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A conceptual study of BRT on highly trafficked roads

Station features and transit oriented development on parts of Väster and Söderleden

Master’s Thesis in the Master’s Programme Infrastructure and Environmental Engineering

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Cover: BRT in Istanbul (Chumwa, 2012), further described in chapter 5.1.

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ABSTRACT

In order to mitigate climate change cities must become more sustainable and one important part of this is to increase transportation by public transport. This has in the Gothenburg region lead to a transportation vision for the year of 2035, for Gothenburg, Mölndal and Partille. The vision contains suggestions for the trunk traffic in the region, and this thesis investigates how a bus rapid transit (BRT) system could be implemented on parts of Väster and Söderleden, with special concern to integration with urban development and what the needs are regarding noise levels and air quality for waiting customers, as well as traffic safety at stations. Furthermore the thesis briefly looks into the aspect of switching mode from bus based to rail based public transport. The work was carried out by performing a literature study on what BRT is, followed by a study of transit oriented development and the preconditions for noise levels, air quality and traffic safety, and BRT versus light rail transit (LRT). After that, information was gathered on the area surrounding the road, and BRT systems in Istanbul, Curitiba and Ottawa was studied with the aim to find viable solutions for the different topics investigated in the thesis. Finally an analysis was carried through where implementation suggestions regarding BRT for Väster and Söderleden was made based on all the previous steps. The challenges with a BRT system on Väster and Söderleden mainly springs from it being a heavily trafficked road, while BRT most commonly is a concept implemented on streets in urban areas with high population density. According to transit oriented development stations should be integrated with urban development such as housing areas, shops, services and so on. It was found that the distance from Järnbrott to surrounding buildings could be problematic, while Frölunda Torg is better suited with the mall, residential buildings and other services in near access to Västerleden and a potential station. Furthermore the stations should be closed in order to reduce noise levels, increase air quality and traffic safety. It was also concluded that a median running way would be more suitable than a shoulder, and the idea of using already existing infrastructure is somewhat limited in the way that reconstruction as widening of the road and rebuilding junctions would be needed. The potential has more to do with using the corridor and its sparsely developed neighboring land than using the actual road, and therefore it was concluded that a separate busway that uses the corridor should be considered further. Such a configuration has potential to work better in terms of transit oriented development as it can be placed on the most suitable side, and integration between stations and development would be more easily achieved. Furthermore the three global examples of BRT showed no great solutions in terms of noise levels or air quality, but gave tips concerning issues with traffic safety.

Regarding LRT and BRT systems, it was found that LRT is not necessarily superior to BRT. It does have a larger capacity, but the capacity gained by invested money was larger for BRT than LRT. By looking at the examples abroad it became clear that BRT systems have the possibility to carry a lot of customers, 30 000 per hour and direction at maximum in Istanbul. The future built environment in the area, noise levels, emissions and traffic flow are factors that are difficult to predict, which affect the prospects of a BRT system. Furthermore economy needs to be taken under careful consideration since it will have a fundamental impact on how the system can be implemented.

Key words: bus rapid transit, transit oriented development, noise levels, air quality, traffic safety, stations, public transport, light rail transit

En konceptuell studie av BRT på högtrafikerade vägar
Stationsegenskaper och kollektivtrafikanpassad bebyggelse på delar av Väster- och Söderleden

Examensarbete inom masterprogrammet Infrastructure and Environmental Engineering

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SAMMANFATTNING

För att hindra klimatförändringar behöver städer bli mer hållbara och en viktig del av detta är att öka andelen transporter med kollektivtrafik. Detta har i Göteborgsregionen lett till en målbild för år 2035, för Göteborg, Mölndal och Partille. Målbilden innehåller förslag för utveckling av stomkollektivtrafiken i regionen, och den här tesen undersöker hur ett bus rapid transit (BRT) system skulle kunna införas på delar av Väster- och Söderleden, med fokus på kollektivtrafikanpassad bebyggelse samt vad situationen är gällande bullernivåer, luftkvalitet och säkerhet vid stationslägen. Vidare undersöks i tesen aspekten av att övergå från BRT till spårväg. Arbetet utfördes genom en litteraturstudie i vad BRT är och bör inneha för egenskaper, följt av en studie av kollektivtrafikanpassad bebyggelse, förutsättningar för bullernivåer, luftkvalitet och trafiksäkerhet, samt BRT kontra spårväg. Information om närområdet för Väster- och Söderleden samlades in, och BRT-system i Istanbul, Curitiba och Ottawa studerades med syftet att finna möjliga lösningar för de olika ämnen som tesen undersöker. Slutligen genomfördes en analys med förslag för ett eventuellt införande av BRT på Väster- och Söderleden baserat på de genomförda studierna.
Utmaningarna med ett BRT-system på Väster- och Söderleden stammar främst från att vägen är hårt trafikerad, då BRT vanligtvis är ett koncept som implementeras på vägar i urbana områden med högre invånardensitet än motorvägsområden. I enlighet med kollektivtrafikanpassad bebyggelse ska stationer vara integrerade med stadsbebyggelse såsom bostadsområden, tjänster och service. Det framgick att distanserna från Järnbrott till bebyggelsen kan vara problematisk, medan Frölunda Torg är bättre lämpad med köpcenter, bostadsområden och annan service i nära avstånd till Västerleden och en potentiell station. Vidare bör stationerna vara stängda för att minska buller och öka luftkvalitén samt vara lämpliga ur trafiksäkerhetssynpunkt. Slutsatsen drogs även att en median bussbana är lämpligare än en separat bussfil förlagd längst till höger, samt att användning av redan existerande infrastruktur är begränsad eftersom breddning av vägen och potentiell ombyggnation av mot skulle behövas. Möjligheterna ligger snarare i att använda korridoren och dess obebyggda närområde än vägen som sådan. Följaktligen konkluderades att en separat bussbana som använder korridoren bör undersökas vidare och en sådan anses ha bättre möjligheter gällande kollektivtrafikanpassad bebyggelse, då den kan förläggas på mest lämplig sida av korridoren och integration av stationer och bebyggelse är mer genomförbart. De tre studerade utländska BRT-

exemplen visade inga direkta lösningar för buller och luft, men gav tips gällande säkerhetsaspekter. Gällande BRT kontra LRT-system påvisades att LRT inte nödvändigtvis är överlägsen BRT, då LRT har högre kapacitet men kapaciteten per investerad krona är högre för BRT. Studien av utländska exempel visade att BRT kan transportera stora mängder passagerare, upp till 30 000 per timme och riktning i Istanbul. Den framtida byggda miljön, bullernivåer, emissioner och trafikflöden är faktorer som är svåra att anta och som påverkar utsikterna för ett BRT-system. Vidare behöver ekonomiska aspekter tas noggrann hänsyn till, eftersom de har en fundamental påverkan på hur systemet kan komma att utformas.

Nyckelord: bus rapid transit, kollektivtrafikanpassad bebyggelse, buller, luftkvalitet trafiksäkerhet, stationer, kollektivtrafik, spårväg

Contents

Preface

This thesis was written from January to June 2016 at the Department of GeoEngineering at Chalmers University of Technology. The idea of the thesis came forward with help from Jörn Engström at Västra Götalandsregionen who works with a public transportation vision for Gothenburg, Mölndal and Partille. Guidance was given from Sweco Society and Senior lecturer Gunnar Lannér at Chalmers University of Technology. Furthermore Lannér supervised the project and has been a great support throughout the work.

Gothenburg May 2016

Erika Lennartsson, Emma Olsson

Notations

Accessibility: the term does not include the accessibility features for disabled people in this thesis.
Bus rapid transit, BRT: a bus based public transport system with similarities to a metro
Express-BRT: BRT on highly trafficked roads
GMP 2035: An abbreviation for the transportation vision for Gothenburg, Mölndal and Partille in the year of 2035
Light rail transit, LRT: trams
Operational speed: Average speed, time at bus stop included
Ridership: Amount of boardings, usually given per hour or day
Transit oriented development, TOD: a policy used to synchronize public transport and other urban development
Transit: Movement of people from one place to another, in this report referred to as public transportation

1. Introduction

An efficient transport system is an important part of obtaining a sustainable city. Goals have therefore been established concerning modal shares for the different passenger transportation modes in Gothenburg (Göteborgs Stad, 2016). In 2035 at least 35% of the trips in Gothenburg are made by walking or cycling, and at least 55% of the motorized trips are carried by public transport which gives modal shares according to Table 1, where present figures also are described. Furthermore there is also a goal ensuring that the travel time between two important nodes is no more than 30 minutes for either public transport or car. There are no prognosis for the population in Gothenburg in 2035, however the city is predicted to have 640 119 inhabitants in 2025. Furthermore for each 1000 people there are on average 285 cars[1] (SCB/Stadsledningskontoret, Göteborgs Stad, 2016).

Table 1:Present modal shares for transportation in 2015 and goals for 2035.

Year	**2015**	**2035**
Population	548 190	-
Walking and cycling	27%	35%
Public Transport	27%	36%
Automobile	46%	29%

1.1 Background

Gothenburg is expanding as a region with its neighboring municipalities Mölndal and Partille. This increases the number of residents and workplaces, which puts demands on the development of the transport system in the region. To achieve the transportation goals for modal shares there is an on-going work of developing a transportation vision of the year 2035, made by the public transport authority of Västra Götalandsregionen, city of Gothenburg, city of Mölndal and the municipality of Partille. This work is abbreviated as GMP 2035 which stands for Gothenburg, Mölndal, Partille the year of 2035. The work of GMP 2035 addresses the trunk traffic in the region, which is the public transport network that consists of trams, trunk buses, express buses and commuter trains (Västra Götalandsregionen, 2015).

In an analysis report of GMP 2035 made in October 2015 (Västra Götalandsregionen, 2015) suggestions of implementing a transport system called BRT, which stands for bus rapid transit were made. BRT is a concept of mass transit that has special service, design and infrastructure compared to regular bus systems. The suggestions for GMP 2035 contain what is distinguished as traditional BRT for more dense urban areas but also BRT that goes on motorways and larger arterial roads, which is called Express-BRT in this report. The Express-BRT corridors are meant to provide high capacity and fast bus service mainly as cross-links to already existing radial links, and a map with a proposal of the corridors can be seen in Figure 1. These suggestions aim to overall enhance the express transit of the city and make it easier to travel between specific destinations without needing to enter the city center along the journey, making journeys shorter and faster meanwhile easing the congestion in the city center.

[1] Owned by a private person or a private company

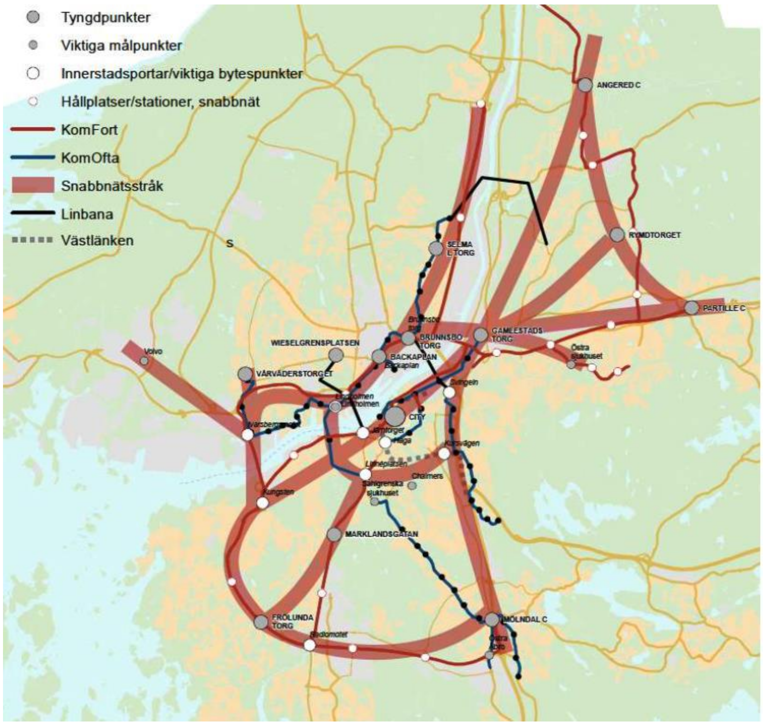

Figure 1. Map over Gothenburg with stretches that are proposed for Express-BRT in GMP 2035 analysis report, marked in bold red and called Snabbnätsstråk in the legend (Västra Götalandsregionen, 2015).

