of nested and mixed logit models, which both are extensions of the traditional MNL structure, designed to mitigate those limitations. Still, the simplicity of the MNL is also its greatest advantage since it makes it easily interpreted and by extension its reported findings easy to applicate in the real world. Since in a meta-analysis one must be able to compare the results of different studies, the literature search was oriented towards, but not limited to, finding studies taking on an MNL approach in their respective mode choice models. In Section 3.5.1 (Equation 5) the MNL model was formulated as:

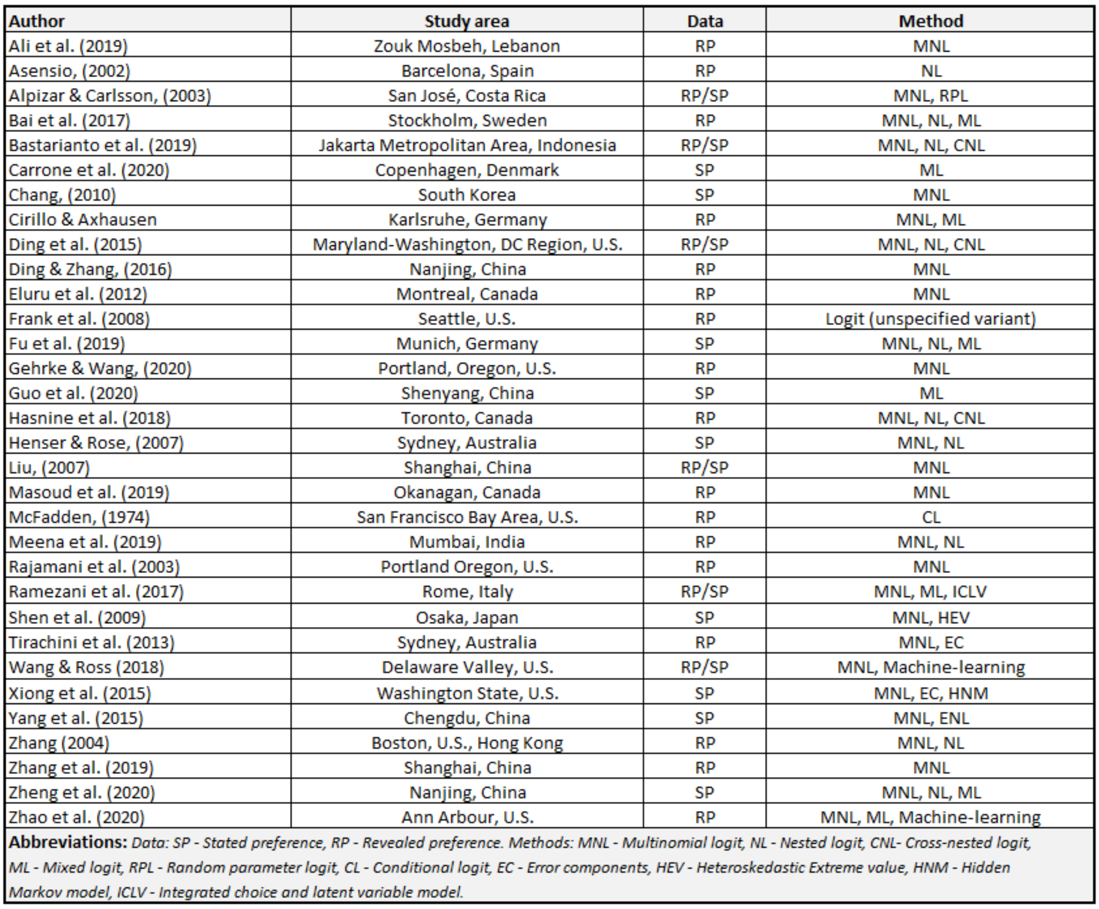
$$P_{iq} = \frac{e^{V_{iq}}}{\sum_{A_j \in A(q)} e^{V_{jq}}} \tag{5}$$

4.1.1 Collected studies

A total number of 32 studies dealing with mode choice in some aspect was collected for the analysis. The studies are geographically distributed, which is visible in Table 1, and represent conditions in various locations in North America, Europe, Asia and Oceania. Some studies were found to make use of several different models in their mode choice estimations. Most often the reason for this was to compare the difference in performance between various types of models, for example between the multinomial logit and the nested logit or between the multinomial logit and some machine-learning or other model specification. In those situations, regardless of which model is found to be superior, the results from the multinomial logit model are the ones in focus for the meta-analysis. Travel time, which is the focus for this analysis, is an important measure of the service offered by the transport alternative. As such it is seldom unaccounted for in mode choice models. The same can be said for travel cost, which is another service variable. Regarding socioeconomic variables those are typically represented by age, income, family status, car ownership etcetera. Apart from those general variables, when other variables are included, they are often representative of a special interest to the study at hand. Some put special interest in how the built environment and the urban form affect mode choice. Others have aims of finding the importance of reliability, the value of time, or the effect of a proposed future investment. However, this do not hinder a subsequent evaluation of the travel time variable. Other distinctive features between the collective studies are trip purpose, i.e. some studies focus exclusively on e.g. work-trips while others do not, and a few consider tours or trip-chains rather than individual trips.

Complete references to the collected studies are listed in Appendix I.

Table 1. Collected studies for meta-analysis.



Author	Study area	Data	Method
Ali et al. (2019)	Zouk Mosbeh, Lebanon	RP	MNL
Asensio, (2002)	Barcelona, Spain	RP	NL
Alpizar & Carlsson, (2003)	San José, Costa Rica	RP/SP	MNL, RPL
Bai et al. (2017)	Stockholm, Sweden	RP	MNL, NL, ML
Bastarianto et al. (2019)	Jakarta Metropolitan Area, Indonesia	RP/SP	MNL, NL, CNL
Carrone et al. (2020)	Copenhagen, Denmark	SP	ML
Chang, (2010)	South Korea	SP	MNL
Cirillo & Axhausen	Karlsruhe, Germany	RP	MNL, ML
Ding et al. (2015)	Maryland-Washington, DC Region, U.S.	RP/SP	MNL, NL, CNL
Ding & Zhang, (2016)	Nanjing, China	RP	MNL
Eluru et al. (2012)	Montreal, Canada	RP	MNL
Frank et al. (2008)	Seattle, U.S.	RP	Logit (unspecified variant)
Fu et al. (2019)	Munich, Germany	SP	MNL, NL, ML
Gehrke & Wang, (2020)	Portland, Oregon, U.S.	RP	MNL
Guo et al. (2020)	Shenyang, China	SP	ML
Hasnine et al. (2018)	Toronto, Canada	RP	MNL, NL, CNL
Henser & Rose, (2007)	Sydney, Australia	SP	MNL, NL
Liu, (2007)	Shanghai, China	RP/SP	MNL
Masoud et al. (2019)	Okanagan, Canada	RP	MNL
McFadden, (1974)	San Francisco Bay Area, U.S.	RP	CL
Meena et al. (2019)	Mumbai, India	RP	MNL, NL
Rajamani et al. (2003)	Portland Oregon, U.S.	RP	MNL
Ramezani et al. (2017)	Rome, Italy	RP/SP	MNL, ML, ICLV
Shen et al. (2009)	Osaka, Japan	SP	MNL, HEV
Tirachini et al. (2013)	Sydney, Australia	RP	MNL, EC
Wang & Ross (2018)	Delaware Valley, U.S.	RP/SP	MNL, Machine-learning
Xiong et al. (2015)	Washington State, U.S.	SP	MNL, EC, HNM
Yang et al. (2015)	Chengdu, China	SP	MNL, ENL
Zhang (2004)	Boston, U.S., Hong Kong	RP	MNL, NL
Zhang et al. (2019)	Shanghai, China	RP	MNL
Zheng et al. (2020)	Nanjing, China	SP	MNL, NL, ML
Zhao et al. (2020)	Ann Arbour, U.S.	RP	MNL, ML, Machine-learning

Abbreviations: *Data: SP - Stated preference, RP - Revealed preference. Methods: MNL - Multinomial logit, NL - Nested logit, CNL- Cross-nested logit, ML - Mixed logit, RPL - Random parameter logit, CL - Conditional logit, EC - Error components, HEV - Heteroskedastic Extreme value, HNM - Hidden Markov model, ICLV - Integrated choice and latent variable model.*

4.1.2 Compilation through elasticity computations

The findings of the reviewed studies must be converted into a common measure for them to be mutually comparable, and by extension for aggregated conclusions to be derived. Elasticities of the travel time variable are thus derived from the respective mode choice model estimations. More specifically it is own-elasticities that are derived. Unfortunately, far from every study report the necessary data required for those computations. Elasticities are dependent on the ratio between the proportional change in the response variable and the explanatory variable respectively. Thus, to estimate that relationship one requires information about the probability of choosing a particular mode before and after a change regarding travel time is made, holding all other variables constant. Since each model is based upon an observed sample population, the initial probability needs to be computed using sample means of the model parameters to be adherent. Many studies, however, only report the estimated regression coefficients of the model and do not reveal much about the data (i.e the sample population) it is based upon. While this enable for comparison of the relative strength between varios factors significant in the mode choice process, and allow computation of e.g. the value of time, it is not enough for elasticity derivations. As such, elasticities are either extracted directly from the reviewed studies in the cases where those are reported or calculated by using mean values of the explanatory variables and the estimated regression coefficients when possible. Studies failing to provide sufficient information are discarded from the meta-analysis. Regarding elasticities that could be extracted directly, it should be noted that not all of them were computed based on results from multinomial logit models.

As covered in Section 3.5.2, there are different ways in which elasticities can be calculated and due to the chosen method, the outcome may express a slight variation. At first, elasticity computations were carried out incrementally for a five-minute and ten-minute travel time saving respectively. However, due to the differences in reported mean travel times among the studies, five- or ten-minute changes represented quite substantially different portions of the total travel times. Also, where elasticities where already reported by authors it seemed customary to do so using point elasticities. For that reason, it was decided to exclusively use that measure and already performed computations were modified. According to Ewing and Cervero (2010) point elasticities from logistic regression models can be computed using the following formula where β and $\bar{x}$ represent the regression coefficient and the mean value of the variable of interest (i.e. travel time) respectively. The term $\left(\frac{\bar{y}}{n}\right)$ is the mean estimated probability by which the studied mode will be chosen.

$$E = \beta * \bar{x}\left(1 - \left(\frac{\bar{y}}{n}\right)\right) \tag{16}$$

The elasticity computation procedure is initialised by calculating the utility of each mode present in the mode choice model by using reported mean values and statistics of the study sample. Due to the decision to focus on mode choice studies taking a multinomial logit approach, the utility functions are likely to be organised in the common linear form. When all utilities are known the probability of choosing each mode is derived from the multinomial logit discrete choice model formulation. The desired point elasticities are then calculated with the formula above using the travel time regression coefficient (either total travel time by transit or in-vehicle time) and the recently estimated choice probability concerning the mode of interest. Presuming that reduced travel times are desirable the regression coefficient should always be negative. Own-elasticities occurring due to changes in travel time should thus also be negative unless they are reported in absolute values.

4.1.3 Presentation of results

The results from the meta-analysis will be compiled into a few different measures since the elasticities derived from the collected studies will have slightly different meanings. Ideally it would be interesting present elasticities differentiated by modes to see if there is any modal variation in the valuation of travel time change. Results will also be split according to which form of travel time the elasticity describe, i.e. if it is travel time in its aggregated form across the entire trip or if it only refers to in-vehicle time. If the sample is skewed in some way, for instance geographically, it might be necessary to weight the result. This process is facilitated if the sample of studies is large. Ultimately the derived elasticities will be presented as averages, weighted or plain.

4.2 Gothenburg network model

Municipal Gothenburg is the area of interest in this study. The city is situated by a river outlet on the Swedish west coast and features a transit network constituted by trams, busses, trains, and to some degree ferries (Västtrafik, 2020). The core of the system is made up by the tram network supplemented by trunk bus lines while the ferries take care of some cross-river traffic in addition to serving the southern half of the archipelago. A route network map is provided in Appendix II. Connections to surrounding areas are provided by express buses and commuter trains. The Central Station (Centralstationen) is the main transportation hub and most every significant transit line in the city are routed through this place if the stops surrounding the station are included in the definition. Consequently, the area suffers under congested conditions, especially during peak hours, inferring slow transit operating speeds. On the positive side, its connectivity is excellent. From this point it is possible to reach any other place in the city with a direct service. Since all major lines are more or less organised in a diametrical manner connectivity weakens as one moves outward in the system.

Stop spacing in the tram network is on average 600 meters, but 30 stops are placed less than 400 apart, and seven less than 240 meters (Västsvenska Handelskammaren, 2015). Spacings tend to be lower in the city centre. Due to the tram system’s configuration it is subject to operating restrictions. The Maximum speed is set to 50 km/h on sections with mixed-traffic operation or that are semi-separated except in the old city core where it is not allowed to go faster than 30 km/h (Göteborgs Spårvägar, 2020b). In peripheral areas where the track has its own embankment the speed limit is 60 km/h. The average operating speed in the tram network is currently 22 km/h (Rambøll, 2017). The effects of congestion and frequent stop spacing become obvious if a distinction is made between central and non-central areas. The average speed is 26 km/h outside the city centre and a mere 17.6 km/h within (Västsvenska Handelskammaren, 2015).

4.2.1 Activity centres

When planning for a network extension the initial step consists of identifying relevant activity centres. Activity centres can vary in size but are typically high-density areas, areas with high concentrations of retail or office space, and large entertainment or recreation facilities (Meyer & ITE, 2016). Hospitals, universities, government complexes, institutions, among other well-visited locations, are also potential activity centres. There are different ways of identifying these centres and some methods are more sophisticated than others. Casello and Smith (2006) concludes from a literature review that a common definition of activity centres, and method to identify them, are places where the job concentration is higher than in the surrounding areas. They themselves advocate for a slightly different definition which also consider the trip-attracting strength of different employment types, rather than just flat number of employees. Cats, Wang and Zhao (2015), on the other hand, uses transport flow data as an identification tool. As such, transport nodes could also be considered activity centres provided the passenger flows are large enough. For the sake of simplicity, this study considers activity centres as areas that attracts a considerable number of trips. They can be identified by any mean or measure available to the analyst, including the utilization of local knowledge.

4.2.2 Alignment

The next step is to connect the identified activity centres. This procedure is carried out ad hoc, with each connected centre representing a stop on a new hypothetical transit service. Depending on how these are spatially distributed in relation to one another, it can be difficult to integrate all of them in a functional manner. Some may be greatly offset compared to the bulk of centres while others might be found in very close proximity. In the first case, if deemed reasonable, those could be excluded. As for the second case, centres in proximity could be aggregated into one larger entity. It is desirable to connect as many of the identified activity centres as possible since this will increase the number of trips the service might provide for. However, the line still needs to be attractive to its users so too many detours will not be appreciated. Also, since the goal is to improve the performance of the transport system, it is important that the connection is made in either a way not already present, or by using a mode that offers a higher quality service.

4.2.3 Determination of mode

As a last step in the initiating procedure, it is necessary to determine presumed modal characteristics of the proposed service. Features that need to be taken into consideration are what kind of mode it is planned to be, relevant modal vehicle motion characteristics, and its expected delays related to stops (Daganzo, 2010). It is also necessary to determine whether the intended service is supposed to be integrated with the existing network. For example, if the service is a bus line it will probably use the road network already in place between its designated stops. If it is a rail-based service, it will be more separated from other modes and the route it takes can be freer in relation to the existing network. On the other hand, this would infer access and egress times which then need to be accounted for, for instance with a fixed penalty. At this stage one could consider several modes, or different modal characteristics, to subsequently evaluate the impact of different options. For the case of Gothenburg, however, only mass transit is of interest meaning the chosen mode will be rail-based with rail-related modal characteristics.

4.2.4 Transit travel time estimation

To be able to evaluate what effect the new transit service will have on travel times, those must first be estimated, both in a base scenario corresponding to the existing system performance, and in a hypothetical scenario where the new service is implemented. Transit travel times in the base scenario are estimated with the help of timetables and schedules under the assumption that those are reliable. This must include in-vehicle travel time as well as time lost due to accessing stops and doing necessary transfers. If the starting point of a trip, or if the destination is not served by a stop, one would in addition need to add time corresponding to the distance required to walk. Regarding the hypothetical scenario, those travel times are calculated based on the distance between stops (activity centres), and modal characteristics on acceleration, breaking, maximum speed, cruising speed, stop delay, and access penalty.