There are guidelines with recommendations of how to conduct BRT in a Swedish context, yet these guidelines mainly focus on traditional BRT for more urban areas and are not fully applicable on Express-BRT. Therefore it is of interest to study the concept of Express-BRT.

1.2 Aim and objectives

This thesis aims at investigating the prospects of an Express-BRT on Väster and Söderleden, both in terms of noise levels, air quality and traffic safety at stations, as well as connecting the BRT with urban development. These aspects were chosen since they are thought to be of extra importance on a heavily trafficked road compared to a BRT system on regular streets in the more central parts of a city.

Furthermore there is a general idea that rail based public transportation is preferred over bus based, this thesis therefore also briefly investigates the reasons for this and briefly compare the two systems of light rail transit and bus rapid transit.

Based on the aim the following objectives were investigated:

- Does the Express-BRT have special aspects that need to be addressed when it comes to air quality, noise levels and traffic safety at stations, and if so how should these be dealt with?
- What are the preconditions and prospects for transit oriented development in the area?
- Is it reasonable to continue to have BRT, or should light rail transit be introduced as a next step when the route is heavily used?

1.3 Scope

- Two potential stations along the stretch were investigated: Frölunda Torg and Järnbrott.
- The design of the stations does not concern the physical shape in a detailed aspect, which for example means that the size will not be addressed with measurements.
- When investigating the station configuration due to noise levels and air quality, the issue was to reduce the exposure for customers, not actually reduce the levels.
- Economic aspects were not considered further than approximated sums in the BRT versus LRT chapter.

1.4 Method

In order to answer the objectives and make implementation suggestions for Väster and Söderleden the first step was to study BRT on a conceptual level to gain understanding of the theory of the system. The next chapter contains information about the research questions regarding stations, transit oriented development and BRT versus LRT, and why they are considered important to investigate. This was carried out by a literature study.

Secondly a literature study of the preconditions concerning the research questions was carried out for Väster and Söderleden with its surroundings. This was later used in order to perform the analysis for implementation of a BRT system. After the study of Väster and Söderleden three different BRT systems were investigated in order to learn how BRT systems can be configured and see how the aspects described in the objectives have been dealt with on other locations. The following cities were chosen:

- Istanbul, Turkey
- Curitiba, Brazil
- Ottawa, Canada

The reason for choosing Istanbul was that its BRT system runs entirely on a freeway and thereby is interesting for this thesis. Curitiba's BRT has a different setup compared to Istanbul and does not run on the freeway, but was chosen since it is considered to be an iconic model of BRT with extensive transit oriented development. Ottawa partly run on the freeway and this alongside the preconception that the city would be somewhat similar to Gothenburg when it comes to welfare, economic terms and environmental awareness was the reason for studying this system. These examples were studied by literature and through use of Google Maps. Since the systems are diverse not all aspects are dealt with in all three cases, and therefore the case studies are presented with somewhat different approaches. BRT versus LRT is only described in Ottawa since no information was found that there are plans for transformation in the other two systems. After each case study a minor analysis follows with focus on the performance of the system in question.

Based on findings from the literature studies and the case studies, a final analysis was performed regarding station features concerning noise levels, air quality and traffic safety, and transit oriented development in the study area. Moreover BRT versus LRT and some additional aspects found to be of importance, such as running way configuration, were analyzed.

2 Bus Rapid Transit

One of the definitions of BRT is ''*...a high-quality bus based transit system that delivers fast, comfortable, and cost-effective urban mobility through the provision of segregated right-of-way infrastructure, rapid and frequent operations, and excellence in marketing and customer service. BRT essentially emulates the performance and amenity characteristics of a modern rail-based transit system but at a fraction of the cost.*'' (Wright & Hook, 2007)

2.1 Swedish BRT Guidelines

As explained in the definition above, BRT is a bus system that has specific characteristics and can be compared to rail systems rather than regular bus systems. It aims at providing high-quality transportation that is faster and more comfortable than regular bus traffic, and has a strong identity in the transport system and in the city to enhance orientation and understanding. There is no complete BRT system in Sweden as of today, and a report providing guidelines for BRT called *Guidelines for attractive public transport with a focus on BRT* made by X2AB (2015) has been carried through with the aim of supporting planning and implementation of such a system. A BRT system has according to these guidelines several important factors and some of these are presented below to provide an understanding of the concept.

- Infrastructure – BRT has dedicated infrastructure and is separated from other modes, and the alignment should be as straight as possible.
- Stations – BRT stops are more similar to stations than conventional bus stops. BRT station standard includes weather protection, sufficient seating space, proper lighting, real-time information and maps for orientation. Bicycle amenities are provided as well as bicycle paths connected to the station in order to encourage biking as a transport mode to the station. Furthermore pedestrian infrastructure and further transits are integrated with the station area. The stations is designed in a way that enables the bus to enter the stations without making side turns, which gives increased comfort and saves time.
- Clear identity – It is important that the BRT has a clear and distinct identity that helps customers to understand the product and orient themselves in the system. A successful BRT identity can additionally act as a city attraction force and thereby add value to the city image.
- Vehicles – Comfortable vehicles with unique design, wide doors, entry in the same level as the platform, real-time information and preferably low noise levels, especially at stations.
- Speed and comfort – Priority in intersections as well as straight corridors allow timesavings and a smooth ride.
- Service – BRT has high frequency and long service hours.
- On time –BRT provides high regularity and few delays.
- Payment – Tickets are bought in a way that does not create a bottleneck when entering and leaving the bus, for instance on the station before boarding the bus.

BRT Guidelines emphasizes the importance that in order to make a BRT system attractive a most vital part is to construct the route between important larger destinations within the city and let it pass several smaller ones such as schools, residential buildings and super markets on its way (X2AB, 2015), and construct stations at these locations. Equal amount of passengers in each direction should be strived for in order to fully maximize the utility and efficiency of the system, and the route should be placed through housing areas instead of on the side of them. In the guidelines it is also mentioned that larger roads should be avoided when implementing BRT since these often are found in the outskirts of cities, with too large distances to housing areas (X2AB, 2015).

2.2 Bus Rapid Transit on highly trafficked roads

BRT Guidelines refer to BRT as a system where buses run in urban areas, rather than on highly trafficked roads that many times are located outside dense development. This report however investigates BRT in the form of BRT on larger roads where already existing transport corridors are used, in this thesis called Express-BRT, concerning the suggestions of a network of Express-BRT on the large arterial roads in Gothenburg. The term Express-BRT is not a recognized standard but an expression borrowed from the work of GMP 2035, and in this report a way to specify that the BRT goes on motorways or larger arterial roads. There are no Swedish guidelines developed to suit especially Express-BRT, although some of the guidelines by X2AB are applicable to both regular BRT and Express-BRT. There are several international examples of Express-BRT and a few are provided in the case studies section.

The American Public Transport Authority (APTA) has made recommendations that are applicable to Express-BRT and in order to gain understanding for how Express-BRT can be constructed some of the main features of the APTA recommendations are presented below. These recommendations concern the placement of busway and stations and the recommendations are therefore considered to be relevant also for countries with different transportation policies than the US such as Sweden.

APTA (2010) suggests that the running way of Express-BRT can be either separate, or as a median, shoulder or high occupancy vehicle (HOV) lane of a freeway or arterial road. A separate arrangement means that the bus operates completely free from other traffic on its own infrastructure. It is considered that the separate running way has the best performance when it comes to achieving a high standard of BRT as it provides travel completely without obstructions and can be fitted suitably to existing development. It is according to APTA however the most expensive option when compared to implementing a running way on a freeway or arterial road since it demands its own infrastructure.

Moreover, it is proposed by APTA (2010) that the median running way on a freeway or large arterial road is a space efficient option since these roads usually have an existing median barrier and therefore the need for widening the road can be somewhat smaller. If the station is placed in the middle of the running way, only one platform is needed for both directions. The median running way demands a rather sophisticated station setup where the passengers can get to and from the station in a safe and comfortable way. Further this option can be considered rather visible and clear for the road users, which strengthens the BRT brand.

The right-side shoulder of a freeway is also a possible setup for Express-BRT. According to APTA (2010) this typically has lower costs for investment since it is based on utilizing an already existing lane. A potential issue with busways on shoulders is that when a vehicle needs to use the shoulder for an emergency stop, the bus will have to enter the adjacent general traffic. Additionally the buses have to share road space with vehicles that are leaving or entering the freeway, which compromise the free flow of the BRT bus. Shoulder running ways on arterial roads can lead to significant disturbances if the shoulder is used by other vehicles.

It is additionally suggested by APTA (2010) that the running way can be placed on HOV lanes, where the lane is dedicated for buses and car pools, yet this is problematic when the bus needs to enter and exit the lane in mixed traffic in order to make stops, and an additional challenge is that the bus becomes mixed with other vehicles on the actual HOV lane. Using already existing HOV lanes can be space efficient if there is capacity available for the BRT, which then leads to a lesser need for widening of the road.

3 Further information regarding research questions

This chapter provides information on transit oriented development and preconditions concerning air quality, noise levels and traffic safety. Furthermore features of BRT and LRT are described.

3.1 Stations aspects

The following chapters describe features concerning air quality, noise levels and traffic safety, and why these are important to consider when it comes to Express-BRT.

3.1.1 Air quality

Road traffic is one of the main contributors to poor air quality in cities. Pollution from traffic consists of several substances such as nitrogen oxides, sulfur oxides, hydrocarbons, carbon monoxide, ground leveled ozone and particular matter. Air polluted from traffic has negative health effects for humans and can cause lung disease, cardio-vascular disease and cancer. For instance, particles from road traffic that mainly originate from wear of tires and road surface, combustion, and fine particles on the road, are estimated to cause thousands of early deaths in Sweden every year according Trafikverket (2016a). Further it is stated that nitrogen dioxide often is used as an indicator of how the air quality is, since other pollution and foremost fine particles have a correlation with the amount of NO_2 in the air.

Sweden aims to have a transportation fleet independent of fossil fuel in the year of 2030, which is a step on the way towards reaching a sustainable and resource efficient energy provision in the year of 2050 with no net emissions of greenhouse gases (Miljö- och energidepartementet, 2008). This is suggested to happen with a change towards renewable fuel such as hybrids and electrically driven vehicles. A fossil free transportation fleet will affect traffic related local air pollution depending on what fuel is used. If combustion engines are used with biofuel, there will still be emissions from combustion meanwhile non-combustion engines such as electric lead to zero emission for propelling the vehicle although emissions can occur when producing the electricity. This means that traffic related air pollution would improve in general if the transportation fleet becomes fossil fuel free. However there will still be local air pollution in form of particles since these are primarily dependent of the contact between tires and road surface.

3.1.2 Noise levels

Noise can cause health problems such as hearing disorders, heart diseases and sleeping disturbances. It is approximated to cause a total loss of 1-1.6 million disability adjusted life years[2] (WHO, 2016) in high income European countries, which is a measure used to calculate number of healthy years lost due to illness. In Sweden noise should be restricted to 45 dB(A) in transit terminals (Boverket, 2011), and since Express-BRT will run along heavily trafficked roads and too high levels are assumed to decrease the overall experience of the Express-BRT for the costumer, the issue of noise levels is of great importance.

[2] a standardized measure of healthy years of life lost to illness, disability or early death.

Since there are goals for having a fossil free transportation fleet in 2030 there will probably be more hybrids and electrical vehicles in the year of 2035. These vehicles cause less noise than ordinary combustion driven vehicles, but only until certain speeds are reached. The difference in noise levels are approximated to vanish above 20-30 km/h for private cars and 50-70 km/h for heavy traffic, since the dominating source of noise above these speeds are originated from the tires and not the engine (Eklund et al., 2013), and therefore the issue of noise levels will be important in the future as well.

There are different possibilities for noise reduction for an Express-BRT station; a station with noise barriers along the platforms, a station that is closed to some extent, or a station that is completely closed. A completely closed station with careful design could reach around 40 dB(A) lower noise levels, while stations not completely closed could reduce the levels with around 20-25 dB(A), and a station surrounded with noise barriers could at best reduce levels with 10 dB(A) (Thorsson, 2016).

3.1.3 Traffic safety

According to the zero vision in Sweden no one should get fatally injured or injured for life in traffic. There is a strong correlation between speed and mortality when it comes to accidents between cars and pedestrians. The chance for survival is 90% and 20% when the car has a speed of 30 km/h and 50km/h respectively, and speeds around 60 km/h or more cause almost certain fatality (Trafikverket, 2012). 16% of the seriously injured cyclists and 69% of the killed cyclists between the years of 2007-2012 were due to collisions with a motor driven vehicle, and the most common location for accidents between these modes are at crossings (Niska & Eriksson, 2013). Based on the correlation between speed and fatality it is of great importance to carefully design the infrastructure on a road with high speed such as Väster and Söderleden.

Bus stops on freeways and larger roads shall be separated from the main road and constructed as an isolated stop, and grade-separated cyclist and pedestrian paths are required (Svenska kommunförbundet, 2004). Furthermore an isolated stop on a heavily trafficked road needs to have some sort of fence or railing towards the road to prevent pedestrians from walking into the traffic (Vägverket, 2010). Furthermore Duduta et al. (2015) states that the largest number of accidents in BRT systems occur on major transfer stations, which is explained to be due to the large number of vehicle and pedestrian traffic, and in order to minimize accidents the passengers should be offered direct routes or transfer between routes on the same platform. The drawback with this scheme is however that it requires a lot of space.

3.2 Transit Oriented Development

Transit oriented development (TOD) is a concept that concerns integration of public transportation and the built environment, emphasizing the importance of for instance mixed development, density, distance to stations and having the development along public transportation corridors.

During the previous century bus systems were generally popular but not very thought through and were many times constructed due to the fact that planners did not want to plan for public transportation (Stojanovski, 2013a). This had to do with the flexibility of the bus, it could go wherever and therefore planning was seen as unnecessary, and the bus is still today many times considered a pre-face for introducing light rail, which is further discussed in chapter 3.3. This flexibility to some extent makes the bus unclear and more difficult to use compared to light rail transit (Stojanovski & Kottenhoff, 2013). There is however a need for planning for all types of public transport and it should be integrated in the master- and local plans, so that for instance new buildings and other services are developed in contact with development of public transport and vice versa. This way of thinking is referred to as transit oriented development which can be defined as *a policy to synchronize urban and regional planning and development with public transportation*, hence where the development of a city has taken certain consideration towards public transport systems (Stojanovski, 2013a). Implementation of BRT in Swedish cities is according to the same report a challenge, mainly due to the scattered centers within cities, urban sprawl and the large difference in travel time between public transport and the automobile, and the concept of TOD should be used in order to increase the chances of successful BTR implementation.

TOD originates from North America and was established by architect Peter Calthorpe in the beginning of the nineties (Calthorpe Associates, 2015). In Europe the similar concept of *compact cities* has long been used. This involves accomplishing higher density and diversity within areas and switching the demand for use of private cars towards a public transport system, ideas that are vital in TOD as well. In order to accomplish TOD and compact cities, integrated and intermodal transport systems are important factors (Stojanovski, 2013b), and having a bus station closer than a parking lot (Stojanovski & Kottenhoff, 2013). Areas with increased density and diversity is thought to result in more people living close to services and job places which helps create a sustainable city and reduce the need for cars. The diverse development is further beneficial to achieve even passenger flows in both directions, reducing overloaded buses in one direction and empty in the other direction. In the work of GMP 2035 it is stated that the development of public transport in Gothenburg should be connected to the development of the city in terms of for example connecting parts of the city that does not have public transport today, which will increase the accessibility to housing areas, work places, services and education (Västra Götalandsregionen, 2016).

TOD is categorized in three different steps by Stojanovski and Kottenhoff (2013), where the first one include planning for TOD in masterplans, adapting the development of society towards TOD and for instance marketing its image for the public. The second step involves increasing the density in the already existing development and adapting already existing infrastructure towards a more public transport friendly use such as introducing dedicated bus lanes. The final step has to do with new investment such as constructing bus ways, new buildings and if needed demolishing buildings in favor for busways. Ideally BRT is implemented and urban development follows as a natural consequence, but in cities that are not growing rapidly houses and BRT should be built gradually in order to meet demands of sufficient density for a BRT service (Stojanovski, 2016).

Stojanovski and Kottenhoff (2013) further describes that different kinds of services should be established in line of sight from stations, and that the routes should be located straight through the development and not on the side since this will increase the travel time. The report concluded that in Karlstad areas with schools, health care buildings and commercial buildings generate more trips taken by public transport, and it is stated that a mixture of residential buildings and workplaces should be strived for. Out of the people who reside in the area 66% should be people living there and 33% should be people working.

The willingness to walk to transit differ somewhat according to different sources, however the distance is somewhere around 400 meters (Zhao et al., 2003), but in Europe people tend to be willing to walk a bit longer distances and the faster the service is the further people are willing to walk (Walker, 2016). When it comes to the willingness to travel by bike the maximum distance is approximated to be between 5-10 km (Trivector, 2012). Jorge Gill (2016) looked into common distances for which different modes were used in the Dutch city region of Randstad, which can be seen in Figure 2. As can be seen the bike is used mostly at distances around 1 km. If there are barriers like for example freeways, train tracks and so on the willingness to walk to transit is however likely reduced.

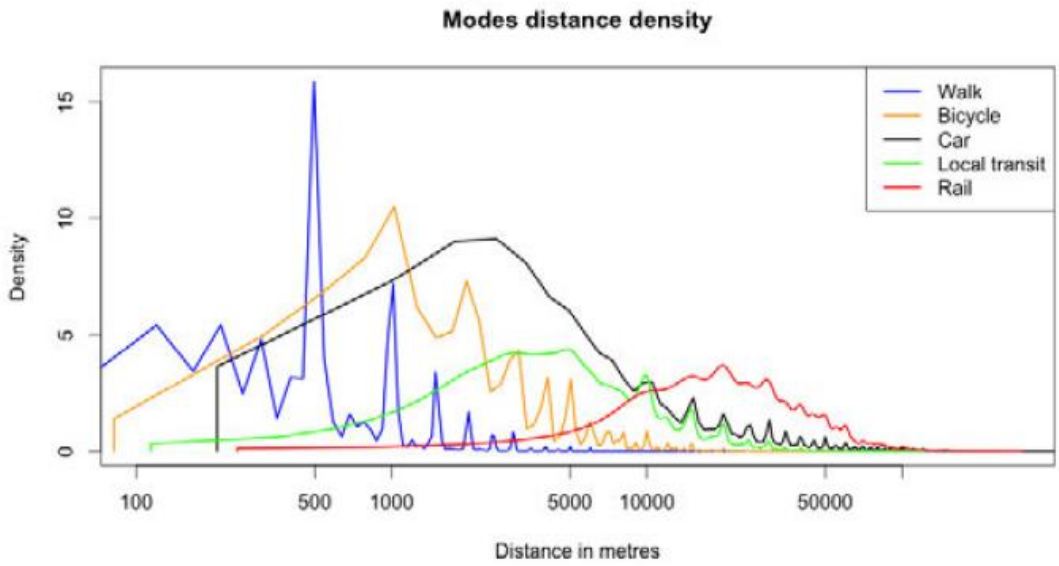

Figure 2: Distances people in Randstad, the Netherlands, tend to be willing to travel by the different modes (Gil, 2016).

In order to have a successful public transport system many citizens need to have the same travel demand at the same time (Stojanovski & Kottenhoff, 2013). The same report mentions 6 000 residents and workplaces in a radius of 500 meters along a 5 km long BRT-route as suitable for a timetable of 10 minutes in Västra Götalands län. In Canada and USA cities with a total urban population of above 750 000 inhabitants are seen as suitable in order to have a successful BRT-system (Transportation research board, 2003). However Stojanovski and Kottenhoff (2013) mention examples of BRT in the US where the population is a lot smaller, down to 150 000.

3.3 BRT versus LRT

Important features of light rail transit systems that a BRT system should contain are smooth alignment, stations with high accessibility, distinctive identity, priority in intersections and separation from other modes (X2AB, 2015). The same report mentions that having these features fulfilled in a BRT system would enable a switch from BRT to LRT in the future, should the ridership increase. The idea of preferring

LRT over BRT can be seen in the GMP 2035 vision where two lines are to be constructed in a way that enables future transformation from BRT to LRT, and also in the discussion of what system should be implemented on Dag Hammarskjöldsleden. There is however no discussion concerning this on Väster and Söderleden, but since this way of thinking occurs features of the modes and reasons for differentiated preferences are described below.

Hensher et al. (2008) questions the idea that public transportation should evolve from being bus-based in mixed traffic towards becoming a rail system. He argues that BRT-systems such as Bogota with ridership of up to 35 000 trips in the main corridor per hour and direction during peak hour, compared to a heavily trafficked rail line in Sydney which at that time had 14 000 trips per hour and direction shows that BRT can outperform rail based systems. He also concludes that BRT systems are more likely to become a success in places where bus is a good experience compared to where it is a bad experience.

LRT is generally considered to exhaust less greenhouse gases, but this has to do with what type of fuel a BRT were to have. Furthermore the energy demand of the two types can be quite similar due to the energy consuming construction process of light rail, but the operating costs are larger for LRT, and Table 2 further describes important features of BRT and LRT according to a report made by WSP (2011) where the advantages of choosing a bus based public transport is described.

Table 2: Capacity and investment cost for BRT and LRT in Sweden. The capacity is based on people both standing and sitting. The different investment costs for light rail has to do with the different preconditions that can occur.

Type	LRT	BRT
Capacity [passengers/vehicle]	180	165
Capacity [passengers/vehicle and hour]	5400-5500	5000
Investment cost [MSEK/km]	101-483	61

The capacity for BRT is based on the capacity of bi-articulated buses in Gothenburg running for example route 16, and the capacity per hour is based on a time table of two minutes (WSP, 2011). The numbers for capacity of standard LRT in Gothenburg is somewhat higher than the table states with up to 234 passengers/vehicle (Göteborgs Spårvägar, 2016), and in Lund there are trams with 250 passengers/vehicle (Bengtsson & Strömberg, 2012). The capacity of the bi-articulated buses includes people both standing and sitting, and there is a recommendation of maximum 70 km/h when there are standing passengers in buses (VGR, 2016), which leads to an issue on larger arterial roads where the speed is higher.

According to WSP (2011) the capacity gained by each million invested are approximately 45% higher for BRT compared to LRT, and there are no differences in travel time between the two modes as long as they are given the same preconditions concerning distance between stations, priority and separation from other modes. Furthermore the rail bonus[3] is brought up which is a rather uncertain matter that has to do with people preferring LRT over buses with similar standard. It is discussed that the political view seem to be more positive towards LRT than bus based

[3] Sve: Spårfaktorn

transportation systems in Sweden, and that there appears to be more positive feelings towards financing the more expensive LRT systems than BTR systems.