Travel time is a matter of vehicle motion (Vuchic, 2007). For a transit line, it is made up by the sum of a transit vehicle's travel time between individual stops with inclusion of the time spent idle. The time it takes to move between two consecutive stops is determined by a vehicle's acceleration and deceleration capabilities, its maximum speed, the possible utilization of coasting, and the stop distance. The vehicle movement can be considered as four regimes. First, the acceleration regime when the vehicle increases speed from a stand-still up to maximum speed. Second, the constant-speed regime where the vehicle operates at maximum speed. Third, the coasting regime. Coasting is when the vehicle stops providing thrust and instead coasts at a constant rate of deceleration. This is common among rail-based modes because of the low rolling resistance. Coasting entails a saving of energy at the cost of increased travel time. The fourth regime, the breaking regime, is when the vehicle actively decelerates.

The manner of vehicle movement is constrained by the spacing in meters, S, between stops. Dependent on technical characteristics there is a certain minimum distance required for the vehicle to reach its designed maximum speed v_{max} (measured in meters per second), and thereafter have enough distance left to break into a standstill. This is called critical distance and is a function of the maximum speed and the mean acceleration $\bar{a}$, and deceleration $\bar{b}$, capabilities:

$$S_c = \frac{v_{max}^2}{2}\left(\frac{1}{\bar{a}} + \frac{1}{\bar{b}}\right) \tag{17}$$

If S is larger than S_c, maximum speed will be reached, and coasting may be utilized if desirable. In cases where constant speed is maintained between the acceleration and breaking regimes the station-to-station travel time can be expressed as

$$T_s = \frac{S}{v_{max}} + T_l \tag{18}$$

where T_l is the incremental time lost due to stopping. It is representative of the time the vehicle 'falls behind' itself had it continued towards the next stop without stopping. It is in turn given by:

$$T_l = \frac{v_{max}}{2}\left(\frac{1}{\bar{a}} + \frac{1}{\bar{b}}\right) + t_s \tag{19}$$

The last term, t_s, in the expression above represents the time required at each stop for door management and to let people on and off. As such this form of station-to-station travel time can be divided into four intervals namely acceleration, constant speed, breaking, and stop dwell time. If coasting is utilized, the constant speed interval would be replaced by a slight deceleration caused primarily by rolling and air resistance. This can be expressed as

$$T_s = \frac{v_{max}}{\bar{a}} + \frac{v_{max} - v_c}{c} + \frac{v_c}{\bar{b}} + t_s = v_{max}\left(\frac{1}{\bar{a}} + \frac{1}{c}\right) + v_c\left(\frac{1}{\bar{b}} - \frac{1}{c}\right) + t_s \tag{20}$$

where c is the deceleration rate during coasting and v_c is the current speed when braking is initiated. When coasting is planned for, an initial computation of v_c is made using the following equation:

$$V_c = \sqrt{\frac{25.92\bar{a}\bar{b}cS - \bar{b}(\bar{a} + c)V_{max}^2}{\bar{a}(c - \bar{b})}} \tag{21}$$

Observe that V_c in this equation denotes the speed in kilometres per hour. If coasting goes on for long it eventually imposes undesirably long travel times due to lower speed. In such cases an additional fifth interval of maintained cruising speed t_v, normally taken as the maximum speed, is introduced. The equations for this interval and its imposed alteration on station-to-station travel time is presented below.

$$t_v = \frac{S}{v_{max}} - \frac{v_{max}}{2}\left(\frac{1}{\bar{a}} + \frac{1}{c}\right) - \frac{v_c^2}{2v_{max}}\left(\frac{1}{\bar{\bar{b}}} - \frac{1}{c}\right) \tag{22}$$

$$T_s = v_{max}\left(\frac{1}{\bar{a}} + \frac{1}{c}\right) + v_c\left(\frac{1}{\bar{\bar{b}}} - \frac{1}{c}\right) + t_v + t_s \tag{23}$$

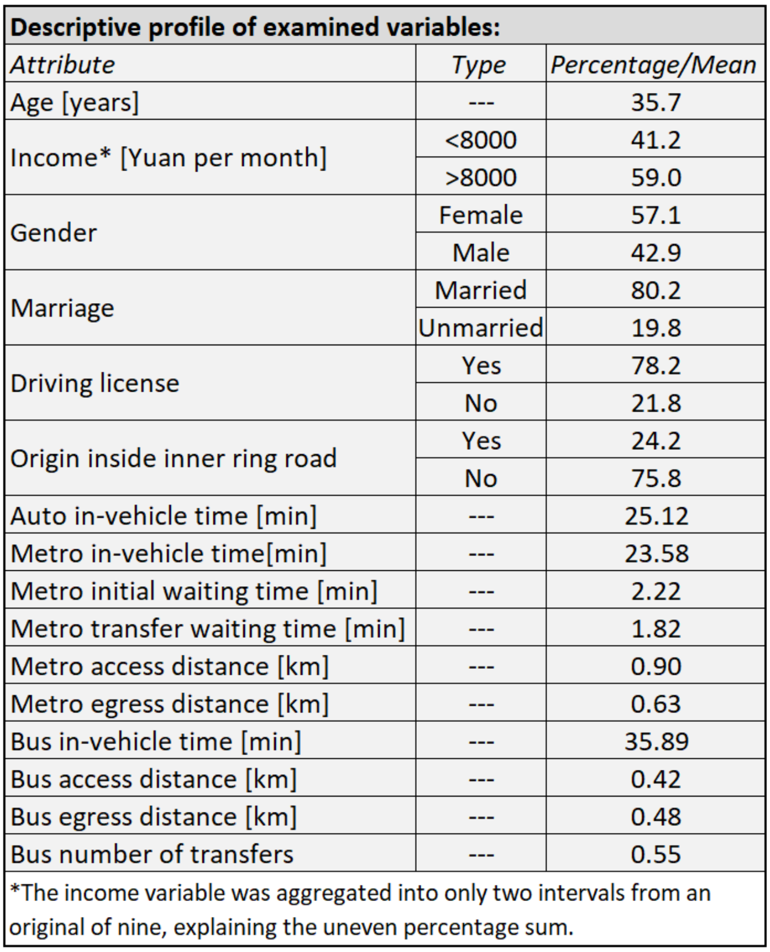
5. Results & Analysis

Results are organised in the following manner. First, conclusions from the meta-analysis of the travel time aspect in the mode choice process will be presented. Then follows a description of the network model including reasons for its configuration and the supposed effect it entails on the transit system. Lastly, the meta-analysis findings will be applied on the network model to illustrate the possible change in mode split, which was the objective of this work.

5.1 Meta-analysis of the influence of travel time on mode choice

The literature search resulted in a collection of 32 relevant studies and elasticities could be extracted or computed from 16 of them. Data from Zhang et al. (2019) is presented to explain the process behind obtaining the elasticities. The mode choice model at hand consider the socio-demographic variables age, income, gender, marriage, and possession of driving license. Mode-specific attributes include travel time (in-vehicle time) waiting time and access time. The model also accounts for the number of transfers made by bus-users and location of trip origin. Table 2 contain statistics regarding the mentioned variables which are derived from a sample population in Shanghai, China. Categorical variables are reported as percentages and continuous variables are reported using mean values. Modes of interest in the study are auto (car), metro and bus.

Table 2. Sample statistics on model variables from Zhang (2019).



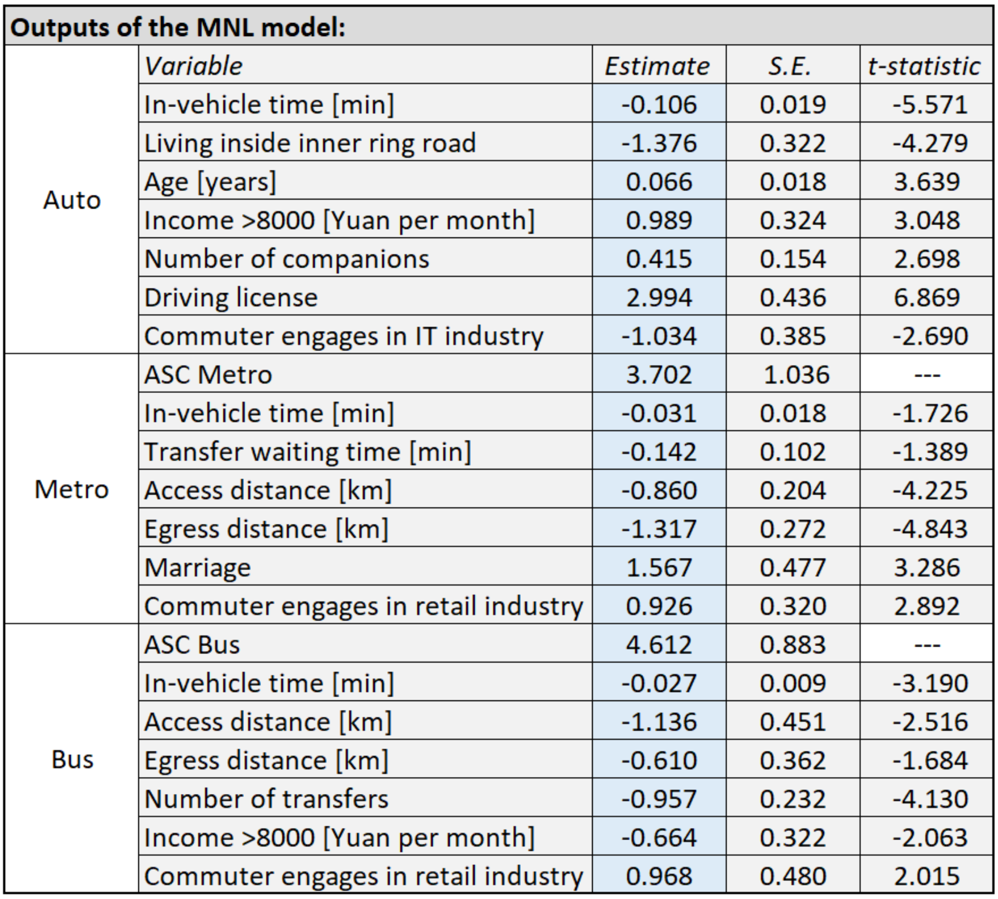
Descriptive profile of examined variables:

Attribute	*Type*	*Percentage/Mean*
Age [years]	---	35.7
Income* [Yuan per month]	<8000	41.2
	>8000	59.0
Gender	Female	57.1
	Male	42.9
Marriage	Married	80.2
	Unmarried	19.8
Driving license	Yes	78.2
	No	21.8
Origin inside inner ring road	Yes	24.2
	No	75.8
Auto in-vehicle time [min]	---	25.12
Metro in-vehicle time[min]	---	23.58
Metro initial waiting time [min]	---	2.22
Metro transfer waiting time [min]	---	1.82
Metro access distance [km]	---	0.90
Metro egress distance [km]	---	0.63
Bus in-vehicle time [min]	---	35.89
Bus access distance [km]	---	0.42
Bus egress distance [km]	---	0.48
Bus number of transfers	---	0.55

*The income variable was aggregated into only two intervals from an original of nine, explaining the uneven percentage sum.

Sample statistics are a prerequisite for elasticities to be extracted. They are also the data used to estimate the discrete choice model parameters. The estimation process is carried out with the aid of computer software and depending on which specific program is used there may be slight variations in how the results are provided. In general, however, parameters are presented in a table such as in Table 3, where it is possible to read which variables are significant for each respective mode. Information regarding model performance is also typically included but it is not shown here. The estimates in the blue column represent the coefficients with regard to specific variables in the utility function of each respective mode. For example, having an income exceeding 8000 Yuan per month increases the utility of auto, but at the same time it decreases the utility for bus. In-vehicle time act negatively on all three alternatives but the impact is not the same for each mode.

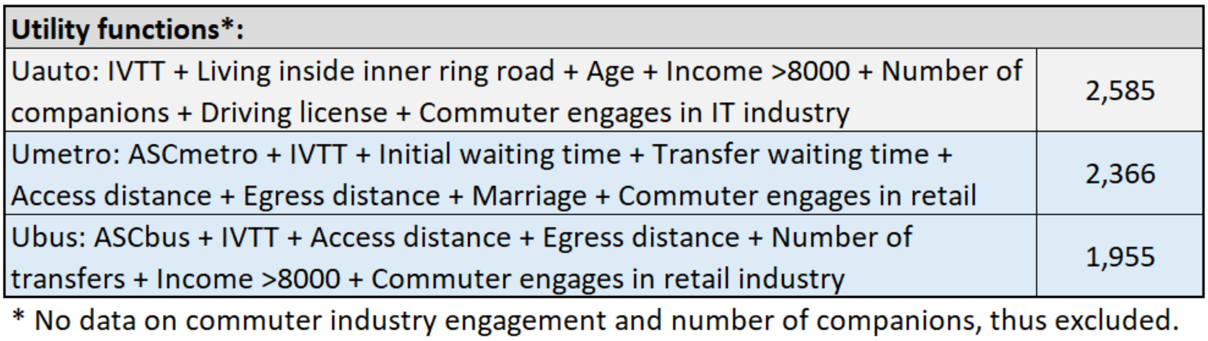
Table 3. MNL model estimation results from Zhang (2019).



Outputs of the MNL model:				
	Variable	*Estimate*	*S.E.*	*t-statistic*
Auto	In-vehicle time [min]	-0.106	0.019	-5.571
	Living inside inner ring road	-1.376	0.322	-4.279
	Age [years]	0.066	0.018	3.639
	Income >8000 [Yuan per month]	0.989	0.324	3.048
	Number of companions	0.415	0.154	2.698
	Driving license	2.994	0.436	6.869
	Commuter engages in IT industry	-1.034	0.385	-2.690
Metro	ASC Metro	3.702	1.036	---
	In-vehicle time [min]	-0.031	0.018	-1.726
	Transfer waiting time [min]	-0.142	0.102	-1.389
	Access distance [km]	-0.860	0.204	-4.225
	Egress distance [km]	-1.317	0.272	-4.843
	Marriage	1.567	0.477	3.286
	Commuter engages in retail industry	0.926	0.320	2.892
Bus	ASC Bus	4.612	0.883	---
	In-vehicle time [min]	-0.027	0.009	-3.190
	Access distance [km]	-1.136	0.451	-2.516
	Egress distance [km]	-0.610	0.362	-1.684
	Number of transfers	-0.957	0.232	-4.130
	Income >8000 [Yuan per month]	-0.664	0.322	-2.063
	Commuter engages in retail industry	0.968	0.480	2.015

To derive elasticities, the observed utilities of each alternative is calculated by multiplying the value of the variable with the estimated coefficient, and then adding all terms together. Since the utilities are specific to each individual the sample statistics presented earlier in Table 2 are used to get a value representative for the population as a whole. Which parameters are included in each utility function and their values based on sample data is presented in Table 4.

Table 4. *Utility function formulations and values. Based on data from Zhang (2019).*

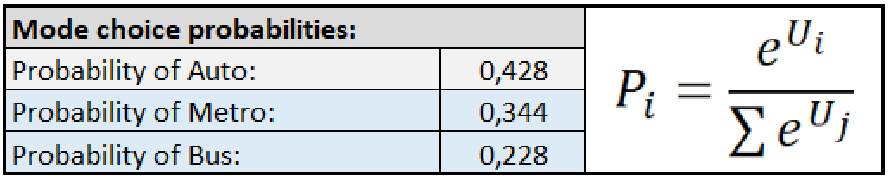


Utility functions*:	
Uauto: IVTT + Living inside inner ring road + Age + Income >8000 + Number of companions + Driving license + Commuter engages in IT industry	2,585
Umetro: ASCmetro + IVTT + Initial waiting time + Transfer waiting time + Access distance + Egress distance + Marriage + Commuter engages in retail	2,366
Ubus: ASCbus + IVTT + Access distance + Egress distance + Number of transfers + Income >8000 + Commuter engages in retail industry	1,955

* No data on commuter industry engagement and number of companions, thus excluded.

The utilities are then used in the MNL formula (Equation 5) to estimate the probability for choosing a certain mode. The modal shares in this example is provided in Table 5. These probabilities can then be used to derive desired point elasticities, in this particular example for bus and metro respectively, using the estimated model coefficients and the mean sample values for in-vehicle travel time. The elasticities derived from Zhang et al. (2019) are displayed in Table 6.