In a study made by Ohnmacht (2012), 74% of respondents preferred trams over buses[4], and the most common reason for this had to do with the reliability that springs from the right of way trams have, while environmental aspects[5] were the second most important attribute. Furthermore the most common reason for preferring bus was having positive feelings towards the mode, which is categorized as a physiological attribute. The second most important reason for choosing a bus had to do with seating and the space in the bus, while this attribute were found on fifth place when it came to those preferring trams. Ohnmacht concluded that the main reasons for preferring trams were more objective and rational than the reasons for preferring bus, which were psychological, social and emotional to a larger extent.

[4] Trams and buses had the same availability and timetable in this study.
[5] Environmental aspects are defined as environmentally friendly, no exhaust, less noisy, less energy consumption (Ohnmacht, 2012).

4 The study area of Väster and Söderleden

The road E6.20 is a ring road in the western part of Gothenburg which goes from Mölndal via Västra Frölunda to Angered and passes Gnistängstunneln, Älvsborgsbron, Tuve and Angeredsbron. The road that is of interest in this thesis is the part between Mölndal and Västra Frölunda which is called Söderleden and a short segment of Västerleden from Västra Frölunda to Frölunda Torg which is next to Tynneredsmotet, see Figure 3.

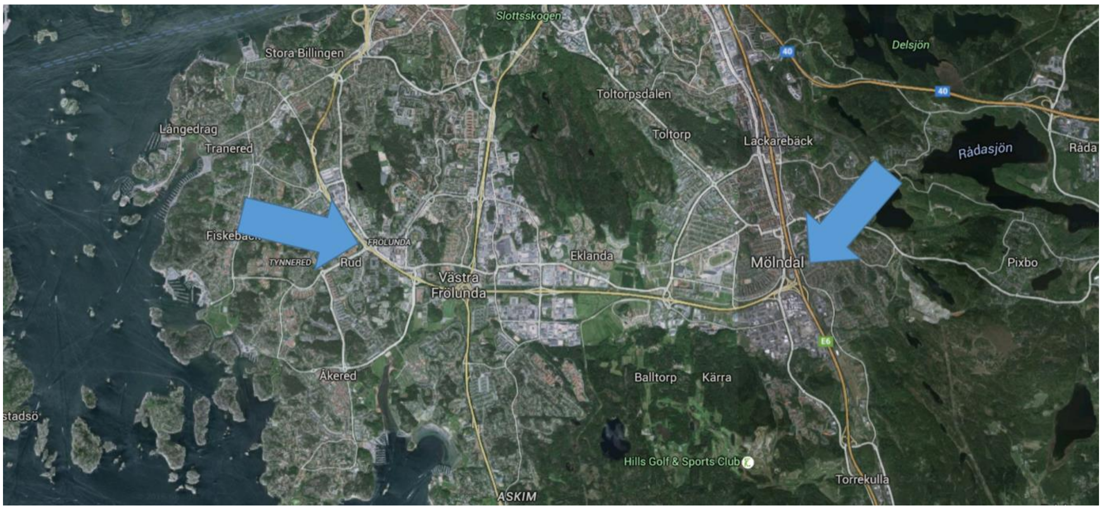

Figure 3: Map from Google Maps displaying the stretch and its surrounding.

E6.20 is a primary road of national interest, and is owned by the Traffic Administration. It is a designated road for transportation of hazardous goods and is an important corridor for freight transports to and from the harbor of Gothenburg and the industries on the island of Hisingen (Structor Mark Göteborg AB, 2015a). The area surrounding Söderleden is called Fässbergsdalen, which is divided between the municipalities of Gothenburg and Mölndal. The investigated stretch is used by commuters and people with destinations such as housing areas and different kinds of services that are situated in the surrounding areas, and according to analysis made in the master plan for Fässbergsdalen about 60 % of the cars passing the border between Mölndal and Gothenburg has origin or destination along the stretch of Väster and Söderleden (Stadsbyggnadskontoren Mölndal och Göteborg, 2012).

Söderleden has capacity issues where traffic jams sometimes occur during peak hours on several locations (Structor Mark Göteborg AB, 2015a), therefore new lanes in both directions between Sisjömotet and Fässbergsmotet, and in the eastern direction between Fässbergsmotet and Åbromotet will be constructed sometime between 2017 and 2019 alongside new acceleration and exit lanes on Sisjömotet. The design of this construction is based on a prognosis of expected traffic flow of the year of 2020, and one aim of the project is to benefit development of new and attractive housing- and working areas with proper public transportation facilities. It will be a first step towards reaching higher capacities where the future goal is to have three lanes in each direction on Väster and Söderleden, but since the accessibility during construction of such lanes all along the road would become too poor the upgradation is divided into steps (Structor Mark Göteborg AB, 2015a).

4.1 Road data, noise levels and air quality

The road is on average 24 meters in width, with two lanes in each direction separated by railings, see Figure 4, and has a maximum allowed speed of 80 km/h Åbrå – Järnbrott and 70 km/h Järnbrott – Hisingen (Trafikverket, 2016b). The road had around 52 000 vehicles/day, with 6% heavy traffic in 2013 and a yearly increase of 4% on average, which can be compared to 1.5-2% in Gothenburg overall, and predictions indicates a flow of 80 000 vehicles/day by the year of 2020 (Structor Mark Göteborg AB, 2015a).

Figure 4: The road E6.20 near Järnbrottsmotet where railings separate the two directions, Google Maps, 2015.

In this thesis, the noise levels on the road were approximated by measurements from E20 in Partille, where levels on facades placed at about 20 meters from the road has been measured to around 74 dB(A) equivalents as a daytime mean (Forssén et al., 2005). The noise level in the median of the road can be approximated to have an increase of 5-6 dB(A) (Thorsson, 2016), which gives values reaching up to 80 dB(A). Furthermore there are measurements for up-coming buildings near Västerleden that are predicted to have levels up to 65-70 dB(A) (Stadsbyggnadskontoret, 2015) at approximately 100 meters away from the road. E20 had a total flow of around 36 500 vehicles/day, where heavy traffic was about 9.6 % in 2002, and a speed limit of 90 km/h (Forssén et al., 2005). These values are similar to the conditions on Väster and Söderleden and alongside the measurements for the buildings near Västerleden this leads to the assumption of values of around 80 dB(A) in the middle of Väster and Söderleden. This indicates that some sort of noise reducing construction must be performed on stations located on Väster and Söderleden in order to meet the level of 45 dB(A) for a transit terminal.

At the environmental website of city of Gothenburg information regarding the air quality in the city is provided. It is stated that Gothenburg is a highly trafficked city and the motorways and large arterial roads is where the air quality is the poorest in the city. NO_2 is the pollutant that Gothenburg has most problems with and it is used as an indicator of air quality. (Göteborgs Stad, n.d.a) A map over mean daily values of NO_2 for Gothenburg is presented in Figure 5, where Väster and Söderleden is marked with a circle. As can be seen the levels exceed the national limits of 60 µg/m^3 (Naturvårdsverket, 2015). Furthermore, is it is presented that during late winter and spring the particle concentration around the roads, mainly due to tires against the road surface and sand, can be so high that it might be dangerous to the health (Göteborgs Stad, n.d.b).

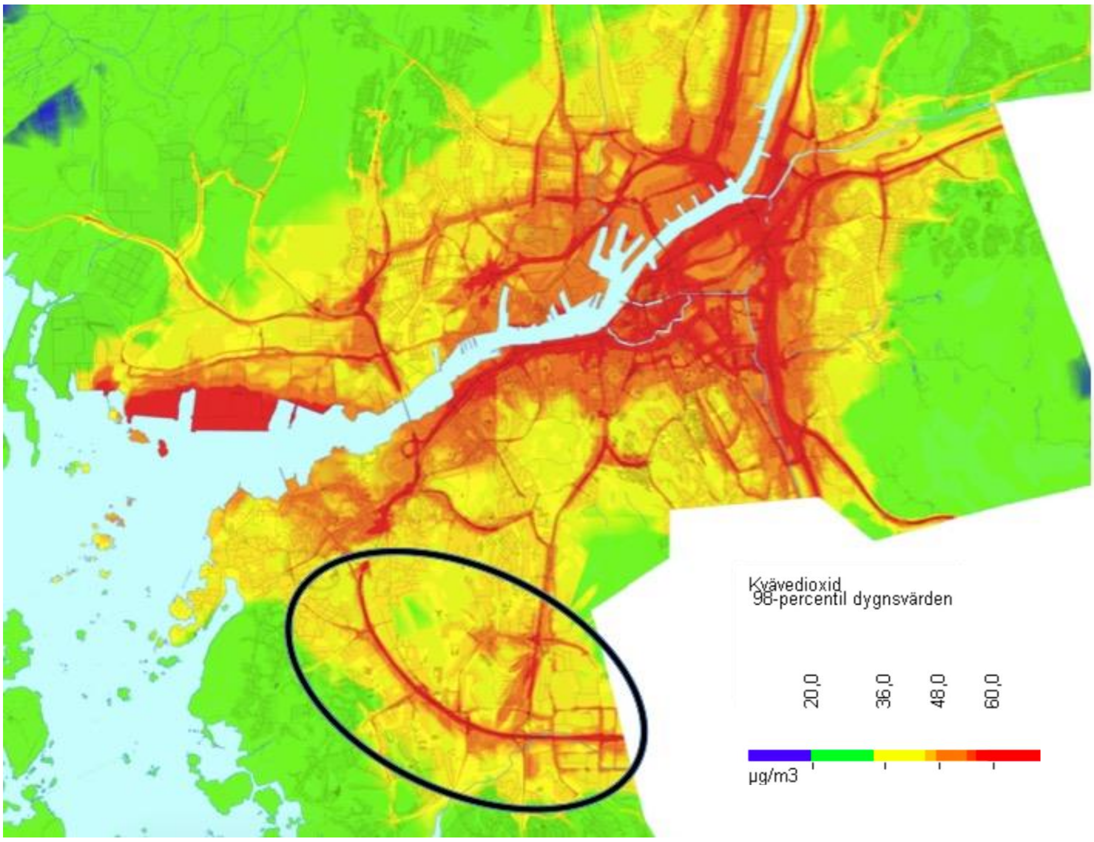

Figure 5. Pollution map over Gothenburg with Väster and Söderleden marked with a circle (Göteborgs Stad, n.d.c).

4.2 The built environment

The road consists of several grade separated junctions, see Figure 6 for information of the different names and distances compared to the center of Mölndal. These junctions have bridge pillars in the median of the road.

Figure 6: Name of junctions along the studied stretch and their distance to the center of Mölndal.

Fässbergsdalen is a business oriented area and holds 24 000 job opportunities, and the job opportunities are predicted to increase with between 4 500 to 9 000 to the year of 2025, while the activities are transforming from being dominated by industries towards becoming more service, logistic and business oriented (Stadsbyggnadskontoren Mölndal och Göteborg, 2012). According to the master plan there are plans for transforming the area towards becoming more diverse, with both services and living areas, and in line with this new residential buildings are planned in areas such as Sisjön, Frölunda, Åby and the northern parts of Högsbo. Today there are housing areas in Eklanda, Åby, Kobbegården, Pilegården, Sisjön, Balltorp and the central parts of Mölndal with near access to services and jobs in the area.

There are bus lanes on parts of Västerleden and the stretch between Järnbrottsmotet and Linnéplatsen, but not on Söderleden. Light rail connects the central parts of Gothenburg to Frölunda Torg, as well as the central parts of Mölndal, and buses run between Linnéplatsen and Särö as well as on Väster and Söderleden from Mölndal to Hisingen, see Figure 7. In total three light rail routes and 15 bus routes ascend Frölunda Torg, which contains residential buildings and a large shopping center with a record of 67 300 visitors per day in 2013 (Frölunda Torg, n.d.). Västerleden passes the shopping center and the bus station about a hundred meters away. The station has a building containing a waiting hall with a café and public toilets, and parking facilities are in near access.