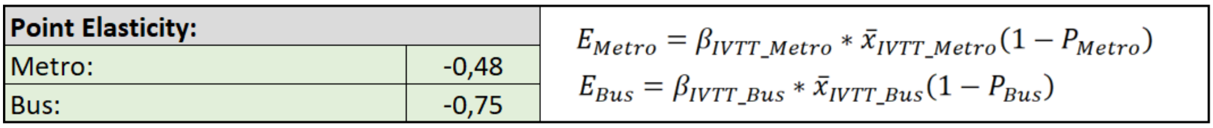
Table 5. Mode choice probabilities based on mean sample data from Zhang (2019).



Mode choice probabilities:	
Probability of Auto:	0,428
Probability of Metro:	0,344
Probability of Bus:	0,228

$$P_i = \frac{e^{U_i}}{\sum e^{U_j}}$$

Table 6. Derived point elasticities from model estimated by Zhang (2019).



Point Elasticity:	
Metro:	-0,48
Bus:	-0,75

$$E_{Metro} = \beta_{IVTT\_Metro} * \bar{x}_{IVTT\_Metro}(1 - P_{Metro})$$
$$E_{Bus} = \beta_{IVTT\_Bus} * \bar{x}_{IVTT\_Bus}(1 - P_{Bus})$$

All studies included in the meta-analysis and their derived elasticities regarding travel time are presented in Table 7. Occasional seemingly missing data points and vague formulations in some of the included studies compelled a few assumptions during the elasticity computation process. Those are listed in Appendix III.

Table 7. Collected studies that allowed for elasticity derivations and their values.

Author	***Study Area***	***N***	***Y***	***X***	***E***
Alpizar & Carlsson. (2003)	San José (Costa Rica)	602	Bus mode choice	Bus travel time	-0,45
Asensio. (2002)	Barcelona	1381	Bus mode choice	Bus IVTT	-0,50
"	"	"	Train mode choice	Train IVTT	-0,24
Carrone et al. (2020)	Copenhagen	1074	Transit mode choice	Transit travel time	-0,73
Ding et al. (2015)	Maryland-Washington (DC)	18510	Transit mode choice	Transit travel time	-2,79
Eluru et al. (2012)	Montreal	4698	Transit mode choice	Transit travel time	-0,20
Frank et al. (2008)	Seattle	8707	Transit mode choice	Transit IVTT	-0,31
Hasnine et al. (2018)	Toronto	3208	Transit mode choice	Transit IVTT	-0,11
Liu. (2007)	Shanghai	91	Metro mode choice	Metro IVTT	-0,19
"	"	"	Bus mode choice	Bus IVTT	-0,52
McFadden, D. (1974)	San Francisco	213	Metro mode choice	Metro IVTT	-0,60
"	"	"	Bus mode choice	Bus IVTT	-0,60
Meena et al. (2017)	Mumbai	530	Transit mode choice	Transit travel time	-1,34
Rajamani et al. (2003)	Portland	2500	Transit mode choice	Transit travel time	-0,87
Xiong et al. (2015)	Washington State	6300	Transit mode choice	Transit IVTT	-0,08
Yang et al. (2015)	Chengdu	1552	Metro mode choice	Metro IVTT	-0,07
Zhang. (2004)	Boston	1619	Transit mode choice	Transit travel time	-2,08
Zhang et al. (2019)	Shanghai	501	Metro mode choice	Metro IVTT	-0,48
"	"	"	Bus mode choice	Bus IVTT	-0,75
Zhao et al. (2020)	Ann Arbour	1163	Transit mode choice	Transit travel time	-1,05

IVTT - In-vehicle travel time

The mode choice models from which the elasticities are derived are found to often use transit as an aggregated choice, representing all available transit alternatives, instead of treating each mode separately. Ten out of sixteen studies are found to take on this approach. Likewise, travel time is treated as either in-vehicle time or total travel time. The in-vehicle-time measure is the dominant form used when modes are treated individually while the total travel time measure is most common when all transit options are treated as a single entity. As can be seen in Table 7, the elasticity values range between -0.07 and -2.79. The uniform negative signs indicate that the probability of choosing transit, or a transit mode, decreases as travel times increase, which is expected. However, for a fair comparison the values need to be treated separately. For example, elasticities of in-vehicle time are generally lower than those of total travel time. This is probably since total travel time involves other aspects of the journey such as access time, waiting time and transfer time, and those are often considered more discomforting than time spent travelling on the vehicle. The larger discomfort is reflected in that time being valued higher by the individual trip-maker which in turn is reflected in the larger (lower) elasticities. Table 8 provide extracted mean values regarding in-vehicle time of metro total travel time for transit in general.

Table 8. Compiled elasticities, mean values.

Travel Time Elasticities	Mean	Max	Min
Bus in-vehicle time:	-0,59	-0,75	-0,50
Metro in-vehicle time:	-0,33	-0,60	-0,07
Transit travel time:	-1,29	-2,79	-0,20
Overall mean:	-0,75	---	---

From Table 8 it can be read that reducing in-vehicle travel time by bus infer a greater modal shift than what would be the case for metro at the same level of reduction. Similar to in-vehicle travel time versus total travel time, this is likely an effect of bus travel being less comfortable than using the metro. It could also reflect difference in level of service, and performance in general, between the two modes. It would have been interesting to see how light rail would stand relative the other two. If level of service is a defining factor one could expect light rail to be placed somewhere in between. However, since the values above regarding bus and metro are based on only four studies which increase the risk for inaccuracies in the results. The elasticity for total transit travel time is based on seven studies and is, as already mentioned, much larger than those of in-vehicle time. In Table 8 is also presented an overall mean value. This is computed by first aggregating separated modal elasticities into a ‘transit option’ by taking the mean value. These are in turn aggregated with the other transit values taking both in-vehicle and total travel time values into account. In studies where only one mode is presented this is also considered a transit option. As such all sixteen studies are used in this particular computation. Note that this provide a very unconventional measure and should thus not be referred to or used outside this work. This value will be given further attention in Section 5.3.

5.2 Creation of a new line

This section goes through the results regarding the suggested new addition to Gothenburg’s transit network. The service is assumed to have modal characteristics representative of rail rapid transit, commonly denoted as mass transit, i.e. the provided service is equal to that of a metro.

5.2.1 Identified activity centres

The identified activity centres are visible in Figure 2 and consist of; Centralstationen, Chalmers (Johanneberg), Gamlestaden, Hjalmar Brantingsplatsen, Järntorget, Korsvägen, Lindholmen, Linnéplatsen, Sahlgrenska, Svingeln, Volvo (Campus Lundby), and Wieselgrensplatsen. The named places include universities, hospitals, attractions, conference centres, places of commerce and business, large employment centres, and important transport nodes. Centralstationen is the major transport hub in the city. In addition to the railway station itself there are several transit stops in close proximity that in the context of this study are treated as the same destination. The same logic is used regarding the other destinations where applicable. For motivation behind the selection of each activity centre and a full account of which stops are included under each one, see Appendix IV.

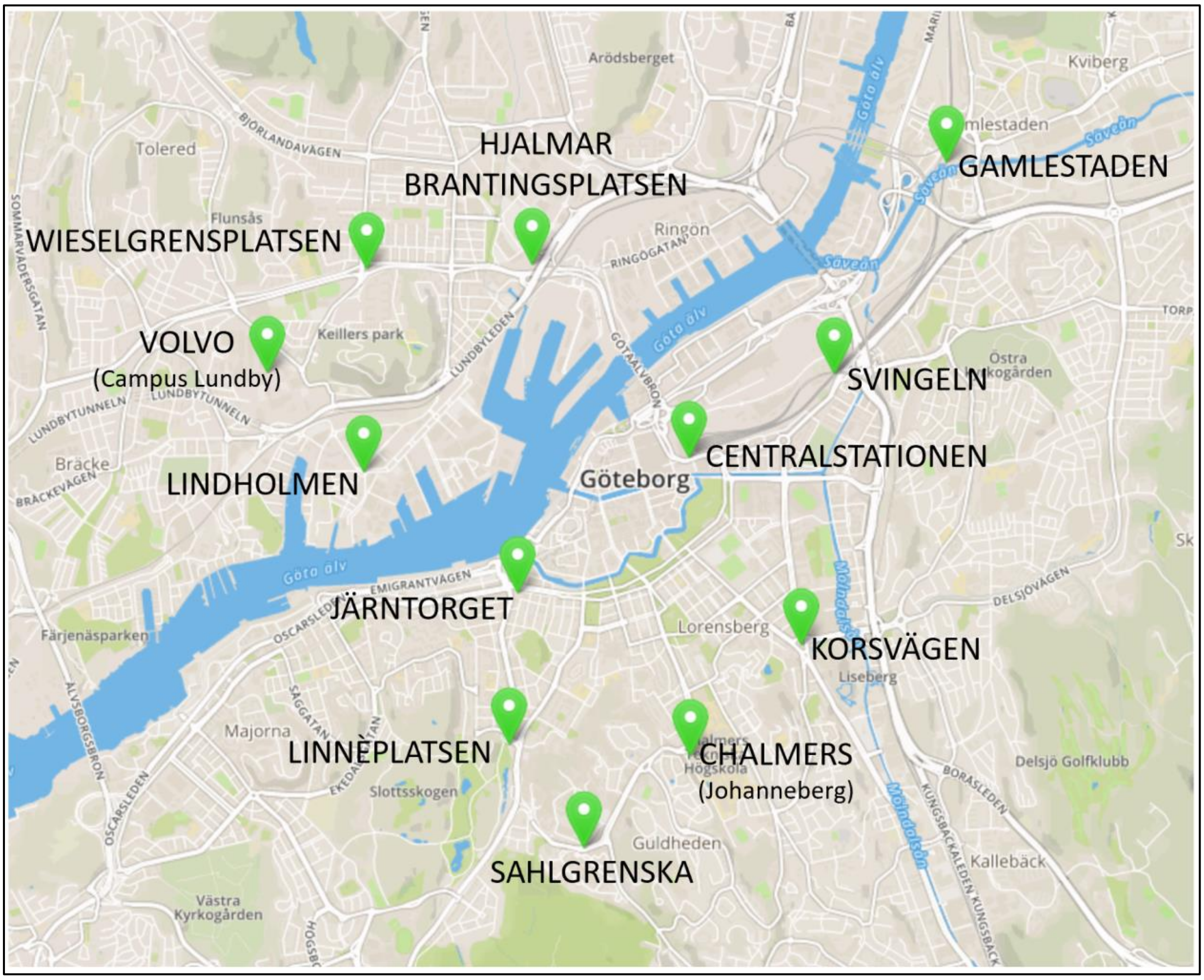


Figure 2. Selected activity centres and their locations. Created from GotMap, (Göteborgs Stad, 2020c).

Activity centres were selected based on local knowledge but cross-referenced against transit ridership data from the local transit agency Västtrafik (Personal communication, March 10, 2020). The data in question originates from an automated passenger count system which is installed on most every of the agency's vehicles and covers the average weekday number of boarding and alighting passengers for every transit stop in the city. The data, which was collected during the month of September 2019 provide an indication of the relative strength of attraction between different places in the city. With the wider definition of the activity centres explained above, the chosen destinations include seven out of the top ten most frequently used stops, and twelve of the top twenty. Two other activity centres that were initially considered are Arendal (Port of Gothenburg) and Volvo Sörred. Not only do they host major employers in the region, both are also poorly served, if at all, by the transit system today. Eventually, however, those were deemed too offset relative the other activity centres. Three other places that could have been included based on the ridership data are Angereds Centrum, Marklandsgatan and Frölunda Torg. These are however also quite peripheral locations why it was decided not to include them. Solely selecting activity centres based on ridership is not desirable since this excludes areas where transit service is currently poor. The excluded activity centres and their position relative the other ones are displayed in Figure 3. All in all, the selected activity centres make up 36% of all ridership data points in terms of boarding and alighting passengers.

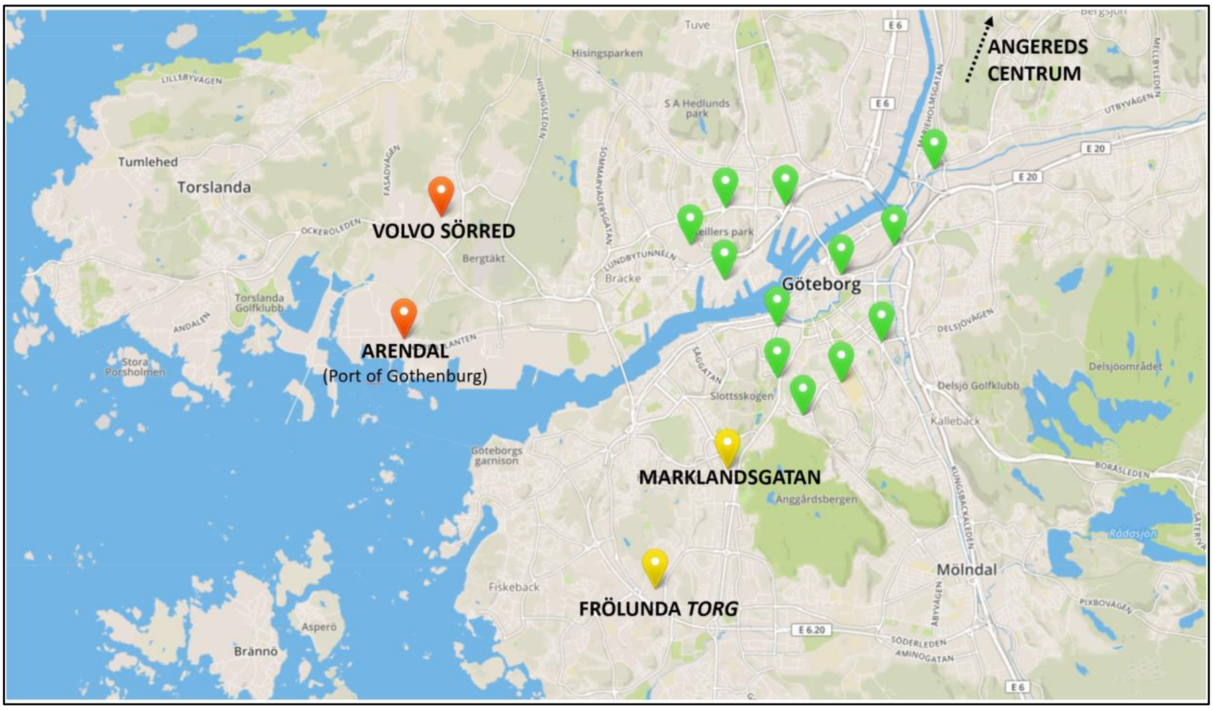


Figure 3. *All considered activity centres and their locations. Green: Included. Red: Initially considered but eventually excluded. Yellow: Motivated on basis of ridership data, but eventually rejected. Created from GotMap, (Göteborgs Stad, 2020c).*

5.2.2 Line alignment - A circular complement

The proposed line design, which is depicted in Figure 4, has a closed configuration and is shaped as a dented circle. For the most part it encloses the very city centre, the exception being at the location for Centralstationen, hence its dented form. By configuring the line as a complete circle, the mobility is increased dramatically in contrast to a design with two distinct ends. The circularity makes so that the last stop on the line never is farther away than the next stop going in the opposite direction. Given that the proposed line is about eighteen kilometres long, whichever stop is used as reference, one is never more than nine kilometres away from any destination. Before the final alignment was set a few alterations were made. First, because of a political decision to construct a new transport link across the river between Stigberget and Lindholmen, the activity centre Järntorget is substituted for Stigbergstorget. Since Stigbergstorget is slightly less traversed than Järntorget, the ridership portion covered by the activity centres is reduced to 34%, down from the previous 36%. Although these plans are in the future and it is yet to be decided which form this link will take, bridge or tunnel, the substitution is made to better align with municipal policy. Second, the spacing between the two stops Hjalmar Brantingsplatsen and Gamlestaden was found to be unreasonably long. Between those stops is a district called Ringön which today mostly consist of small-scale industry and business. However, the area is marked for future redevelopment in the municipal comprehensive plan. If the line is realised it would be unwise to not plan for a stop in this area. For that reason, a ‘dummy stop’ was added at this location.