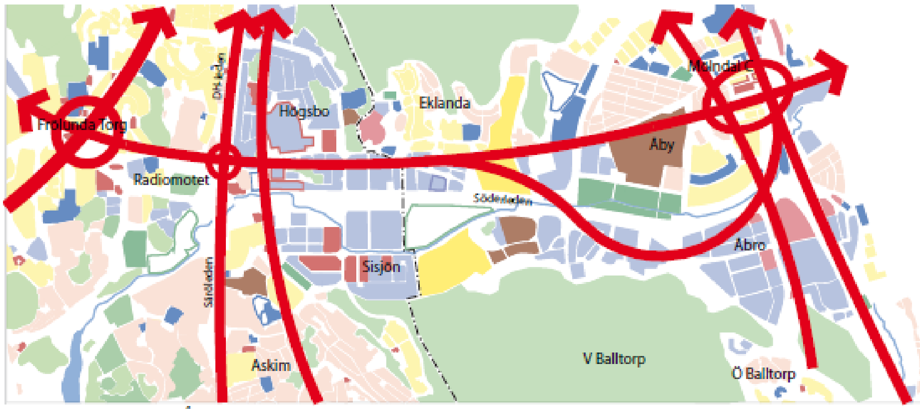

Figure 7: Public transport in Fässbergsdalen and its surroundings (Stadsbyggnadskontoren Mölndal och Göteborg, 2012).

The area surrounding Järnbrott is not dense, with fields of grass, trees and water, and according to the master plan for Fässbergsdalen (Stadsbyggnadskontoren Mölndal och Göteborg, 2012) there are no plans for densification. The distance between Järnbrott and the outermost part of Pilegården, which is the junction's nearest housing area, is around 300 meters (Eniro, 2016). Other housing areas are located more than 500 meters away. And there is a service area about 200 meters in the north-eastern direction, measured from the middle of the junction. The area had 8600[6] inhabitants in 2009 (WSP, 2009), although this area does not have the same boundaries as the area that holds 24 000 job opportunities, see Figure 8. For example the housing areas of Kobbegården and Pilegården are not included within the red box, leading to lower residential values. Järnbrott is classified as an important transfer station (Västra Götalandsregionen, 2016) were traffic from the southern parts of Gothenburg is connected to traffic on Väster and Söderleden and Dag Hammarskjöldsleden. There are in total three stations that are classified as such important transfer stations and they have in common that there probably not will be any urban development connected to the stations in the time horizon of GMP 2035.

[6] This area is 10 km^2 and defined as Högsbo/Sisjön, the western part of Mölndals city centre, Åbro, Åby and Eklanda.

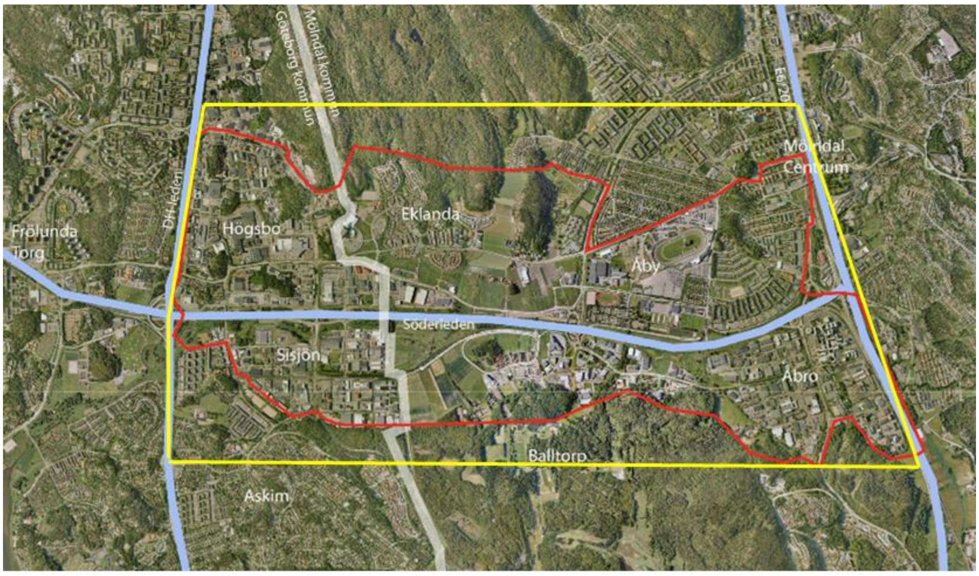

Figure 8: The yellow box describes the area that holds 24 000 job opportunities, while the red one describes the area that holds 8600 residents (Stadsbyggnadskontoren Mölndal och Göteborg, 2012) and (WSP, 2009).

The cycling infrastructure in the area can be seen in Figure 9. There is a tunnel for pedestrians and cyclists under Söderleden in-between Kobbegårdsvägen and Sisjövägen, a pedestrian bridge near Åbyvägen, a tunnel under Järnbrottsmotet and two bridges on either side of Frölundamotet. The northernmost of the two bridges connects Frölunda Torg with housing areas on the other side of Västerleden. It is not prohibited to walk or cycle on Väster and Söderleden, but since there are local paths the road is free from these types of modes (Structor Mark Göteborg AB, 2015b).

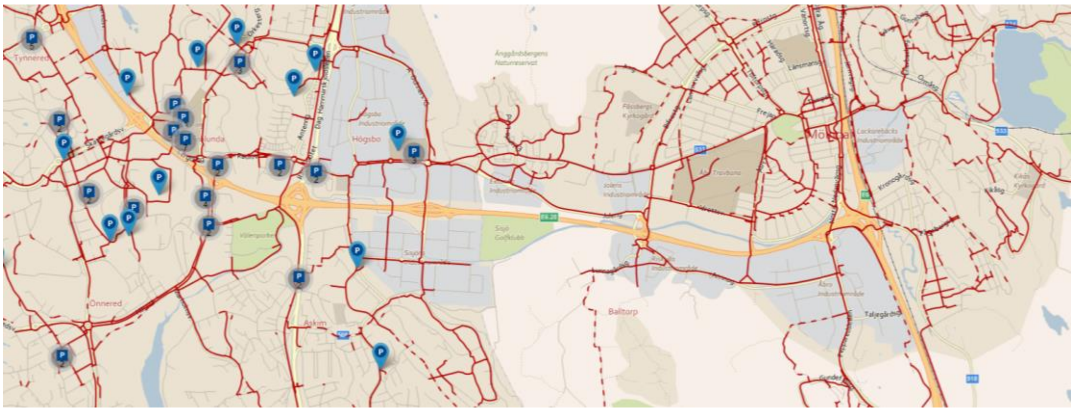

Figure 9: Cycle paths in the area, marked in red, and parking facilities for cycles (Trafikverket, Trafikkontoret, Västtrafik, 2016).

5 Global examples of BRT

Three examples of BRT are presented in this chapter; Istanbul, Curitiba and Ottawa.

5.1 Case study: Istanbul

Istanbul is the largest city in Turkey and the fifth largest in the world in terms of population, located on both the European side and the Asian side of the country and was estimated to have 14.2 million residents in 2014 (World Population Review, 2015). According to the transport authority Istanbul Electric Tram and Tunnel Enterprises, IETT (n.d), the public transport system in the city consists of metro, rail and tramway, conventional buses, BRT, minibuses and taxi.

Istanbul has a BRT system on the D100 freeway that goes through the city and serves as an important transport corridor for Turkey. Its name is Metrobüs and it operated for the first time in 2007. Since then the system has expanded and been built in totally 4 phases, consisting of 45 stations on a 52 kilometer stretch exclusively on the freeway. Istanbul suffers from traffic congestion, which was one of the main reasons for implementing the system. In 2005 the first phase of Metrobüs was initiated on the most congested stretch of the freeway, and operation started two years later. In 2008, 2009 and 2011 the remaining phases started construction, and it is considered that the system was planned and built rather fast. The main part of Metrobüs, with 38 stations, is placed on the European side of Istanbul. (Yazici et al., 2013)

It is presented on the website of IETT (n.d.) that the daily ridership is 800 000 passengers and that Metrobüs' share of Istanbul's public transportation is around 8,3 %. Metrobüs is operating at full capacity in peak hours, and is estimated to carry 30 000 people per hour and direction in its most loaded segments (IETT, 2012). Its average operating speed of 40 km/h is comparatively high, where many BRT systems have speeds in the range of 14 to 40 km/h (Carrigan et al., 2013). The high speed and ridership figures has made Metrobüs to be considered a successful BRT system in Turkey and also internationally. Figure 10 below shows a schematic figure over the public transport network in Istanbul where Metrobüs is marked in beige color.

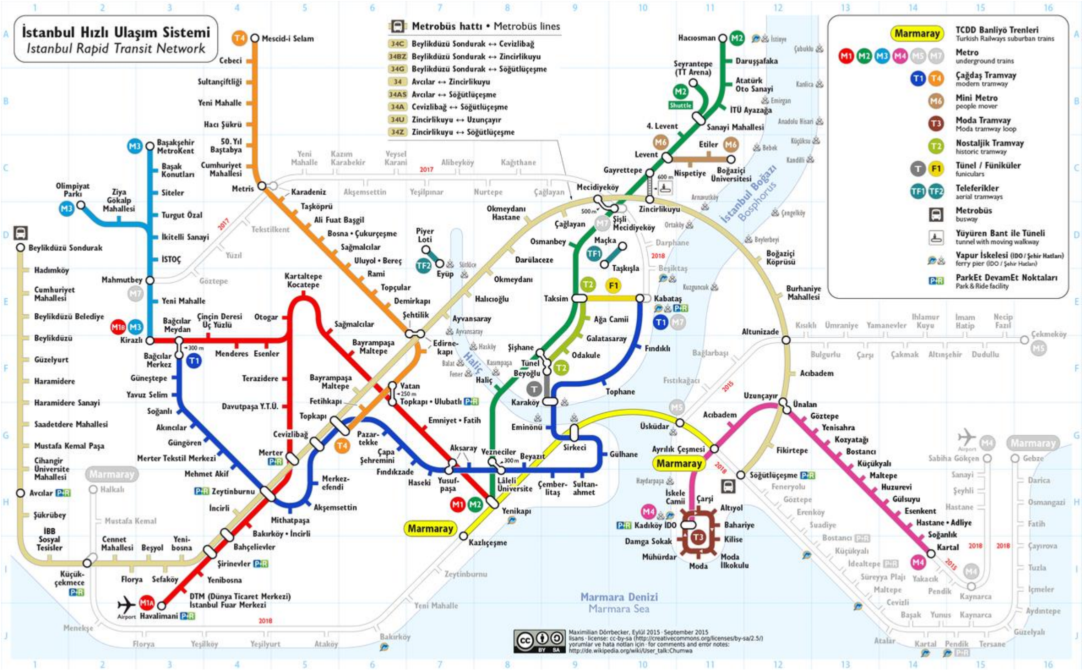

Figure 10. Schematic figure over Istanbul's public transport network with Metrobüs BRT marked in beige color. (Dörrbecker, 2015)

Yazici et al. (2013) conclude with data from IETT that the main socio-economic groups that use Metrobüs are low and middle-income people and the majority of the trips are made for commuting to school or work. Through additional data of IETT it is stated that a Metrobüs costumer saves in average 63% in travel time, and based on a survey it was shown that the time gain was the most important factor when the costumers choose to use Metrobüs. Additionally it is stated that the majority of the costumers reach Metrobüs stations by foot, followed by minibuses and conventional IETT buses.

5.1.1 Stations and running way

Metrobüs has a median running way configuration and its placement on a freeway, without interference from other traffic and with straight alignment, is one of the reasons that it can reach such high speed. There is only one lane in each direction, which leads to no space for overtaking without entering the opposite traffic lane. According to Yüce (2013) the lack of additional lanes is mainly due to the importance of the D100 freeway, which Metrobüs was competing with to get space. The stations are placed in a central position in the busway and the buses drive in opposite direction of the regular traffic flow, leaving the bus doors placed on the right hand side of the bus (Yurdagül & Gerçek, 2013). A photo of this can be seen below in Figure 11.

Figure 11. Photo over Mecidiyeköy station. It shows how the busway is located in the middle of the freeway and how the station is placed centered in the busway, with buses driving in opposite direction of regular traffic. (Chumwa, 2012)

In their report, Yurdagül & Gerçek (2013) further describes Istanbul's BRT. The stations are placed with a rather high average distance of around 1200 meters, which is an additional fact that enhances the speed performance of the system. The stations vary somewhat in standard, and the average station is not designed as a full shelter, instead it has a design that is rather open to the surroundings, and examples of this can be seen in both in Figure 11 and additionally from the street view in Figure 12. This means that costumers are exposed directly to the noise of the freeway and the same goes for air quality. Due to the BRT's placement in the middle of the freeway there are overpasses and underpasses in order for the costumers to reach the stations by walking. The overpasses are also open and lack shelter for the costumers, and the configuration can partly be seen in Figure 12 below.

Figure 12. Photo from Google Maps 2015, illuastrating a station with overpasses.

Embarq Turkey through Ghasemlou et al. (2014) made an inventory in 2014 about challenges of Metrobüs. Since Metrobüs opened in 2007 it has been under on-going modernization to reach higher standard and safety. This includes for instance widening of station platforms, upgrading overpasses, providing more extensive fencing and creating better pedestrian infrastructure. There are issues on a systematic level that have occurred that are connected to the station and running way configuration of Metrobüs. These are mainly crowding at stations and accidents with people making shortcuts over the freeway to reach the station area.

Crowding in stations happen during peak hours, due to overloading of costumers, and also during system failures such as a vehicle breakdown or an accident. Since there is no room for buses to perform overtakes without risking colliding with opposite buses, any type of happening has a significant risk of creating a bottleneck. When stations are overloaded with costumers, people get pushed or walk voluntarily onto the actual running way, which imposes a great safety risk. To try to ease the crowing situations and create more order, separate boarding and alighting has been conducted in some stations. This however has not been enough to solve this issue. (Ghasemlou et al., 2014)

The second issue that has been a problem since Metrobüs opened is that people enter the actual freeway in order to make shortcuts to reach the Metrobüs station without using the dedicated overpasses or underpasses. This is a major safety problem since the system is surrounded by a freeway with vehicles in speed thereafter, leading to a situation where severe as well as fatal injuries occur. Since stations of Metrobüs are open in relation to their surrounding area, they can be reached by its endpoint or its sides if a person decides to cross the freeway to enter it. There are fences in varying extents surrounding the station areas to prevent this from happening, but they are not high enough nor cover a stretch that is long enough in order for people to stop entering the freeway. (Ghasemlou et al., 2014)

5.1.2 Transit Oriented Development

The Metrobüs stations in the middle of D100 freeway are in many cases located with significant distance from housing development (Stojanovski & Kottenhoff, 2013).

Figure 13 shows a picture of a housing area that is under development, taken from the D100 freeway where Metrobüs runs.

Figure 13. Picture taken from the D100 freeway where Metrobüs goes. A housing area can be seen within a distance from the transport corridor. (Stojanovski, 2012)

As mentioned previously, the implementation of Metrobüs can be considered rather urgent. According to Yüce (2013) this can be noticed in the fact that no consideration was taken to the master plan of urban development in the city. There actually was an urban master plan being developed at the same time, but this was not integrated with the planning of Metrobüs. This is seen in lack of transit oriented development of the Metrobüs system. Yüce further states that there also was a central plan for the city transportation being made around the same time period, but neither this was included when it came to the development of Metrobüs. The lack of collaboration between the transportation plan and Metrobüs can for instance be seen in insufficient integration between Metrobüs and metro and tram stops. The development of station surroundings varies in the Metrobüs system. There are stations, mostly on the European side, that are integrated with development such as schools and shopping centers. In these cases, the development was there before the Metrobüs stations were built (Yüce, 2013).

It is furthermore stated by Yüce (2013) that the urgent decision-making of Metrobüs can be seen in for instance that stations were being added to the BRT shortly after opening due to the passenger demand being too high for the system to handle. It is reasonable to assume that this could have been avoided with more careful planning and for instance more lanes. Metrobüs was barely developed for the at-the-time existing transportation demand without consideration taken to future urban and transportation development, and this could be one of the reasons why Metrobüs operated at full capacity early on.

5.1.2.1 Accessibility features

The accessibility regarding connection to other transport options varies across the Metrobüs stations. According to Yüce (2013) the stations are connected to regular IETT buses and minibuses, and some stations are also connected to light rail systems and the city subway. However in many station areas there is insufficient integration between the different modes, which has resulted in long walks of up to 450 meters when making transfers from Metrobüs to another transport option.

It is stated by Ghasemlou et al. (2014) that facilities for pedestrians are not fully developed in the Metrobüs system. There are too few pedestrian paths and few of them connect the Metrobüs system. The pedestrian infrastructure that do exist have poor standard with for instance lack of railings and bad maintenance of surface resulting in rough paths. There also needs to be pavement upgrading at the areas where minibuses and regular buses stop next to the stations so that people can walk safe and comfortable to and from Metrobüs' over and underpasses. It is further stated that pedestrian infrastructure is neglected in large parts of Istanbul.

When it comes to cycling amenities, Metrobüs does not provide enough to obtain sufficient accessibility. According to World BRT (2012) there is no dedicated cycling infrastructure along the Metrobüs corridor and further there are no possibilities for cycle sharing or cycle parking. This makes it difficult to use cycle to and from Metrobüs, and it overall appears that non-motorized trips have been neglected in the system.

5.1.3 Analysis Metrobüs

From the literature study of Metrobüs, it is noted that the system is high performing with impressive numbers of ridership, time savings and speed. Nevertheless, there are also weaknesses in the system.

As noted the accessibility of Metrobüs is a shortcoming, party caused by poor pedestrian infrastructure and lack of cycle amenities. The same goes for integration and connections with other parts of the public transport system. Long walking distances of up to 450 meters for interchanging cannot be considered successful integration of the different modes in the public transport network. In a Swedish context, the accessibility features of Metrobüs would not be sufficient and they can be considered to prevent development of non-motorized transport. Metrobüs have a high share of people walking to and from the system despite poor pedestrian infrastructure, but this should not be assumed for Sweden if conditions concerning pedestrian infrastructure were similar.

The station setup of Metrobüs can be considered space and economically efficient and it markets the system due to the distinct placement in the middle of a freeway. One of the main drawbacks with the Metrobüs stations is that people enter the running way as the stations get overcrowded. Overloading can occur from the fact that the system was not dimensioned to meet the actual demand, or from poor design, where a possible solution could be to have a limit of how many people that are allowed to enter the platform. More frequent service would reduce the overloading of people, however Metrobüs already operates at full capacity in peak hours. Larger stations would only solve some of the space problematic, but it is understood that additional lanes would significantly improve the situation. It would give buses the chance to overtake at stations and reduce dwelling time while waiting for other buses, and also enable overtakes during the trip if there is a breakdown or some failure causing a bottleneck.

Metrobüs was not allowed more lanes due to importance of the D100 freeway. The importance of lanes for overtakes when competing for space is a lesson to be learned from Metrobüs which can be applied to other BRT projects. Yet it is not clear how important additional lanes are in systems that have a significantly lower degree of users, presumably the case in Gothenburg. It is important to analyze whether there is a need for additional lanes even for systems that have low ridership, as for instance bus break down and bad weather conditions can cause bottlenecks that demands overtakes.

Regarding transit oriented development Metrobüs performs rather poorly. The fact that it was developed during the same time as an urban as well as a transportation master plan, yet planned isolated from these, can be considered an example of inadequate planning. This cannot be seen in poor ridership of Metrobüs, but the total travel times and possibilities to make other activities in connection to the trip are likely negatively affected. Metrobüs solves the task of getting people fast from station A to station B, however it lacks essential features of transit oriented development, which should be recognized as a shortcoming of the system.

When considering the success of Metrobüs in terms of its high ridership and capacity, the way it was implemented and also the socio-economic terms of its users could be contemplated. As mentioned, Metrobüs was implemented to serve an existing traffic situation with no room for growth with the consequence that it was used at full capacity from start. Further, the users are mainly low and middle class, which is something that should be considered if looking at implementing a similar system in a country like Sweden where many people afford to avoid using public transport if it does not correspond to their preferences. If the low and middle class residents of Istanbul were to increase their income and their demand of standard, the shortcomings of Metrobüs could have a larger impact on the costumers' transport choices.

5.2 Case study: Curitiba

Curitiba is a city located in the south of Brazil, it is the seventh largest city in the country and was estimated to have around 1.8 million residents in 2007 (City of Curitiba, n.d.). The bus system in Curitiba is the core of the transport system in the city and one of the most famous BRT systems is the world. It is called Rede Integrada de Transporte, RIT, which is Portuguese and stands for integrated transit network. RIT is often recognized as a success story due to its iconic model of mass transit integrated with urban development.

In the report *Curitiba, the cradle of Bus Rapid Transit*, Lindau et al. (2010a) provides a description of the Curitiba BRT system. It is explained that RIT was not developed as a full BRT system from start; the foundation of the system was introduced with separate busways as early as in the 1970s. The system further evolved with BRT characteristics in the 1980s, such as tube shaped stations with leveled boarding and alighting, prepayment and articulated buses. Since then the system has expanded and advanced and is now classified as to having the highest possible standard of BRT in its latest implemented corridor.

RIT consists of a network of trunk and feeder services that have been developed initially from five main structural axes, which can be seen to the left in Figure 14. The structural axes carry trunk services that are called express lines and direct lines, where the express lines stop more frequently than the direct lines. The direct lines also go outside the main structural axes, which can be seen in the right part of Figure 14 where the whole trunk BRT system is illustrated of the year 2005. Additions to the trunk system are feeder lines that operates as traditional bus services and do not have priority over regular traffic. (Lindau et al., 2010a)

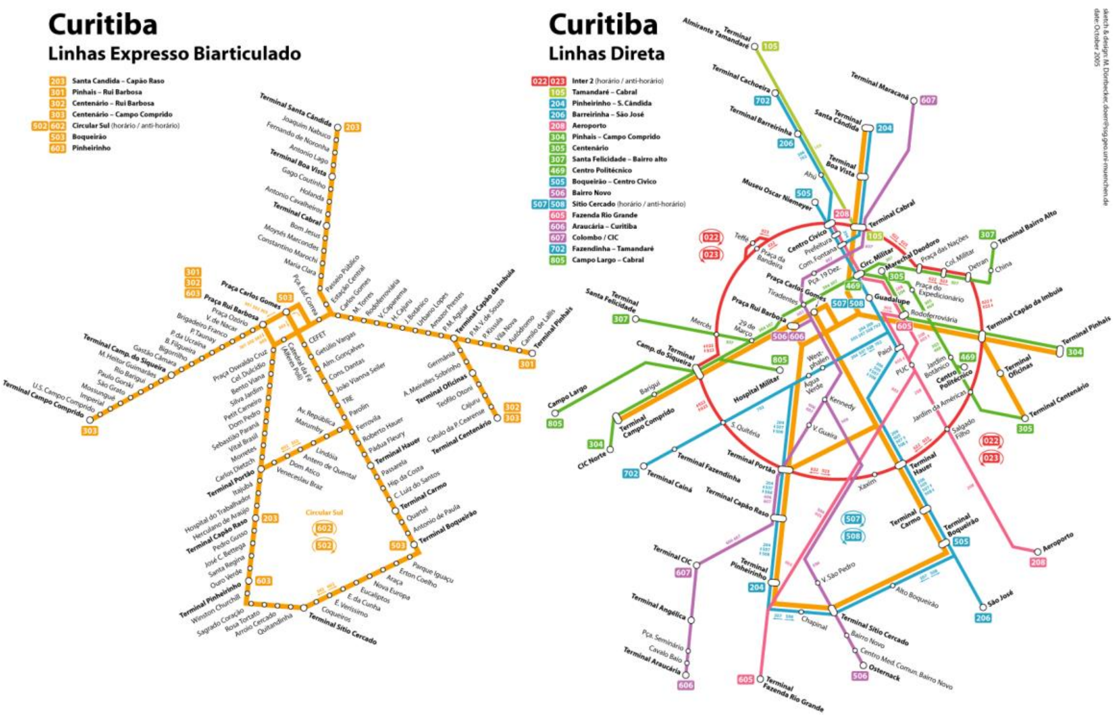

Figure 14. Map over the RIT system with the five main structural axes to the left and the whole trunk system to the right (Dörrbecker, 2005).