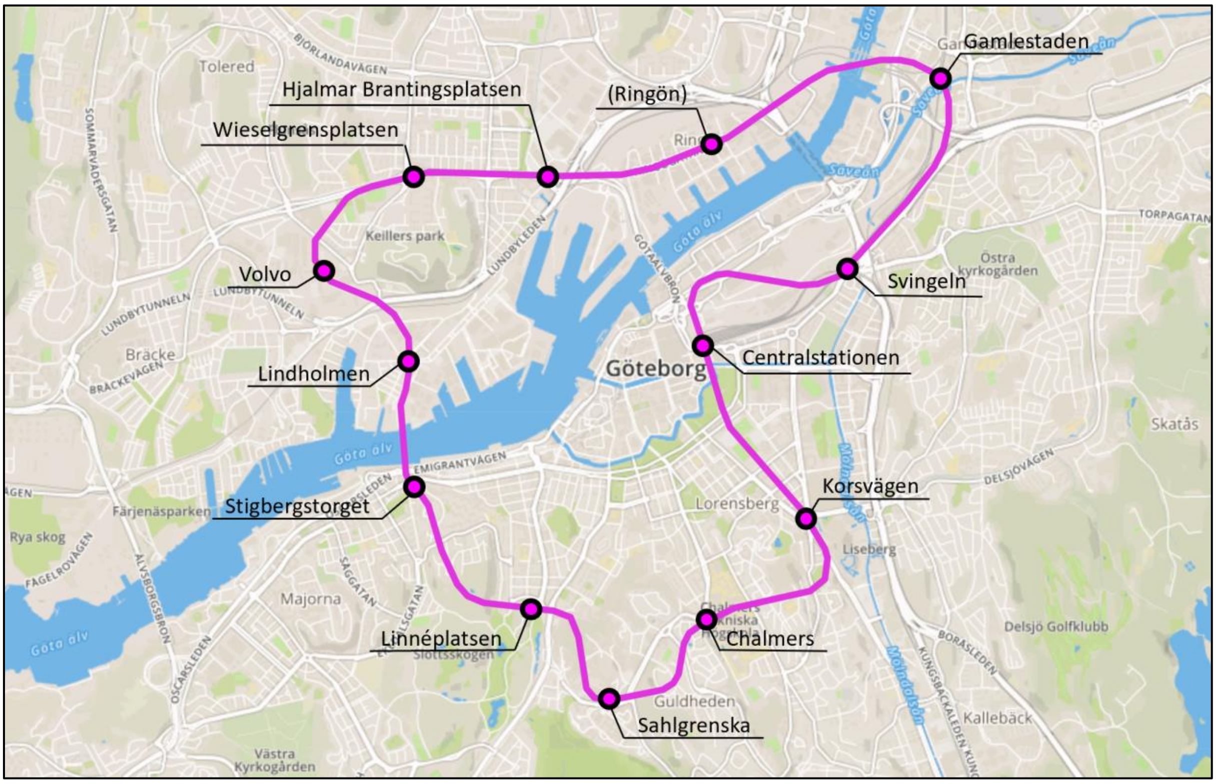
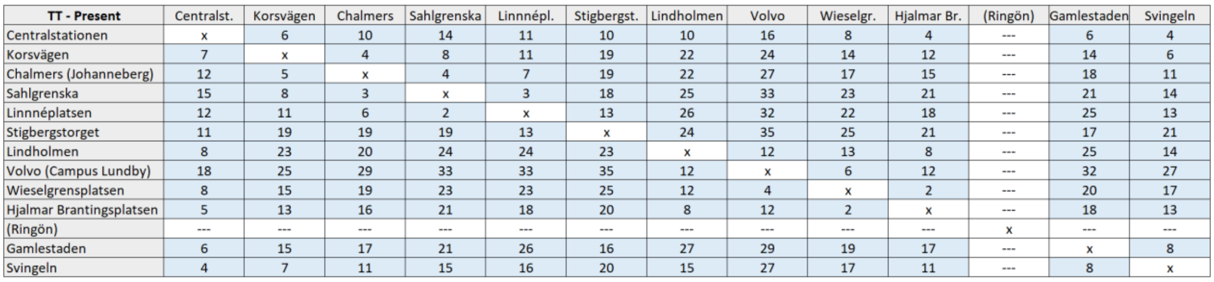


Figure 4. Proposed line configuration with marked stops. Created from GotMap, (Göteborgs Stad, 2020c)

The present travel times between the selected activity centres are presented in Table 9. The data was derived from timetables using the local transit authority's trip planning tool (Västtrafik, 2020). The search was performed using Tuesday the 3rd of March 2020 as a reference for all relations except those regarding Stigbergstorget which was collected later due to originally not having been included. The relations depict the fastest transit option commencing between 7:30-8:00 AM, and in cases where several alternatives were available the most direct option was chosen. Figures are inclusive of transfer time where required and spans from the moment of boarding to the moment of alighting, or by other means arriving at the destination stop. Tranfers are kept as short as possible but never less than five minutes. The only current transit option available to the area of Ringön consist of an inferior bus service. Because of the poor service it is not deemed relevant to compare travel times regarding this particular location and they are thus omitted from the table. The switch from Järntorget to Stigbergstorget was made after the Covid-19 virus hit Europe. Due to the restrictions enforced as a result of the virus public transit saw reduced service frequency. As a result, the travel times to and from Stigbergstorget might have been affected by less smooth transfers causing increased travel times by up to two minutes on some relations.

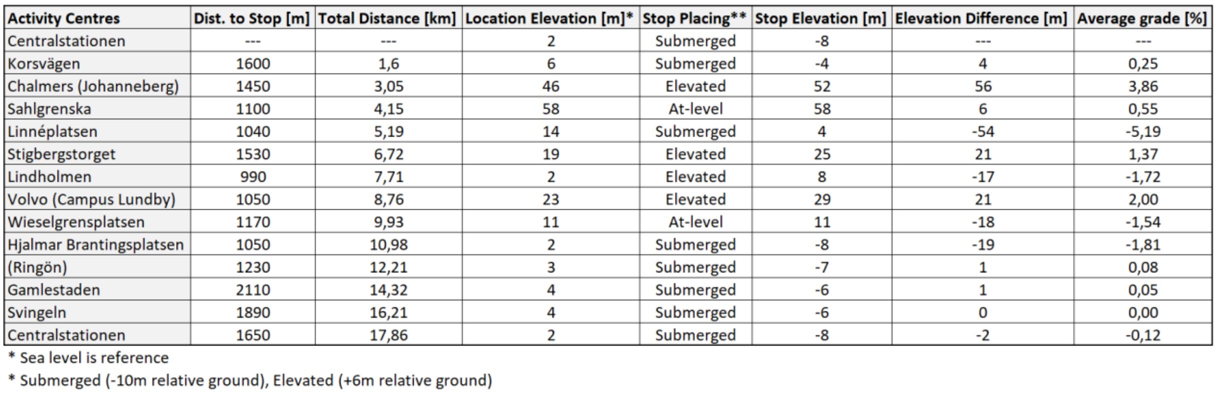
Table 9. Fastest transit travel option [min] between selected activity centres, present.



TT - Present	Centralst.	Korsvägen	Chalmers	Sahlgrenska	Linnépl.	Stigbergst.	Lindholmen	Volvo	Wieselgr.	Hjalmar Br.	(Ringön)	Gamlestaden	Svingeln
Centralstationen	x	6	10	14	11	10	10	16	8	4	---	6	4
Korsvägen	7	x	4	8	11	19	22	24	14	12	---	14	6
Chalmers (Johanneberg)	12	5	x	4	7	19	22	27	17	15	---	18	11
Sahlgrenska	15	8	3	x	3	18	25	33	23	21	---	21	14
Linnéplatsen	12	11	6	2	x	13	26	32	22	18	---	25	13
Stigbergstorget	11	19	19	19	13	x	24	35	25	21	---	17	21
Lindholmen	8	23	20	24	24	23	x	12	13	8	---	25	14
Volvo (Campus Lundby)	18	25	29	33	33	35	12	x	6	12	---	32	27
Wieselgrensplatsen	8	15	19	23	23	25	12	4	x	2	---	20	17
Hjalmar Brantingsplatsen	5	13	16	21	18	20	8	12	2	x	---	18	13
(Ringön)	---	---	---	---	---	---	---	---	---	---	x	---	---
Gamlestaden	6	15	17	21	26	16	27	29	19	17	---	x	8
Svingeln	4	7	11	15	16	20	15	27	17	11	---	8	x

Table 10 depict the interrelated stop characteristics regarding distance, elevation, stop embodiment and intermediate inclines. The reasoning behind submersion or not regarding stops adhere to local conditions around the location such as space limitations due to on-site developments. Average stop spacing amounts to 1374 meters.

Table 10. Information on proposed stop configuration.

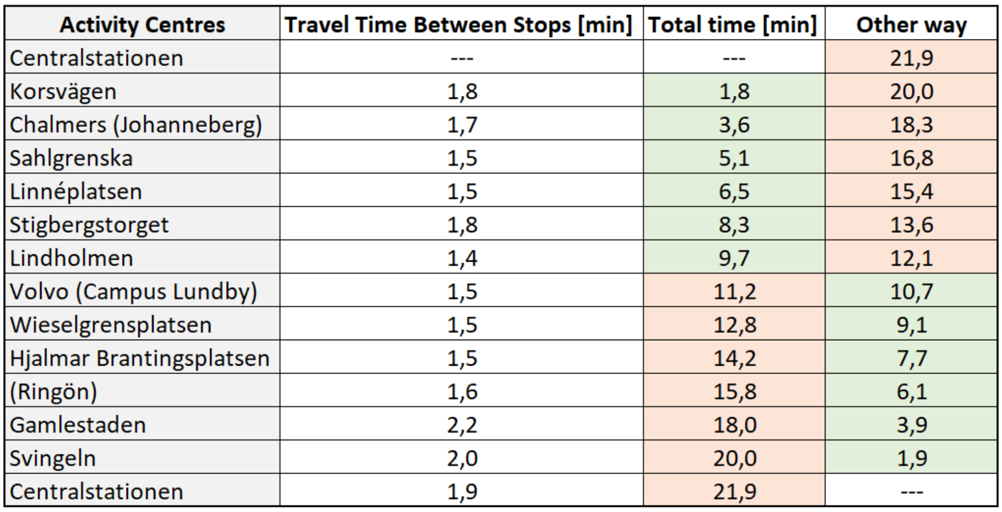


Activity Centres	**Dist. to Stop [m]**	**Total Distance [km]**	**Location Elevation [m]***	**Stop Placing****	**Stop Elevation [m]**	**Elevation Difference [m]**	**Average grade [%]**
Centralstationen	---	---	2	Submerged	-8	---	---
Korsvägen	1600	1,6	6	Submerged	-4	4	0,25
Chalmers (Johanneberg)	1450	3,05	46	Elevated	52	56	3,86
Sahlgrenska	1100	4,15	58	At-level	58	6	0,55
Linnéplatsen	1040	5,19	14	Submerged	4	-54	-5,19
Stigbergstorget	1530	6,72	19	Elevated	25	21	1,37
Lindholmen	990	7,71	2	Elevated	8	-17	-1,72
Volvo (Campus Lundby)	1050	8,76	23	Elevated	29	21	2,00
Wieselgrensplatsen	1170	9,93	11	At-level	11	-18	-1,54
Hjalmar Brantingsplatsen	1050	10,98	2	Submerged	-8	-19	-1,81
(Ringön)	1230	12,21	3	Submerged	-7	1	0,08
Gamlestaden	2110	14,32	4	Submerged	-6	1	0,05
Svingeln	1890	16,21	4	Submerged	-6	0	0,00
Centralstationen	1650	17,86	2	Submerged	-8	-2	-0,12

* Sea level is reference
* Submerged (-10m relative ground), Elevated (+6m relative ground)

Table 11 present travel times to the other stops using Centralstationen as the trip origin. Since the proposed line alignment contain quite substantial height differences, inferring varying grades between different stops, the station-to-station travel time was calculated ignorant of potential coasting. The possibility for coasting in this case is heavily affected these inclinations and also by vehicle design features which are outside the scope of this study. Therefore, Equations 17-19 presented in Chapter 4 are used for these computations. Travel time calculations are made using typical modal operating characteristics in use today as defined by Vuchic (2007, p. 173). More specifically a two-car articulated light rail transit vehicle was used as reference implying acceleration and breaking figures of 0.8 m/s^2 and 1.2m/s^2 respectively. The maximum speed was set to 90 km/h and the stop dwell time to 20 s. Operation presuppose ROW category A. This makes for an operating speed of 49 km/h which is much above the current tram operation at on average 22 km/h. The critical distance using those values was found to be just over 650 meters which is well within the margin considering the shortest stop spacing is 990 meters. A second computation was performed using improved values reflecting more modern technological and operational standards. In this case the parameters are set to 120 km/h as maximum speed, 1.2m/s^2 for both acceleration and breaking, and a stop dwell time of only 12 s (Vuchic, 2007, p. 130). The critical distance with those figures increases to 925 meters. Although the first computation used more modest figures, they still make for a considerable improvement compared to the present situation and as such they were considered 'good enough' a comparative measure. The rest of this chapter will thus only consider those results. For the interested reader the results using the improved values can be found in Appendix V. The mean difference per stop between the improved values and the modest ones comes in at just over a minute on average.

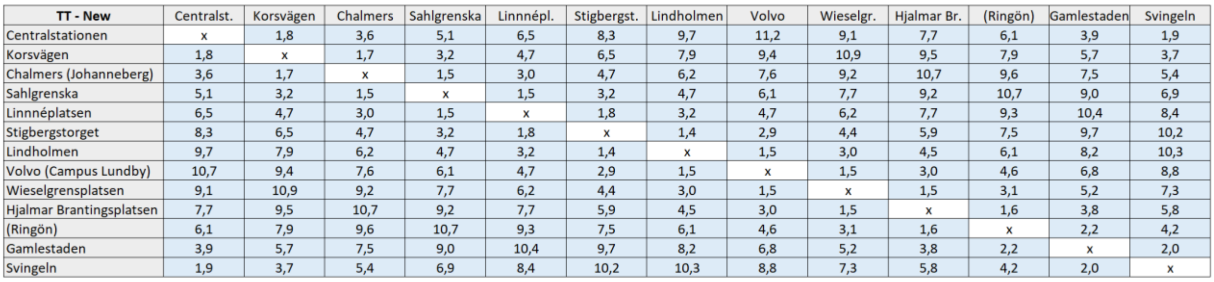
Table 11. Travel time between stops and end-to-end.



Activity Centres	Travel Time Between Stops [min]	Total time [min]	Other way
Centralstationen	---	---	21,9
Korsvägen	1,8	1,8	20,0
Chalmers (Johanneberg)	1,7	3,6	18,3
Sahlgrenska	1,5	5,1	16,8
Linnéplatsen	1,5	6,5	15,4
Stigbergstorget	1,8	8,3	13,6
Lindholmen	1,4	9,7	12,1
Volvo (Campus Lundby)	1,5	11,2	10,7
Wieselgrensplatsen	1,5	12,8	9,1
Hjalmar Brantingsplatsen	1,5	14,2	7,7
(Ringön)	1,6	15,8	6,1
Gamlestaden	2,2	18,0	3,9
Svingeln	2,0	20,0	1,9
Centralstationen	1,9	21,9	---

Since the line is circular in composition there will be a shift along the line where the consecutive stop would be reached faster by originally having travelled in the opposite direction. This is represented by the green and red colours in the last two columns. The same computational procedure is conducted for every activity centre and the quickest alternative is presented in Table 12.

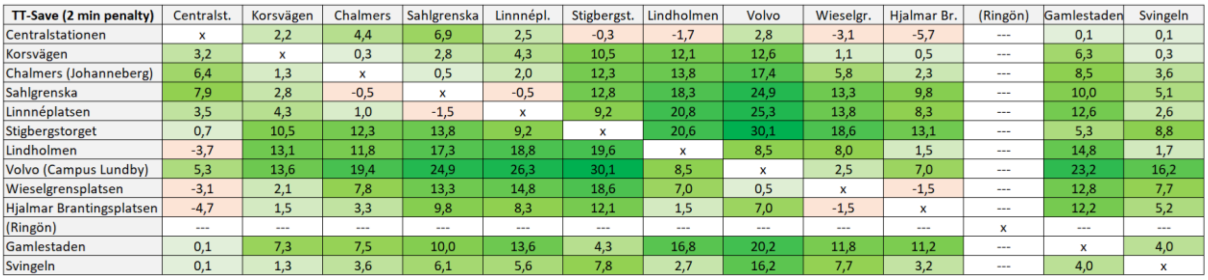
Table 12. Possible travel times between selected activity centres with the proposed new transit service.