Lindau et al. (2010a) describes that in 2009 an additional main corridor, which has been recognized to have excellent BRT standard, started to operate. It is called the green line and goes only on biofuel, and has a somewhat different configuration from the five main structural axes. Moreover, a seventh corridor opened in 2014 as a part of the RIT system, however this one consists of conventional bus service without BRT standards (BRT Data, n.d.).

The RIT system operates on several different types of roads, which are further described in the chapter below, with a total length of 83 kilometers and 342 stations (URBS, 2015). According to the website of BRT Data (n.d.) there is a variation of operational speed due to differentiated services in the system, ranging from around 18 to 28 km/h. The highest operating speed is for direct services and has been achieved in the recently opened green line and also in another corridor where extra lanes have been added for possibilities of overtaking. Moreover, the peak load per hour and direction in the most loaded segment of the system was measured to 12 500 passengers in the year of 2013. The ridership was estimated in 2015 to be around 800 000 passengers per day (URBS, 2015).

According to the urban development office URBS (2014), the modal split for transport in the city is 45% for buses, 22% for automobile, and 25% for walking and cycling. The share of buses can be considered rather high, though the year for which these figures are valid for is not stated. It is furthermore stated by Pacione (2005) that Curitiba has been one of the cities in Brazil with the highest car ownership per capita for a long time. In 2005, it had the second highest share after Brasilia with around one car per three residents, and at the same time the use of petrol was 30% lower than comparable cities in Brazil. (Pacione, 2005)

5.2.1 Stations and running way

The structural axes of RIT are mainly built after a system called the trinary road system, which originally was created in Curitiba (Cervero, 1998). A conceptual figure of the trinary road system is illustrated in Figure 15. Lindau et al. (2010a) describes RIT's trinary road system as a concept of one main boulevard in a central position, and two parallel streets that are placed with some distance to each side of the main boulevard. The main boulevard has buses in both directions in the median of the road and one station for each direction, and it has local traffic adjacent to the busway. On the main boulevard there is a BRT service that locally is called express buses, however these have frequent stops as opposed to other definitions of express lines as rapid service with few stops. The parallel roads, one going to the city and one going away from the city, have traffic with higher speeds than the main avenue. These roads carry BRT that operates in higher speed than the express lines and are locally called direct bus services. (Lindau et al., 2010a).

As can be seen illustrated in Figure 15, characteristics of the built environment is incorporated in the trinary road system concept, where high density mixed development is placed close to the main boulevard, and less dense mainly residential development is positioned farther away from the structural axis.

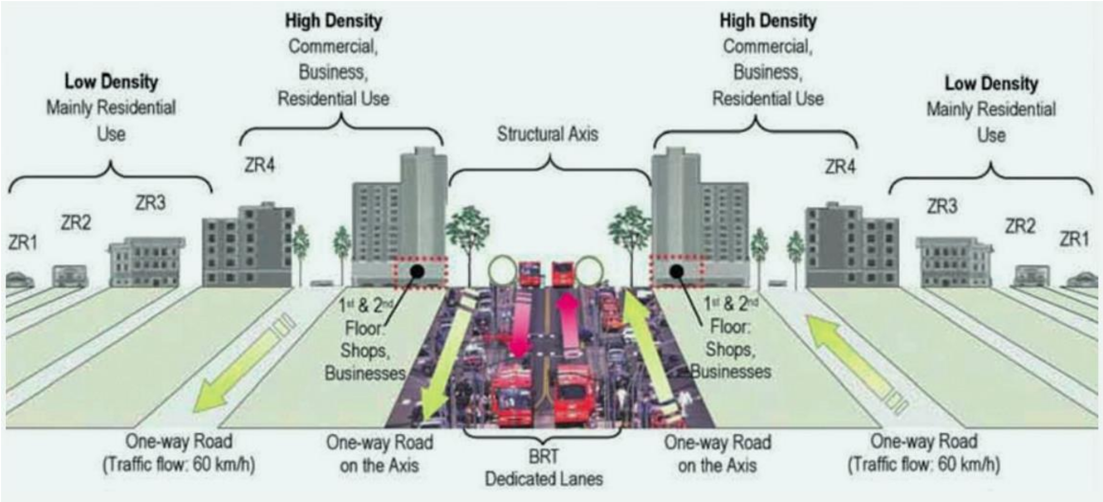

Figure 15: A conceptual model over the trinary road system that has been used in Curitiba. The structural axis can be seen in the middle as a main boulevard, and the parallel roads that go in one direction is illustrated on the sides. (Lindau et al., 2010b)

Intersections of RIT consist of signalized at-grade intersections. It is presented by the Inter-American Development Bank (2003) that RIT generally has suffered from problems with buses having insufficient priority at intersections. Therefore the system has undergone modernization and optimization of its traffic signaling system, in order to give buses full priority and make the transit times shorter.

The stations of RIT are well known for their tube-shaped design, which can be seen in Figure 16, and are accessed through regular pedestrian crossings. The bus doors are placed on the right-hand side and the buses go in the same direction as regular traffic (BRT Data, n.d.), leading to a setup where there are two tube stations at each stop, one for each direction. On the website of BRT Data (n.d.), it is stated that the average distance between stations approximately is 680 meters, although there is a significant variation in station distance due to the differentiated services that RIT offers. For instance the green line has an average of 1700 meters for its direct service and the most recent feeder corridor has around 250 meters in average.

Figure 16: A photo over the RIT station Praca Ozório, where the tube design is illustrated (Morio, 2006).

Cervero (1998) states that in addition to regular stations for just one service, there are well planned transfer stations with short walking distances, which enhances the interchanging performance of the system. The transfer stations are located in the endpoints of the corridors and also in-between on the main boulevard busway, where several services connect. Express, direct and feeder lines connect to the transfer stations for integration and possibilities of differentiated trips. (Cervero, 1998) The tube design of RIT's stations works as shelter for the costumers while waiting for the bus since they are a closed glass structure except for the short sides. These open sides lead to the tube having no significant advantages in terms of noise and air quality. To achieve levelled-boarding according to BRT standards the stations are elevated as seen in Figure 16. There are stations that have stairs that costumers need to use to enter the tube, also shown in Figure 16.

The tube station is considered to represent an iconic value for the city and have been constructed with the same cylindrical shape since the 1980s. A study of Duduta et al. (n.d.) presents that a problem that has been noticed with the stations is that they can pose a safety issue as the doors can be open even though there is no bus coming. In crowded situations, which do occur in the system especially during peak hours, people can get pushed and fall out of the elevated station and onto the running way.

5.2.1.1 The green line

As previously mentioned, the trunk corridor called the green line that opened in 2009 has been recognized as a BRT success story. Through City of Curitiba (2010, in Lindau et al. 2010a) information is held that the green line was implemented on a former freeway and carries operations for both express and direct services, as opposed to the regular trinary axes where direct service operates on parallel roads to the main boulevard. Further it is stated that it is possible to carry these different services and have higher operational speeds due to the presence of extra lanes and large stations areas.

A station setup of the green line can be seen in Figure 17. The station is long enough to accommodate bi-articulated buses in the middle busway and it takes regular feeder buses on the outer sides, making the walk for transfer minimal. There is also space to overtake the bus that has stopped at the station if having a more direct service.

Figure 17. Picture over transfer station Marechal Floriano at the green line (Ortiz, 2013).

It is further explained by City of Curitiba (2010, in Lindau et al. 2010a) that stations of the green line have been improved from the original stations, with for instance sunscreens to protect from heat and rainwater collection that is used for cooling. There are also cameras that are connected to a control center to enhance security. The main tube design is however kept as previously. Additional development that is significant for the green line is that a park for recreational activities has been constructed along the majority of the corridor, as well as more extensive bicycle lanes. (City of Curitiba 2010, in Lindau et al. 2010a) These stations do not have steps for entering, but a ramp with a gentle slope instead, as can be seen in Figure 17.

5.2.2 Transit Oriented Development

In his book *The Transit Metropolis: A Global Inquiry*, Cervero (1998) addresses how Curitiba's BRT system is integrated with transit oriented development and the following chapter is based on this book.

Cervero states that Curitiba is one of the main international examples of TOD. The city has grown rapidly since the 1960s, when it had 400 000 residents, till today's above 1.8 million. During 1970-1980 it was the fastest growing city in Brazil with around 4% growth annually. The rapid growth is considered to be the main driver for Curitiba's planning of integrated transport and land use.

There were some main principles concerning TOD developed in Curitiba according to Cervero. The city center was saturated and it was decided that future growth should be controlled and placed along distinct corridors out from the city core. It was considered that land-use planning in combination with transportation investments was the main way to control and manage spatial growth. The visions of urban form and features drove the progress in transportation that led to separate busways and the trinary road system. It is stated that a general focus was put on designing for movements of people instead of cars, which resulted in priority for pedestrians and mass transit. In 1965 an urban master plan was conducted that was based on these principles and it was the start of the mass transit system of Curitiba. Interesting to note is that most Brazilian cities were being planned for cars during that time. Moreover, Curitiba has been one of the wealthiest cities in Brazil with a comparatively high car ownership, yet RIT became a success.

As previously mentioned the trinary road system concept was originally founded in Curitiba and it is not only the structure of the road system that is the foundation of the trinary system, but the built environment as a whole. Fundamental factors identified by Cervero are density along corridors and a mixed pattern of land use. High density implies a ridership that is large enough to provide frequent services, and a mix of land use means that trips are made in both directions and thereby empty buses are reduced. The buildings that are located between the main boulevard and the two parallel roads are normally high-rise buildings that have commercial activities in the entrance floor and housing and offices on the floors above. Outside the parallel roads density tapers off but there are still services and shops in immediate relation to the busway. Residential areas with lower rise buildings begin to increase the farther away from the corridor. This type of development has been achieved by different regulations and policies of building permissions. As an example, permission to build large shopping centers have been difficult to gain if the center is not placed in close connection to a structural axis.

Cervero further explains that several years prior to the 1965 urban master plan there were plans of expanding the road system in the city with rather wide roads for automobile use. These plans did not make it to realization due to economic reasons and politics, but the city had already gotten the rights-of-way in several corridors. It was these right-of-ways that later became used for the trinary road system, and it is believed that the previous plans of making extensive roads for cars had a fundamental role of the trinary system being possible to implement.

5.2.2.1 Accessibility features

The careful planning of different services that are integrated at the RIT's transfer stations makes the accessibility of interchanges satisfying, and since feeder lines are well integrated with the structural axes the BRT service becomes available for large groups of people. The idea of differentiation in the system is further evolved in the green line where two different services use the same busway which enables people to choose options that suit their travelling preferences.