TT - New	Centralst.	Korsvägen	Chalmers	Sahlgrenska	Linnépl.	Stigbergst.	Lindholmen	Volvo	Wieselgr.	Hjalmar Br.	(Ringön)	Gamlestaden	Svingeln
Centralstationen	x	1,8	3,6	5,1	6,5	8,3	9,7	11,2	9,1	7,7	6,1	3,9	1,9
Korsvägen	1,8	x	1,7	3,2	4,7	6,5	7,9	9,4	10,9	9,5	7,9	5,7	3,7
Chalmers (Johanneberg)	3,6	1,7	x	1,5	3,0	4,7	6,2	7,6	9,2	10,7	9,6	7,5	5,4
Sahlgrenska	5,1	3,2	1,5	x	1,5	3,2	4,7	6,1	7,7	9,2	10,7	9,0	6,9
Linnéplatsen	6,5	4,7	3,0	1,5	x	1,8	3,2	4,7	6,2	7,7	9,3	10,4	8,4
Stigbergstorget	8,3	6,5	4,7	3,2	1,8	x	1,4	2,9	4,4	5,9	7,5	9,7	10,2
Lindholmen	9,7	7,9	6,2	4,7	3,2	1,4	x	1,5	3,0	4,5	6,1	8,2	10,3
Volvo (Campus Lundby)	10,7	9,4	7,6	6,1	4,7	2,9	1,5	x	1,5	3,0	4,6	6,8	8,8
Wieselgrensplatsen	9,1	10,9	9,2	7,7	6,2	4,4	3,0	1,5	x	1,5	3,1	5,2	7,3
Hjalmar Brantingsplatsen	7,7	9,5	10,7	9,2	7,7	5,9	4,5	3,0	1,5	x	1,6	3,8	5,8
(Ringön)	6,1	7,9	9,6	10,7	9,3	7,5	6,1	4,6	3,1	1,6	x	2,2	4,2
Gamlestaden	3,9	5,7	7,5	9,0	10,4	9,7	8,2	6,8	5,2	3,8	2,2	x	2,0
Svingeln	1,9	3,7	5,4	6,9	8,4	10,2	10,3	8,8	7,3	5,8	4,2	2,0	x

Table 13 displays the amount of time that could be saved by using the new transit service compared to the old one. The green colour-scale is used to represent savings and the darker the shade the more time is saved. Red is used to depict relations which take longer to reach. Take note that those figures have been inflicted with an added penalty of one minute at either end of the trip, making two minutes total on each relation. The penalty is a rough estimate of the extra cost of accessing (and leaving) the stop platforms compared to the present case with generally only surface-level platforms. For the new service, eleven out of thirteen stops are suggested to be either elevated or submerged and therefore requiring stairs or escalators to reach. Even the two at-level stops will likely infer extra access times since it might be necessary to use an over- or underpass to reach the desired platform depending on the direction of approach. The pattern in Table 13 suggest quite significant travel time savings for most of the included relations. 60% of them would see a saving greater than five minutes with the new service, and 37% would exceed ten minutes. However, even far larger savings than that do occur, especially where the stop Volvo is involved. The reason for this is that the current transit options are situated near the outer edge of the area whereas the new option is intentionally placed in the centre of it to increase the transit accessibility. Because of this, the travel times in the present case are inclusive of the walk time required to reach this centre-point location, adding approximately ten minutes to the total. Apart from Volvo, the largest savings occur in relations involving Stigbergstorget and Lindholmen which is not unexpected given that the service make use of a yet to be constructed river connection between these two locations. Twelve relations, or 9%, do not result in shorter travel but instead in an increase. Seven of them involve Centralstationen which demonstrates the already excellent connectivity of this location. The other negative relations all involve adjacent stops as seen by their distribution around the centre diagonal in the table.

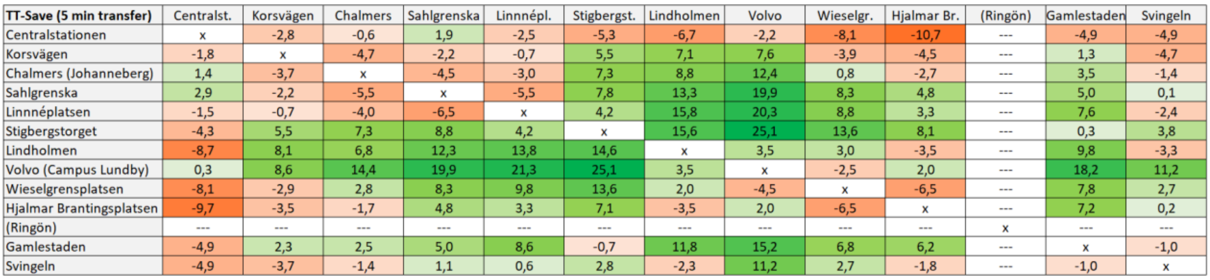
Table 13. Potential travel time savings with the new service. Impaired accessibility accounted for by 1 min penalty at either trip end.



TT-Save (2 min penalty)	Centralst.	Korsvägen	Chalmers	Sahlgrenska	Linnépl.	Stigbergst.	Lindholmen	Volvo	Wieselgr.	Hjalmar Br.	(Ringön)	Gamlestaden	Svingeln
Centralstationen	x	2,2	4,4	6,9	2,5	-0,3	-1,7	2,8	-3,1	-5,7	---	0,1	0,1
Korsvägen	3,2	x	0,3	2,8	4,3	10,5	12,1	12,6	1,1	0,5	---	6,3	0,3
Chalmers (Johanneberg)	6,4	1,3	x	0,5	2,0	12,3	13,8	17,4	5,8	2,3	---	8,5	3,6
Sahlgrenska	7,9	2,8	-0,5	x	-0,5	12,8	18,3	24,9	13,3	9,8	---	10,0	5,1
Linnéplatsen	3,5	4,3	1,0	-1,5	x	9,2	20,8	25,3	13,8	8,3	---	12,6	2,6
Stigbergstorget	0,7	10,5	12,3	13,8	9,2	x	20,6	30,1	18,6	13,1	---	5,3	8,8
Lindholmen	-3,7	13,1	11,8	17,3	18,8	19,6	x	8,5	8,0	1,5	---	14,8	1,7
Volvo (Campus Lundby)	5,3	13,6	19,4	24,9	26,3	30,1	8,5	x	2,5	7,0	---	23,2	16,2
Wieselgrensplatsen	-3,1	2,1	7,8	13,3	14,8	18,6	7,0	0,5	x	-1,5	---	12,8	7,7
Hjalmar Brantingsplatsen	-4,7	1,5	3,3	9,8	8,3	12,1	1,5	7,0	-1,5	x	---	12,2	5,2
(Ringön)	---	---	---	---	---	---	---	---	---	---	x	---	---
Gamlestaden	0,1	7,3	7,5	10,0	13,6	4,3	16,8	20,2	11,8	11,2	---	x	4,0
Svingeln	0,1	1,3	3,6	6,1	5,6	7,8	2,7	16,2	7,7	3,2	---	4,0	x

The travel time savings recently presented do come into effect when a journey both begins and ends at one of the listed activity centres. In the case one end of the journey is located outside the confinements of the circular alignment, it might be necessary to make a transfer to reach the desired destination. Table 14 is supposed to be read as the travel time saved conditional on that the desired journey involves a transfer to or from the new transit line. The transfer is represented by added extra time equal to five minutes which is the safety margin currently used in the transit route planning tool. Since the two-minute access penalty is still in effect, the actual transfer time amounts to six minutes. Under these circumstances it becomes clear that if Centralstationen is your trip destination (or origin), it is unfavourable to make use of the new service. Instead you benefit from making a direct trip with the vehicle you are currently on. This is most likely a possibility for the case of Centralstationen since most every line serves that location, but it is not necessarily possible in other cases. For example, consider a journey with a peripheral origin and a destination at Sahlgrenska. If you arrive at Korsvägen and choose to transfer to the new service, you will increase your travel time by 2.2 minutes by doing so, given that the line you initially were on will later stop by Sahlgrenska as well. However, if the initial line does not serve Sahlgrenska, you would still be required to transfer, and in that situation you would save 2.8 minutes (Table 13) by transferring to the new service instead of an already existing one. As such, Table 14 provide some interesting information, although it does not apply to every situation. Still, about 60% of all relations do result in travel time savings despite the presence of a transfer.

Table 14. Potential travel time savings conditional of a 5 min transfer.

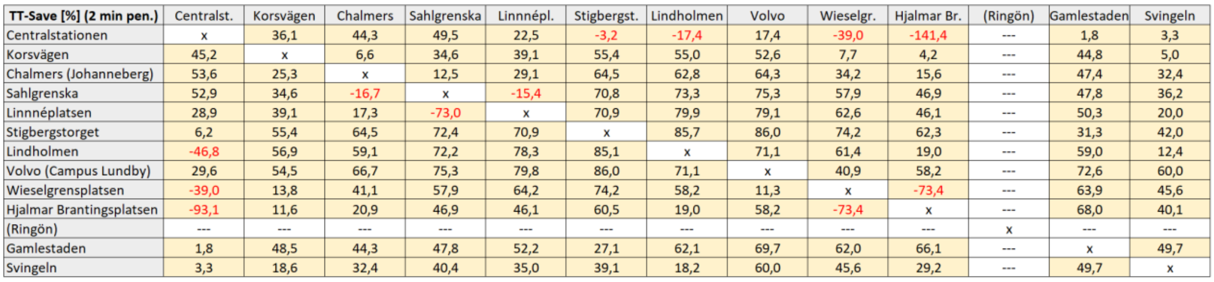


TT-Save (5 min transfer)	Centralst.	Korsvägen	Chalmers	Sahlgrenska	Linnnépl.	Stigbergst.	Lindholmen	Volvo	Wieselgr.	Hjalmar Br.	(Ringön)	Gamlestaden	Svingeln
Centralstationen	x	-2,8	-0,6	1,9	-2,5	-5,3	-6,7	-2,2	-8,1	-10,7	---	-4,9	-4,9
Korsvägen	-1,8	x	-4,7	-2,2	-0,7	5,5	7,1	7,6	-3,9	-4,5	---	1,3	-4,7
Chalmers (Johanneberg)	1,4	-3,7	x	-4,5	-3,0	7,3	8,8	12,4	0,8	-2,7	---	3,5	-1,4
Sahlgrenska	2,9	-2,2	-5,5	x	-5,5	7,8	13,3	19,9	8,3	4,8	---	5,0	0,1
Linnéplatsen	-1,5	-0,7	-4,0	-6,5	x	4,2	15,8	20,3	8,8	3,3	---	7,6	-2,4
Stigbergstorget	-4,3	5,5	7,3	8,8	4,2	x	15,6	25,1	13,6	8,1	---	0,3	3,8
Lindholmen	-8,7	8,1	6,8	12,3	13,8	14,6	x	3,5	3,0	-3,5	---	9,8	-3,3
Volvo (Campus Lundby)	0,3	8,6	14,4	19,9	21,3	25,1	3,5	x	-2,5	2,0	---	18,2	11,2
Wieselgrensplatsen	-8,1	-2,9	2,8	8,3	9,8	13,6	2,0	-4,5	x	-6,5	---	7,8	2,7
Hjalmar Brantingsplatsen	-9,7	-3,5	-1,7	4,8	3,3	7,1	-3,5	2,0	-6,5	x	---	7,2	0,2
(Ringön)	---	---	---	---	---	---	---	---	---	---	x	---	---
Gamlestaden	-4,9	2,3	2,5	5,0	8,6	-0,7	11,8	15,2	6,8	6,2	---	x	-1,0
Svingeln	-4,9	-3,7	-1,4	1,1	0,6	2,8	-2,3	11,2	2,7	-1,8	---	-1,0	x

5.3 Possible influence on modal split

In order to predict the influence on mode split occurring as an effect of the new transit service, the derived elasticities from Section 5.1 are used. First, however, it is necessary to know the present transit mode share in the affected area. In 2016, the transit share in Gothenburg was estimated to 29% (Göteborgs Stad, 2016a). The remaining portion of travel was conducted by car (41%), walk (23%), bike (7%). Since the proposed line mostly serve the downtown area of Gothenburg, and these figures are representative for the entire municipality, there is some concern whether these figures are suitable in this scenario. The line is aligned such that all but two stops are situated within three city districts, the last two being on the edge. By only considering these three districts, namely Centrum, Linnéstaden and Lundby, the mode shares are represented by transit at 34.3%, car at 33.7%, and walking and biking make up the remaining 32% (Göteborgs Stad, 2016b). Before the elasticities can be applied, the values of travel time savings presented in Table 13 are converted into percentages by also accounting for the present travel times between the same locations. This is presented in Table 15.

Table 15. Potential travel time savings with the new service expressed as percentages. Impaired accessibility accounted for by 1 min penalty at either trip end.



TT-Save [%] (2 min pen.)	Centralst.	Korsvägen	Chalmers	Sahlgrenska	Linnnépl.	Stigbergst.	Lindholmen	Volvo	Wieselgr.	Hjalmar Br.	(Ringön)	Gamlestaden	Svingeln
Centralstationen	x	36,1	44,3	49,5	22,5	-3,2	-17,4	17,4	-39,0	-141,4	---	1,8	3,3
Korsvägen	45,2	x	6,6	34,6	39,1	55,4	55,0	52,6	7,7	4,2	---	44,8	5,0
Chalmers (Johanneberg)	53,6	25,3	x	12,5	29,1	64,5	62,8	64,3	34,2	15,6	---	47,4	32,4
Sahlgrenska	52,9	34,6	-16,7	x	-15,4	70,8	73,3	75,3	57,9	46,9	---	47,8	36,2
Linnéplatsen	28,9	39,1	17,3	-73,0	x	70,9	79,9	79,1	62,6	46,1	---	50,3	20,0
Stigbergstorget	6,2	55,4	64,5	72,4	70,9	x	85,7	86,0	74,2	62,3	---	31,3	42,0
Lindholmen	-46,8	56,9	59,1	72,2	78,3	85,1	x	71,1	61,4	19,0	---	59,0	12,4
Volvo (Campus Lundby)	29,6	54,5	66,7	75,3	79,8	86,0	71,1	x	40,9	58,2	---	72,6	60,0
Wieselgrensplatsen	-39,0	13,8	41,1	57,9	64,2	74,2	58,2	11,3	x	-73,4	---	63,9	45,6
Hjalmar Brantingsplatsen	-93,1	11,6	20,9	46,9	46,1	60,5	19,0	58,2	-73,4	x	---	68,0	40,1
(Ringön)	---	---	---	---	---	---	---	---	---	---	x	---	---
Gamlestaden	1,8	48,5	44,3	47,8	52,2	27,1	62,1	69,7	62,0	66,1	---	x	49,7
Svingeln	3,3	18,6	32,4	40,4	35,0	39,1	18,2	60,0	45,6	29,2	---	49,7	x

As can be seen in Table 15 the new service has a substantial impact on the mobility between the selected activity centres. The largest travel time reduction amounts to as much as 86% put in relation to the fastest travel option of present. Across all relations the new line brings travel time savings of 42.3% on average. That figure is valid on the premises that the negative relations depicted represents no improvement at all rather than actually implying longer travel times. The assumption is fair given that the new line is suggested as a complement to the existing transit network and not as a replacement.

Since the new service is one of metro standard, albeit not a metro by definition, it can arguably be fair to use the elasticity of metro in-vehicle time (-0.33) to estimate the change in transit mode share. Since elasticities represent ratios of percentage change, travel time savings of 42.3% on average between the selected activity centres result in an increase of the transit mode share by 25.3%, making the new share 39.2%. An increase of 4.9 percentage units. That response, however, imply that the base share of 34.3% represent the metro mode which it obviously does not since metro is not an existing alternative in the Gothenburg transit system. In this case it is representative of all existing transit alternatives and for that reason the transit elasticity (-1.29) might be a better measure. The transit elasticity is also based on total travel time and as such it probably makes better account for transfer and walking. Using the transit elasticity result in a new transit mode share of 53,1%, an increase of 54.7% or 18.8 percentage units. Although some trip relations in the base scenario are inclusive of transfers or walking time or both, many relations are not. For those relations, the travel time saving provided by the new option is indeed a representation of in-vehicle time. The elasticity results in Section 5.1 indicate that elasticities are mode specific. Bus travel time savings are for example implicating larger mode shifts than what would be the case for metro, likely partially because metro travel is less discomforting. Since the Gothenburg transit network consist of predominantly bus and tram operations, a transit alternative of metro standard would also be an upgrade in itself through provision of a greater level of service. For that reason, and since the proposed transit addition partially represent travel time and partially in-vehicle time, it might not be too off to use the overall mean elasticity value in this particular case. If so, the elasticity of -0.75 can be expected to raise the transit mode share to 45.2% from the 34.3% in the base case, an increase by 10.9 percentage units. The described elasticity application scenarios are illustrated in Figure 5.

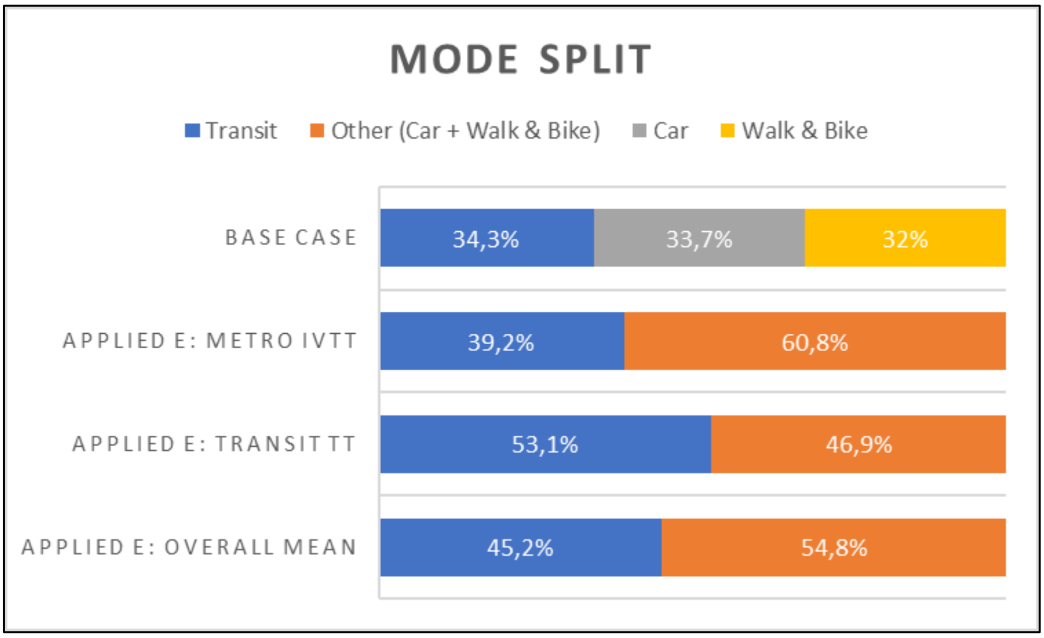


Figure 5. Estimated mode split based on compiled elasticities and travel time savings with the proposed service.

A new transit mode share of 39.2% is presumably an understatement of the effects of travel time savings for reasons already given. Similarly, a share of 53.,1% is probably an overestimate. The truth is most likely found somewhere in between. Unfortunately, there is no telling from where the new riders would come, i.e. if they used to be car travellers or if they switched to transit from previously having walked or cycled. Using an average mean value of proportional travel time savings between trip relations is a significant simplification. It basically implies that the travel demand is distributed such that each relation meets an equal share of the total demand which is an unlikely scenario. If a larger portion of trips take place on relations where the travel time savings are large, then the average value used will be too low. If a larger portion of trips would occur on relations with low, or no travel time savings, the value would instead be too large.

5.3.1 Larger share brings new riders

An increase of the transit mode share infers that people switch to transit from previously having travelled by car, bike, or walk. Knowing the number of trips taking place every day makes it possible to estimate the increased transit demand in terms of new riders. Every day, approximately 250 000 trips are carried out with transit in Gothenburg (Göteborgs Stad, 2020a). The mode split effects presented in the previous section are computed based on the current shares of the three city districts in which the new line pass through. According to Göteborgs Stad (2016b), these three districts account for 44% of all trips carried out in the city. Because of their central orientation and their relatively larger transit mode share in comparison with other districts, it is safe to say that these districts are responsible for at least 44% of all transit trips as well, probably more. Figure 6 provide data on new attracted ridership depending on how the new mode share is estimated.

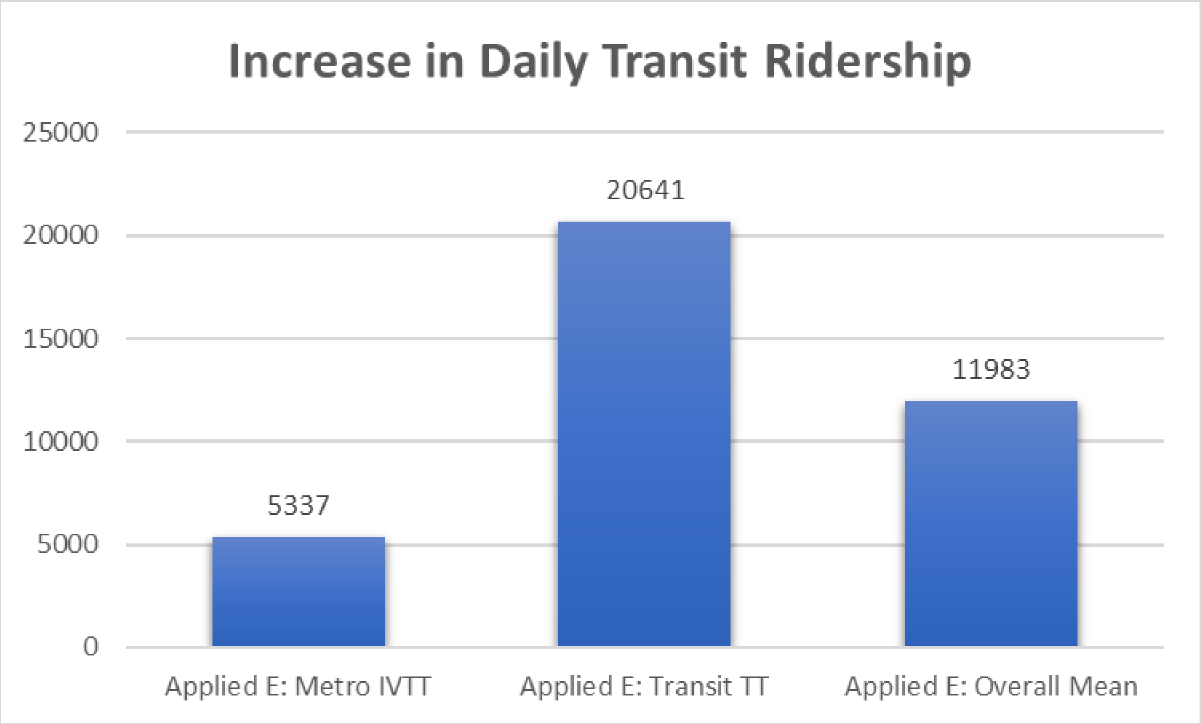


Figure 6. Estimated daily ridership increase from the three most affected districts.

The numbers presented in Figure 6 are not exaggerated, more likely the opposite. That is because the influence of the new line is not restricted to only the area where it is situated but will have diminishing effects all throughout the transit network. Travel time changes, where they are present, will be proportionally smaller if the total trip time is longer which is a likely scenario for commuters from more peripheral locations. Because of this the mode shift effects will also be smaller in these areas, but they will still occur as long as there is time to be saved.

6. Discussion

The previous section provided elasticity measures computed from 16 different studies. Elasticities of mode choice can be used as decision support in transport planning and policy to promote and eventually achieve a desired modal shift towards more sustainable travel options. The meta-analysis is focused on the role of travel time which arguably is the most important factor in the mode choice process. The compiled results can insinuate the effects brought about by network developments leading to reduced travel times. As such it provides an indication of future travel demand in terms of transport mode share that can further be used to estimate ridership which will facilitate for transport agencies in their work to meet the necessary demand for capacity.

The intent of any meta-analysis is to gather findings from a range of different sources within a specified field in order to compile aggregated conclusions. A well-performed analysis based on a large sample will ensure genuine results. This study arrived at three different elasticities concerning bus in-vehicle time (-0.59), metro in-vehicle time (-0.33), and transit travel time (-1.29). It would have been interesting to expand the findings to cover both other modes and other aspects of travel time, however, transit modal separation was not frequently occurring in the selected studies. This may be because of the IIA assumption coupled with the MNL discrete choice model formulation which was a targeted inclusion criterion. Widening the literature search to include other model formulations would most likely result in a larger collection of studies. Since other models are less constrained by the IIA assumption, it is likely a more diverse modal representation would be achieved as well.

Ideally the findings will have a high degree of transferability, i.e. that they can be applied in different situations. What effect a change in travel time will infer will not be the same in every situation, and a greater basis for analysis, i.e. a greater collection of studies, could have allowed for distinction between e.g. different geographical regions. Transport is not uniform. It is strongly affected by policy and behaviour, and those attributes varies from place to place as well. This study had to settle for simple averages since the sample of studies was not considered large enough to derive such distinguished findings, though that drawback might be mitigated by the fact that time is a universal measure which is the same everywhere. Still, there will always be factors, may they be socioeconomic, cultural, or others, that will inevitably entail special conditions from case to case. True is, however, that time is not an infinite resource, and people will likely want to reduce it if given the opportunity.

Some thoughts arose concerning the decision to route the proposed transit line through Centralstationen, despite its already excellent connectivity. From this location you can reach every destination served by the major network with a direct trip, but that is also true the other way around, i.e. from most everywhere it is possible to make direct trips to Centralstationen. The travel time savings presented in Section 5.2 do also clarify that it is the least beneficial stop along the service. For that reason, it is unlikely that people with Centralstationen as an origin or destination will utilize the proposed service, at least not if they must make a transfer to do so. There are, however, other reasons for why it should be included anyway. Centralstationen is the major transit hub in the city and as a result it often suffers under congested conditions. It is also the focal point of regional and interregional travel. Including Centralstationen as a stop on the proposed line might bring a much-needed capacity increase, although some relief may also be brought to the area by an increased number of people transferring at new locations thanks to the alignment of the new service. Still, the proposed line could benefit from deeper research into travellers' attitudes towards this particular stop.

The elasticities used to evaluate the new line have different properties. The proposal infers metro standard in terms of modal characteristics and level of service, but since metro is a mode that currently does not exist in Gothenburg is is not adequate to apply an elasticity of metro travel. That would be to neglect all the other benefits offered by metro systems which would be an improvement compared to the present. For that reason, mode shift is evaluated both with metro- and transit elasticities insinuating that the truth lies somewhere in the middle.

Assessing the potential mode shift and number of new riders attracted by transit owing to the improved service is a cumbersome task. Since the proposed service encircles the downtown area it also has its largest proportionate effect on travel times on these districts. In order to estimate the mode shift occurring on a municipal level, travel times to the included activity centres would have to be evaluated from every other location in the city, a daunting task to say the least. Such a task could however be carried out provided access to origin-destination data. Such data could also be used to improve the accuracy of the results presented in this report as, in practice, each activity center was considered equally attractive. This, alongside a widened meta-analysis discussed earlier, could be a topic for further research.

For many reasons, the ideal results of new transit developments would be to achieve a mode shift from car, i.e. that the new riders attracted used to be car users, or to reduce car dependency in the first place. It is mainly then that positive effects can be gained with respect to the environment, congestion, safety, and so on. The question then arises, will the proposed mass transit service have those results, or will the estimated change in mode split just be a result of pedestrians and cyclists instead taking transit due to the possibility for large savings of time. The answer to this question is subject to speculation. The activity centres featured in the proposal are all quite centrally located and the possibilities of transit travel between them is generally good, albeit less so than with the suggested new service. There is reason to believe that the bulk of all car traffic originating from these areas have their destinations in more peripheral areas, and that their travel options is not improved significantly enough to motivate a mode change. The same goes for car users originating in the periphery that has one of the included activity centres as their destination. Although, some change is likely to occur given the travel time changes in Table 14 are still quite substantial, especially regarding the stops at Lindholmen, Stigbergstorget, and Volvo. In any case, the proposed mass transit addition will undoubtedly bring increased capacity and a significant mobility improvement to the transit network in the downtown area of Gothenburg. Having increased opportunities for people to move around also makes it possible to bring more people in. In that sense, the proposed mass transit development should not only be considered in itself, but as a first piece in a larger puzzle. In time the circular line can be expanded with several diametrical ones, building up towards a new core part of the transit system, ready to meet future challenges.

Since the goal is to achieve more sustainable mobility, planning new infrastructure just based on the existing conditions is not fully satisfying. One does well to remember that transport influence the shape of cities as much as cities influence the structure of the transport systems. That implies that to reach our goals of changing how we travel, it is necessary to provide the required means of transport, if not first then at least simultaneously, and then later let the city adapt within that framework. Transit planning cannot just be reactive, which is much the case today, it needs to become proactive.

7. Conclusion

The influence of travel time on transport mode choice has been evaluated through a meta-analysis approach. Three elasticity measures are derived out of a sample comprised of 16 studies describing the impact of bus in-vehicle time (-0.59), metro in-vehicle time (-0.33) and transit travel time (-1.29). A semi-circular sketch mass transit development is proposed to complement Gothenburg's transit system. On average it brings travel time savings of 42.3% across the included relations. The derived elasticities indicate that the transit mode share may increase with between 4.9 and 18.8 percentage units as a result of the new service offered. This is estimated to bring as much as 20 000 new daily transit riders.

> *"... the transportation planning process begins with an articulation of a vision..."*
> -Meyer & ITE (2016, p.77)

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APPENDIX I - Complete meta-analysis references

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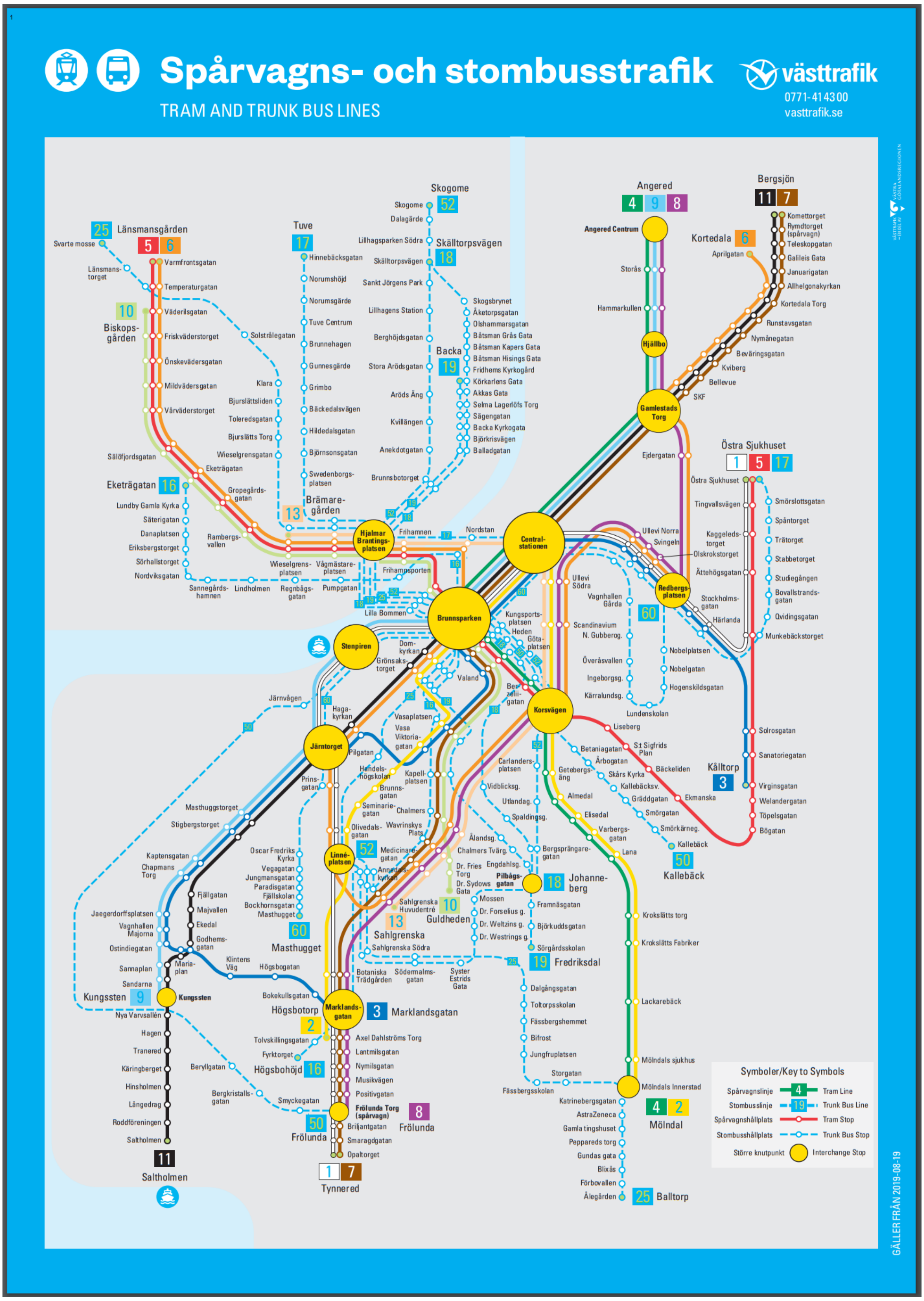
APPENDIX II - Gothenburg transit route network map



Route network map of the Gothenburg transit network (Västtrafik, 2020). Reprinted with permission.

APPENDIX III - Assumptions in elasticity derivations

This section lists assumptions and decisions made during the elasticity compilation process in cases where those were necessary.

Ding et al. (2015): Reported distinguished elasticities between peak- and off-peak hours. Reported elasticities are -0.76 and -0.58 respectively. Aggregated mean value used in Table 7.

Eluru et al. (2012): Elasticity reported as the effect of a five-minute travel time reduction. Measure converted to percentage ratio by considering the share of total trip travel time represented by five minutes.

Frank et al. (2008): Distinguished purpose of trips between home-based work and home-based. Elasticities reported are -0.39 and -0.23 respectively. Aggregated mean value used in Table 7.

Hasnine et al. (2018): Elasticity value was derived from graph.

Xiong et al. (2015): Used two models to compute elasticities of transit in-vehicle time (-0.1023 and -0.0606). Aggregated mean value used in Table 7.

Zhang. (2004): The author distinguished between home-base work trips and home-based non-work trips. Computed elasticities are -1.92 and -2.24 respectively. The value in Table 7 is the aggregated mean of the two. Modal options are drive alone, shared ride, transit, and walk/bike. Cost of travel by mode relative income is computed using whole U.S Dollars even though cost is reported in cents. Vehicles per household member is reported but vehicles per worker is used in the model. For utility calculations those figures are assumed transferable. Driving in-vehicle time was used for drive alone and shared ride trip time, while in- and out-of-vehicle time were used for transit trip time. Statistics regarding three factors of influence could not be identified. Those are trips to CBD, which have a strong negative effect ($\beta = -1.0624, \beta = -0.6650$) on drive alone, but trip destinations are not presented in the paper. Being aged under 30 is found to positively influence ($\beta = 1.1802, \beta = 1.0950$) utility for walking or taking the bike, but like with trips to CBD the share of the sample population which is indeed aged under 30 is not reported. Being female without children are found to have a positive impact on transit utility ($\beta = 0.3985, \beta = 0.3482$), but no such statistic was possible to derive. As a result, those three factors were set to zero in their respective utility functions. It should be noted that this is not a likely scenario. Trips going to the CBD could be expected to make up the bulk of all trips, especially work trips. Still, excluding the parameters was considered more reasonable than making guesses. Out of curiosity, different values regarding the discussed parameters were tested during which substantial shift in mode share between mainly drive alone and walk/bike was detected. Impact on transit travel time elasticity was however marginal.

Zhang et al. (2019): The authors conduct three different model estimations. The model used in this study is the one based on actively collected data (ASC). The model, which consider the modes auto, bus and metro, considers commuter industrial engagement in two distinct sectors. However, no statistics of this engagement is reported in the paper. Neither is data on number of companions which is included in the utility function for auto. As such, the mentioned factors are excluded from the utility, and subsequently mode choice probability calculations.

Industrial engagement would have had a negative impact ($\beta = -1.034$) on auto utility and almost the same effect, but positive, on the utility of either bus ($\beta = 0.968$) or metro ($\beta = 0.926$). Ridning with companions would have had a positive impact ($\beta = 0.415$) on auto utility.

APPENDIX IV - Activity centres and adherent stops

The following section gives a brief explanation for the inclusion of the selected activity centres. If locations with adherent stops are among the 30 most frequently used their rank is specified.

Centralstationen: The railway station and the main transport hub of Gothenburg, centrally situated adjacent to the city’s historical core. Included stops apart from the station itself are Brunnsparken, Drottningtorget, Nils Ericssonterminalen, Nordstan, and Åkareplatsen. In near proximity one finds hotels, restaurants, parks, cafés, shopping, sports venues, and museum, and the city’s administrative center.
Ridership ranks: Brunnsparken (1), Drottningtorget (2), Nordstan (7), Centralstationen (8).

Chalmers (Johanneberg): Chalmers University of Technology is one of two universities in Gothenburg. Chalmers consists of two campuses of which the largest is situated in the district of Johanneberg. The location include the stops Chalmers and Chalmersplatsen.
Ridership rank: Chalmers (23).

Gamlestaden: Originally the location of a precursor town to Gothenburg, Gamlestaden is currently undergoing a shift towards more mixed development from previously having been more focused towards industry and manufacturing. It is also an important transit hub hosting a commuter rail station and serving as a node for tramlines reaching out into the northeastern suburbs. Adherent stops are Gamlestads Torg, Gamlestads Torg Västra, and Kristinedal.
Ridership rank: Gamlestads Torg (23).

Hjalmar Brantingsplatsen: The main transit node on Hisingen, an island separated from the mainland by the Göta river. The river crossings in Gothenburg are sparse and most of all cross-river transit converge at one central bridge. This location acts as a focal point for this converging making it the third most frequently used based on ridership. The only two stops ranked higher are both part of the area around Centralstationen. Apart from being a transit node the area is a center for retail business.
Ridership rank: Hjalmar Brantingsplatsen (3).

Järntorget: Originally included but later replaced by Stigbergstorget, Järntorget is a downtown square and important transit node situated just outside the historic city centre. It is situated in a popular district known for its restaurants, pubs and nightlife. It also borders the picturesque district of Haga with its many cafés. Apart from Järntorget the lesser transit stop Järnvågen is deemed to be adherent.
Ridership rank: Järntorget (5).

Korsvägen: Korsvägen is another important transit node but more importantly it is situated in a very active area consisting of the conference center Svenska Mässan with its incorporated hotel complex Gothia Towers, The amusement park Liseberg, The science centre Universeum, The sports venue of Scandinavium, and the Museum of World Culture. The area also features many restuarants is the site of the Gothenburg University’s Faculty of Humanities. In addition, Götaplatsen hosting a theatre, a concert hall, the City Library, and an arts museum is found nearby.
Ridership rank: Korsvägen (4).

Lindholmen: Lindholmen is currently primarily a center for business and education featuring several office complexes and schools, including the second campus of Chalmers Technical University. The area is planned for extensive urban development of which parts are already under way. Adherent stops are Lindholmen, Lindholmspiren, Lindholmsplatsen and Teknikgatan. Unfortunately there was no ridership data included for Lindholmspiren in the acquired data sheet.
Ridership rank: Lindholmen (29).

Linnéplatsen: Linnéplatsen sits at the entrance to Slottskogen, a large and well-visited park, and at the edge of Linnégatan, a major downtown street. Here one also finds Gothenburgs Museum of Natural History as well as institutions associated with Gothenburg University.
Ridership rank: Linnéplatsen (24).

Sahlgrenska: The activity center bears the same name as the largest hospital in the region. The area is a center for life science in general and also muster university faculties within biology, medicin, and odontology.
Ridership rank: Sahlgrenska Huvudentré (16).

Stigbergstorget: This stop is situated about one kilometre west of Järntorget and replaced said stop in the study for alignment and policy reasons. It is the mainland site for a planned river crossing to Lindholmen. In ridership terms it is about a third as strong as Järntorget. The area can be considered as semi-central and offers proximity to a maritime museum and a city landmark in the form of Masthuggskyrkan which is situated on the adjacent hilltop.
Ridership rank: Stigbergstorget (20).

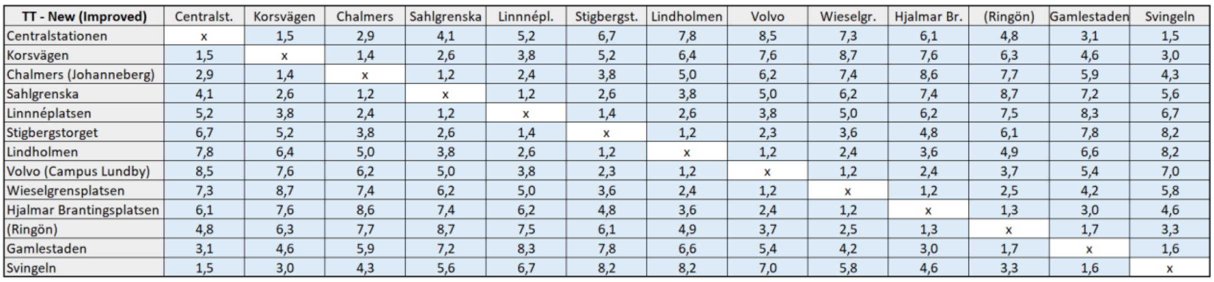
Svingeln: Svingeln is primarily functioning as a transit node. Other objects in proximity is a larger school, a tramway museum, and a historic landmark in the form of the fortification Skansen Wästgöta Lejon.
Ridership rank: Svingeln (11).

Volvo (Campus Lundby): This activity centre was selected on the premises of it being the office and center of operations for Volvo Trucks. The area is also under development into a center for innovation (Campus Lundby) oriented towards future mobility solutions. The area covers a fair amount of land and is as of yet organised in an industrial manner. Transit service is poor. There are currently no transit stops inside the area, but two adjacent stops that can be assumed to partly serve the area are Eketrägatan and Gropegårdsgatan.
Ridership rank: Eketrägatan (19).

Wieselgrensplatsen: Arguably the weakest activity centre selected, Wieselgrensplatsen offers local service in a predominantly residential area. However, there is also a minor hospital and some minor sports venues.
Ridership rank: Wieselgrensplatsen (26).

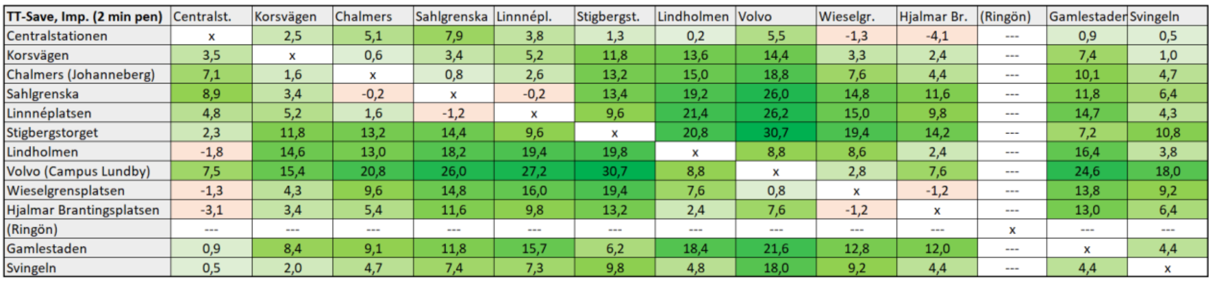
APPENDIX V - Improved case results

Table A.1: Possible travel times between selected activity centres with new transit service and improved operational and technological performance measures.



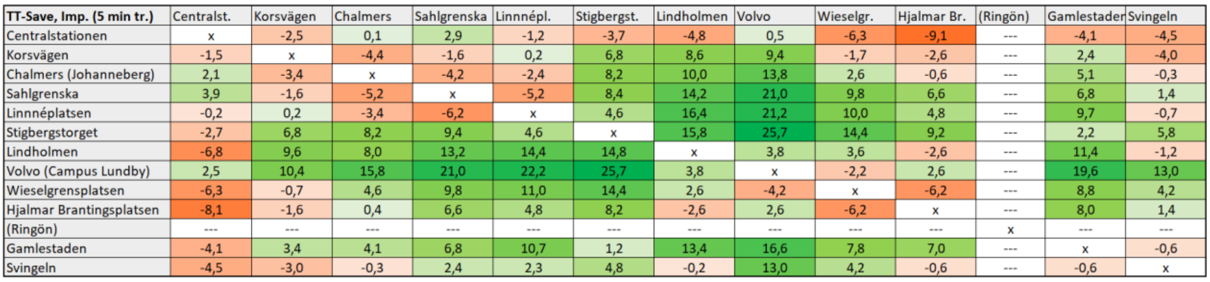
TT - New (Improved)	Centralst.	Korsvägen	Chalmers	Sahlgrenska	Linnnépl.	Stigbergst.	Lindholmen	Volvo	Wieselgr.	Hjalmar Br.	(Ringön)	Gamlestaden	Svingeln
Centralstationen	x	1,5	2,9	4,1	5,2	6,7	7,8	8,5	7,3	6,1	4,8	3,1	1,5
Korsvägen	1,5	x	1,4	2,6	3,8	5,2	6,4	7,6	8,7	7,6	6,3	4,6	3,0
Chalmers (Johanneberg)	2,9	1,4	x	1,2	2,4	3,8	5,0	6,2	7,4	8,6	7,7	5,9	4,3
Sahlgrenska	4,1	2,6	1,2	x	1,2	2,6	3,8	5,0	6,2	7,4	8,7	7,2	5,6
Linnéplatsen	5,2	3,8	2,4	1,2	x	1,4	2,6	3,8	5,0	6,2	7,5	8,3	6,7
Stigbergstorget	6,7	5,2	3,8	2,6	1,4	x	1,2	2,3	3,6	4,8	6,1	7,8	8,2
Lindholmen	7,8	6,4	5,0	3,8	2,6	1,2	x	1,2	2,4	3,6	4,9	6,6	8,2
Volvo (Campus Lundby)	8,5	7,6	6,2	5,0	3,8	2,3	1,2	x	1,2	2,4	3,7	5,4	7,0
Wieselgrensplatsen	7,3	8,7	7,4	6,2	5,0	3,6	2,4	1,2	x	1,2	2,5	4,2	5,8
Hjalmar Brantingsplatsen	6,1	7,6	8,6	7,4	6,2	4,8	3,6	2,4	1,2	x	1,3	3,0	4,6
(Ringön)	4,8	6,3	7,7	8,7	7,5	6,1	4,9	3,7	2,5	1,3	x	1,7	3,3
Gamlestaden	3,1	4,6	5,9	7,2	8,3	7,8	6,6	5,4	4,2	3,0	1,7	x	1,6
Svingeln	1,5	3,0	4,3	5,6	6,7	8,2	8,2	7,0	5,8	4,6	3,3	1,6	x

Table A.2: Possible travel time savings with the new service and improved operational and performance measures. Impaired accessibility accounted for by 1 min penalty at either trip end.



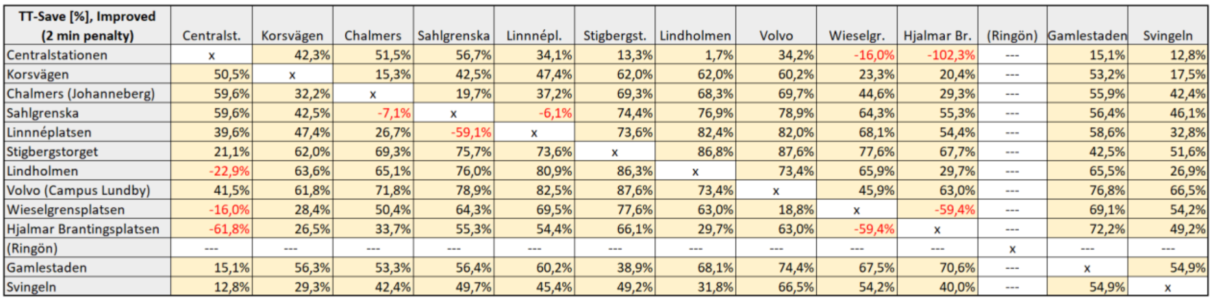
TT-Save, Imp. (2 min pen)	Centralst.	Korsvägen	Chalmers	Sahlgrenska	Linnnépl.	Stigbergst.	Lindholmen	Volvo	Wieselgr.	Hjalmar Br.	(Ringön)	Gamlestaden	Svingeln
Centralstationen	x	2,5	5,1	7,9	3,8	1,3	0,2	5,5	-1,3	-4,1	---	0,9	0,5
Korsvägen	3,5	x	0,6	3,4	5,2	11,8	13,6	14,4	3,3	2,4	---	7,4	1,0
Chalmers (Johanneberg)	7,1	1,6	x	0,8	2,6	13,2	15,0	18,8	7,6	4,4	---	10,1	4,7
Sahlgrenska	8,9	3,4	-0,2	x	-0,2	13,4	19,2	26,0	14,8	11,6	---	11,8	6,4
Linnéplatsen	4,8	5,2	1,6	-1,2	x	9,6	21,4	26,2	15,0	9,8	---	14,7	4,3
Stigbergstorget	2,3	11,8	13,2	14,4	9,6	x	20,8	30,7	19,4	14,2	---	7,2	10,8
Lindholmen	-1,8	14,6	13,0	18,2	19,4	19,8	x	8,8	8,6	2,4	---	16,4	3,8
Volvo (Campus Lundby)	7,5	15,4	20,8	26,0	27,2	30,7	8,8	x	2,8	7,6	---	24,6	18,0
Wieselgrensplatsen	-1,3	4,3	9,6	14,8	16,0	19,4	7,6	0,8	x	-1,2	---	13,8	9,2
Hjalmar Brantingsplatsen	-3,1	3,4	5,4	11,6	9,8	13,2	2,4	7,6	-1,2	x	---	13,0	6,4
(Ringön)	---	---	---	---	---	---	---	---	---	---	x	---	---
Gamlestaden	0,9	8,4	9,1	11,8	15,7	6,2	18,4	21,6	12,8	12,0	---	x	4,4
Svingeln	0,5	2,0	4,7	7,4	7,3	9,8	4,8	18,0	9,2	4,4	---	4,4	x

Table A.3: Potential travel time savings of new transit service with improved values, conditional of a 5 min transfer.



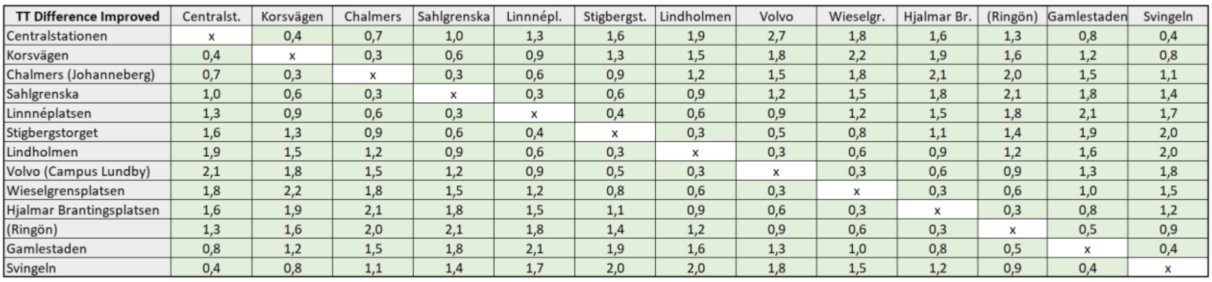
TT-Save, Imp. (5 min tr.)	Centralst.	Korsvägen	Chalmers	Sahlgrenska	Linnnépl.	Stigbergst.	Lindholmen	Volvo	Wieselgr.	Hjalmar Br.	(Ringön)	Gamlestaden	Svingeln
Centralstationen	x	-2,5	0,1	2,9	-1,2	-3,7	-4,8	0,5	-6,3	-9,1	---	-4,1	-4,5
Korsvägen	-1,5	x	-4,4	-1,6	0,2	6,8	8,6	9,4	-1,7	-2,6	---	2,4	-4,0
Chalmers (Johanneberg)	2,1	-3,4	x	-4,2	-2,4	8,2	10,0	13,8	2,6	-0,6	---	5,1	-0,3
Sahlgrenska	3,9	-1,6	-5,2	x	-5,2	8,4	14,2	21,0	9,8	6,6	---	6,8	1,4
Linnéplatsen	-0,2	0,2	-3,4	-6,2	x	4,6	16,4	21,2	10,0	4,8	---	9,7	-0,7
Stigbergstorget	-2,7	6,8	8,2	9,4	4,6	x	15,8	25,7	14,4	9,2	---	2,2	5,8
Lindholmen	-6,8	9,6	8,0	13,2	14,4	14,8	x	3,8	3,6	-2,6	---	11,4	-1,2
Volvo (Campus Lundby)	2,5	10,4	15,8	21,0	22,2	25,7	3,8	x	-2,2	2,6	---	19,6	13,0
Wieselgrensplatsen	-6,3	-0,7	4,6	9,8	11,0	14,4	2,6	-4,2	x	-6,2	---	8,8	4,2
Hjalmar Brantingsplatsen	-8,1	-1,6	0,4	6,6	4,8	8,2	-2,6	2,6	-6,2	x	---	8,0	1,4
(Ringön)	---	---	---	---	---	---	---	---	---	---	x	---	---
Gamlestaden	-4,1	3,4	4,1	6,8	10,7	1,2	13,4	16,6	7,8	7,0	---	x	-0,6
Svingeln	-4,5	-3,0	-0,3	2,4	2,3	4,8	-0,2	13,0	4,2	-0,6	---	-0,6	x

Table A.4: Potential travel time savings with the new service and improved values expressed as percentages. Impaired accessibility accounted for by 1 min penalty at either trip end.



TT-Save [%], Improved (2 min penalty)	Centralst.	Korsvägen	Chalmers	Sahlgrenska	Linnépl.	Stigbergst.	Lindholmen	Volvo	Wieselgr.	Hjalmar Br.	(Ringön)	Gamlestaden	Svingeln
Centralstationen	x	42,3%	51,5%	56,7%	34,1%	13,3%	1,7%	34,2%	-16,0%	-102,3%	---	15,1%	12,8%
Korsvägen	50,5%	x	15,3%	42,5%	47,4%	62,0%	62,0%	60,2%	23,3%	20,4%	---	53,2%	17,5%
Chalmers (Johanneberg)	59,6%	32,2%	x	19,7%	37,2%	69,3%	68,3%	69,7%	44,6%	29,3%	---	55,9%	42,4%
Sahlgrenska	59,6%	42,5%	-7,1%	x	-6,1%	74,4%	76,9%	78,9%	64,3%	55,3%	---	56,4%	46,1%
Linnéplatsen	39,6%	47,4%	26,7%	-59,1%	x	73,6%	82,4%	82,0%	68,1%	54,4%	---	58,6%	32,8%
Stigbergstorget	21,1%	62,0%	69,3%	75,7%	73,6%	x	86,8%	87,6%	77,6%	67,7%	---	42,5%	51,6%
Lindholmen	-22,9%	63,6%	65,1%	76,0%	80,9%	86,3%	x	73,4%	65,9%	29,7%	---	65,5%	26,9%
Volvo (Campus Lundby)	41,5%	61,8%	71,8%	78,9%	82,5%	87,6%	73,4%	x	45,9%	63,0%	---	76,8%	66,5%
Wieselgrensplatsen	-16,0%	28,4%	50,4%	64,3%	69,5%	77,6%	63,0%	18,8%	x	-59,4%	---	69,1%	54,2%
Hjalmar Brantingsplatsen	-61,8%	26,5%	33,7%	55,3%	54,4%	66,1%	29,7%	63,0%	-59,4%	x	---	72,2%	49,2%
(Ringön)	---	---	---	---	---	---	---	---	---	---	x	---	---
Gamlestaden	15,1%	56,3%	53,3%	56,4%	60,2%	38,9%	68,1%	74,4%	67,5%	70,6%	---	x	54,9%
Svingeln	12,8%	29,3%	42,4%	49,7%	45,4%	49,2%	31,8%	66,5%	54,2%	40,0%	---	54,9%	x

Table A.5: Difference in travel times, i.e. time saved, with improved new service compared to base values.



TT Difference Improved	Centralst.	Korsvägen	Chalmers	Sahlgrenska	Linnépl.	Stigbergst.	Lindholmen	Volvo	Wieselgr.	Hjalmar Br.	(Ringön)	Gamlestaden	Svingeln
Centralstationen	x	0,4	0,7	1,0	1,3	1,6	1,9	2,7	1,8	1,6	1,3	0,8	0,4
Korsvägen	0,4	x	0,3	0,6	0,9	1,3	1,5	1,8	2,2	1,9	1,6	1,2	0,8
Chalmers (Johanneberg)	0,7	0,3	x	0,3	0,6	0,9	1,2	1,5	1,8	2,1	2,0	1,5	1,1
Sahlgrenska	1,0	0,6	0,3	x	0,3	0,6	0,9	1,2	1,5	1,8	2,1	1,8	1,4
Linnéplatsen	1,3	0,9	0,6	0,3	x	0,4	0,6	0,9	1,2	1,5	1,8	2,1	1,7
Stigbergstorget	1,6	1,3	0,9	0,6	0,4	x	0,3	0,5	0,8	1,1	1,4	1,9	2,0
Lindholmen	1,9	1,5	1,2	0,9	0,6	0,3	x	0,3	0,6	0,9	1,2	1,6	2,0
Volvo (Campus Lundby)	2,1	1,8	1,5	1,2	0,9	0,5	0,3	x	0,3	0,6	0,9	1,3	1,8
Wieselgrensplatsen	1,8	2,2	1,8	1,5	1,2	0,8	0,6	0,3	x	0,3	0,6	1,0	1,5
Hjalmar Brantingsplatsen	1,6	1,9	2,1	1,8	1,5	1,1	0,9	0,6	0,3	x	0,3	0,8	1,2
(Ringön)	1,3	1,6	2,0	2,1	1,8	1,4	1,2	0,9	0,6	0,3	x	0,5	0,9
Gamlestaden	0,8	1,2	1,5	1,8	2,1	1,9	1,6	1,3	1,0	0,8	0,5	x	0,4
Svingeln	0,4	0,8	1,1	1,4	1,7	2,0	2,0	1,8	1,5	1,2	0,9	0,4	x

APPENDIX VI - Revised Approach

It was not the initial plan to use a meta-analysis approach in this study. The original intent was to determine the effects of a mass transit implementation with aid of the software Visum, developed by PTV Group. PTV Visum is a GIS-based software designed to be used by transport planners when analysing or modelling traffic demand or forecasting future scenarios (PTV Group, 2020). The software can account for different transport modes, both private and public, shared and autonomous, and comes equipped with various demand models and methods. PTV Visum provides means for data provision and decision support and is preferably used at the macroscopic level. For more microscopic tasks there is a sister software called PTV Vissim.

The ambition to work with PTV Visum was motivated by the need to estimate travel times by car between the selected activity centres. Car travel is different from transit since it does not follow a fixed schedule. Instead its travel times are largely affected by road network attributes including road type, urban or rural setting, and speed limit. Travel times may also vary greatly due to traffic flow and congestion which in turn depend on weather conditions and temporal aspects such as time of day, day of week, and season of the year. One method to compute car travel times is with volume-delay functions which are functions that describe the performance of roads (i.e. the time it takes to traverse them) depending on the traffic flow. A variety of those are programmed into PTV Visum for easy application. The most widely used volume-delay function is the BPR-function (named after the organisation that originally promoted it; The Bureau of Public Roads) which is presented below:

$$T = t_0 \times \left(1 + \alpha \left(\frac{V}{C}\right)^{\beta}\right) \tag{24}$$

The BPR function, as do other types of volume-delay functions, describe the travel time T, of a specific road link. That time is dependent on the free-flow time t_0, i.e. the time it takes to traverse the link given there is no other traffic (often computed from the speed limit), the actual traffic volume V, and the vehicle capacity of the link C. The coefficients α and β determine the shape of the time-flow curve as the traffic volume increases and are commonly set to 0.15 and 4 respectively (Saric, Albinovic, Dzebo, & Pozder, 2019). A downside in general with volume-delay functions is that they have trouble capturing the effects of other time-influencing aspects taking place along a road segment, for example intersections. This is clearly manifested in urban areas where the bulk of travel time might not be represented by actual drive time but rather by idle time at signalized intersections. However, there are ways to account also for intersection effects by expanding the volume-delay function expressions.

Using volume-density functions to calculate travel times may cause inaccurate results unless they are calibrated to better represent local conditions (Saric et al., 2019). A calibration process is thus needed against field data from other sources to produce accurate results. To better mimic the conditions in Gothenburg, it was intended to use volume-delay functions developed by the Swedish National Road and Transport Research Institute. The authority has recently developed a set of 76 different functions representative for different road characteristics with respect to type, speed limit, number of lanes, and urban or rural setting (VTI, 2016). The functions consist of two terms, the first representing link travel time and the other constituting a delay term to account for intersections. For urban roads, the intersection delay part is calibrated based on typical Swedish intersection designs, their apparent capacity, and their frequency in the road network.

The use of volume-delay functions requires information about road network layout and traffic volume. This data is often accessible through local authorities and organisations and can be imported into PTV Visum. Gothenburg conduct regular estimates on traffic flow for a large part of the major road network based on a number of measurements. Data, which are provided as weekday averages and afternoon peak, are made available either in a map format (Göteborgs Stad, 2020b) or sorted by street name (Göteborgs Stad, 2020c). Regarding network data it can be accessed via OpenStreetMap (www.openstreetmap.org). The site is a community driven database for world mapdata maintained, updated, and supported for by many different cartographers and other contributors. The data is free to use given source reference to OpenStreetMap and its contributors. Easy extraction of OpenStreetMap data can be made through www.geofabrik.de whom enable downloads of files covering specific geographical regions. The raw data contained in those files can be very extensive why they are likely to require some processing to ensure convenient use PTV Visum.

After having acquired reliable car travel times those are put in relation to transit figures computed in accordance with Section 4.2.4. However, travel time are but one factor affecting a person's choice on how to make his or her trip, may it be an important one. With that said, it is not certain a faster travel time is motivating enough to make a traveller change mode. Estimating modal split is better performed by considering the measure generalised cost which allows for the inclusion of aspects other than just total travel time. One definition of generalised cost that Ortúzar and Willumsen, (2001) use is presented below:

$$C_{ij} = a_1 t_{ij}^{v} + a_2 t_{ij}^{w} + a_3 t_{ij}^{t} + a_4 t_{ij}^{n} + a_1 \delta^{n} + a_1 F_{ij} \tag{25}$$

t_{ij}^{v}: In-vehicle travel time between i and j
t_{ij}^{w}: Walking time to and from stops
t_{ij}^{t}: Waiting time at stops
t_{ij}^{n}: Interchange time
δ^{n}: Intrinsic 'penalty' or resistance to interchange in time units (2-5 min)
F_{ij}: Fare charged to travel between i and j
a_1-a_5: Coefficients associated with the elements of cost above

The coefficients a_1-a_5 allow for different valuations of time for different aspects of a trip. By calculating the 'cost' for transit in the base scenario, and then a new cost for the improved transit option in the hypothetical scenario, this change in utility can be used to estimate the modal shift occurring as an effect of the travel time change. More specifically, that could be done via a form of pivot-point modelling using the multinomial logit model in its incremental form:

$$p'_k = \frac{p_k^0 exp(V_k - V_k^0)}{\sum_j p_j^0 exp\left(V_j - V_j^0\right)} \tag{26}$$

In Equation 26, p'_k is the new market share of trips made by mode k as a result of a utility change $(V_k - V_k^0)$ for that mode. The advantage of this model is that it only requires knowledge about the original market shares, information that is most often available.

Reason for reconsidering

The reason for revising the original approach was due to various reasons. First, it was difficult to scale down the network model to be rough enough to be manageable, yet still maintaining a level of detail to provide good estimates. Another issue of concern was data-availability. To make traffic assignments in Visum, and subsequently to estimate mode share, one requires data on people's trip movements, i.e. origin-destination data. For the car part of the assignment that was problematic since a lot of traffic on the roads are only passing through, having neither start nor end in the areas of interest to the study. Volumes on links would therefore be to low and consequently the travel times as well. A possibility to compensate this by adding external zones, and then use a fuzzy tool to tune the assigned traffic towards the measured volumes, was discussed but eventually deemed unsatisfying. The transit part was also problematic. In addition to the extensive effort it would take to model up Gothenburg's intricate transit network, origin-destination data became an issue here as well. The local transport authority uses an automatic passenger count system to measure the travel demand. Such a system, however, cannot differentiate one person from another, thus it cannot give information on where individuals get on or off. Such information would require smart card data. Electronic cards are in fact used in Gothenburg, but only to a lesser degree, and only when boarding. For those reasons, the original approach was rendered impossible and thus the need to develop a new one became imminent.

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