City of Curitiba (2013) has adopted a plan for cycling investments with the aim to be finished in the year of 2016. In the cycling plan, it was decided to construct 300 kilometers of cycling lanes, which is more than double the 127 kilometers that was present in 2013. It was also decided that cyclists should be given more priority at intersections and in some places the speed of traffic was significantly reduced so that cyclist can share the road with automobile users more safely. To enhance cycling possibilities and make multimodal trips, bike parking was implemented and some of them were connected to the RIT stations, however the majority of the stations lack this type of parking facilities. It was decided that 5% of all parking space should be devoted to cycles. Furthermore a bike rental system was decided upon, in addition to the already existing bike sharing system, but it was not stated to what degree it should be integrated with the RIT.

The cycling plan also includes enhanced mobility measures for pedestrians, with more pedestrian priority and upgradation of walking infrastructure (City of Curitiba, 2013). Due to the trinary road system and the overall urban planning, the general situation for pedestrians in the system can be considered satisfying, which for instance can be seen in the minimized walking distances to the stations.

5.2.3 Analysis RIT

The success of Curitiba’s RIT can for instance be seen in comparatively high national car ownership in combination with high modal share for public transport as well as lower fuel use than the average. Obvious is also the urban attributes that Curitiba presents, with dense and mixed land-use, pedestrian friendly environment and an overall people oriented approach. Once the cycling plan is fully implemented the city will provide more sustainable transportation, yet a shortcoming in the plan is that it does not have cycle amenities at every station and does not seem to present any further creative ideas of cycling integrated with RIT.

There are new elements when it comes to the green line, such as technology for comfort and safety at stations, and more differentiated service with both express and direct routes on the same busway. This variation of service can be worth contemplating despite that the green line has gotten great reviews for its standard. It is understandable that this setup is less space demanding and more efficient when it comes to sharing station areas, but a corridor that keeps different types of services risk being less clear and distinct for the costumers, which is an important factor of the BRT concept.

The integration of different services at some of RIT’s stations is impressive, as people have such short distances to walk to their exchange. However the safety issues that occur at stations when doors are opened without a bus parked are worth noticing, as people can fall out and get hurt, or more dangerously get hit by a bus that is entering the station. As mentioned, there is a similar situation noted in Istanbul’s Metrobüs. This issue is especially important when crowding in stations occur and should be considered when implementing BRT in Swedish contexts, where crowding is probable to be less of an obstacle, but traffic safety is top priority.

When it comes to design, the stations seem to be accepted as viable options as they are still being produced in the same tube shaped structure. As mentioned they pose somewhat as a shelter however they could perform better with a setup of for instance sliding doors on the short sides. Furthermore the steps needed to enter some of the stations, which were illustrated in Figure 16, are likely to function as a bottleneck when many people are to enter or leave the station. This situation is better solved at the larger stations which have a ramp with a gentle slope instead, such as in the green line. Hence, the stations are overall iconic in terms of design but they can be considered having shortcomings that influence the overall standard.

As explained, the trinary road system has obvious benefits and has made the successful development of Curitiba possible. It is an extraordinary example of transit oriented development and therefore an interesting case study for cities that aim to evolve in this matter. Unfortunately more mature cities that do not grow as rapidly as Curitiba did when implementing RIT, like most Swedish cities, are probably less likely to be suitable to take on the planning methods of Curitiba. The trinary road structure, which was possible due to previous plans and claiming of land, would be difficult to mimic in Sweden. Yet other features of the concept, such as traditional TOD principles like density and mixed land use, are more likely to be adoptable in cities with other preconditions than Curitiba.

5.3 Case Study: Ottawa

Ottawa is the capital of Canada, located in the state of Ontario and with a population of 922 000 in 2011 (City of Ottawa, 2013a), which is scattered over a relatively large area. The city borders to the province of Quebec and the city of Gatineau in the north, with the Ottawa River keeping them apart. The city have a BRT system running on the Transitway and the public transport system consist of minibuses, taxis, buses and a light rail transit (City of Ottawa, 2013a). The buses in Ottawa are of the following kind, and can be seen in Figure 18 (Al-Dubikhi & Mees, 2010):

- BRT trunk service
- Express services running on the Transitway in peak hours from local areas
- Local feeders providing service from local areas to the Transitway where passenger have to transfer
- Base service in the downtown of Ottawa

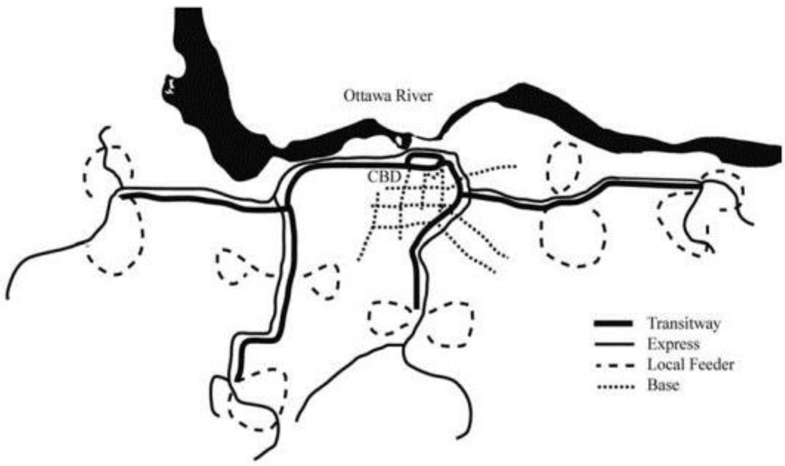

Figure 18: The bus-based public transport system in Ottawa (Al-Dubikhi & Mees, 2010)

The Transitway was constructed in different stages where the first part was opened in 1983 (Al-Dubikhi & Mees, 2010). In 2014 the peak load of the Transitway was 10 000 passengers per hour and direction and the daily ridership was estimated to 240 000 passengers (OC Transpo, 2016 d). Residents in Ottawa owned 508 000 cars in 2011 when summarized over the entire city, which corresponds to 84% of the households owning at least one vehicle (City of Ottawa, 2013a). Ottawa is when compared to both North American and Australian cities one of the least automobile dependent cities, and has comparatively high rates of trips taken by public transport, walking and cycling and is considered a success story of environmental friendly transport policies (Al-Dubikhi & Mees, 2010).

An important feature of the system is that buses going from local areas are allowed to use the running way during peak hours and hence are transformed into express routes, this way transferring between local feeders to BRT is to some extent removed during these times (Al-Dubikhi & Mees, 2010). It has however become a problem with too many buses on the Transitway in the central business districts and therefore the express buses have declined and again been replaced with local feeder to the bus rapid transit service. During off-peak periods transferring between local feeder and

Transitway is needed (Al-Dubikhi & Mees, 2010), which is problematic when traveling from the central parts of the city towards its outer parts since local buses generally operate less frequently than trunk services.

In the transportation master plan of Ottawa the city has listed a number of goals for the ridership of the different modes[7] by the year of 2031, see Table 3.

Table 3: Population and modal share in 2011 and 2031, based on 24 hours (City of Ottawa, 2013a).

Year	2011	2031
Population	922 000	1 135 900
Walking	11.0%	10%
Cycling	2.0%	5%
Transit	15.5%	26%
Automobile	71.5%	59%

5.3.1 Stations and running way

The Transitway contains three trunk lines which can be seen with green, purple and brown lines in Figure 19. The Transitway is operated by OC Transpo and contains 57 stations and 35.4 km of dedicated busway. There are also 4.5 km bus lanes[8] on arterial roads and 12.7 km shoulder bus lanes on freeways and most of the transit network is owned by the city of Ottawa, except the freeways (City of Ottawa, 2013a).

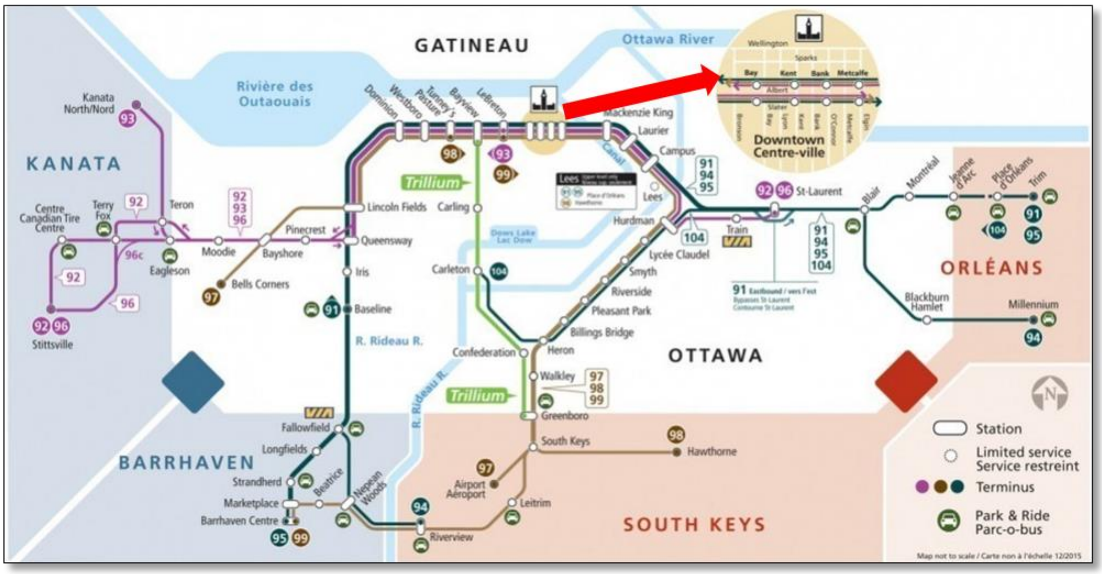

Figure 19: A schematic map over the public transport system in Ottawa (OC Transpo, 2016 c).

The buses run on right hand side, and signal priority devices and queue jumping are some of the measures taken to increase the priority of the Transitway at non-grade separated intersections, (City of Ottawa, 2016d), while grade separated intersections

7 In the transportation master plan of Ottawa journeys taken as automobile passenger is defined as a sustainable mode, while an automobile driver is not, the share for these two modes are summarized in Table 1 and categorized as journeys taken by automobile.

8 "A roadway lane dedicated for use by public transit vehicles that may be open to mixed traffic at some hours of the day or days of the week, and that may also be open to other vehicles such as carpools, taxis or bicycles" (City of Ottawa, 2013a).

can be found on some locations along the stretch. However as the system enters the central parts, which can be seen in the yellow circle in Figure 19, the buses run on exclusive bus lanes on arterial roads with signals optimized for buses (Mucsi, 2016). Traffic jams occur today due to the fact that there is not enough space, and all three trunk lines convert into one corridor downtown and share the same stops (Walker, 2010). The capacity of the corridor was reached around the year of 2000 and the real capacity constraint is considered to be a combined impact of signals and the sharing of bus stops (Mucsi, 2016).

As earlier mentioned in the thesis, it is not unusual that LRT is preferred over BRT and this is something that can be seen in Ottawa, where a new light rail line called *Confederation line* is under construction and will be done in 2018 (City of Ottawa, 2016a). It will replace the BRT from station Tunney's to Blair Station, in a 2.5 km tunnel downtown while the rest 10 km will be on street level (City of Ottawa, 2016b). The aim of the construction is according to City of Ottawa to resolve the traffic jams that occur downtown today and as is mentioned above there is not enough space to increase the number of buses so the confederation line is built to increase the capacity (City of Ottawa, 2016c). Furthermore it is stated that the switch of mode will better the air quality since the vehicles will be electrified, and encourage a 9% increase in ridership due to better comfort, reliability and speed, while the operational savings will land around $16M per year due to greater capacity at a lower unit cost (City of Ottawa, 2016c). Some stations will be moved and constructed in the median of the freeway (Mucsi, 2016).

The stations have an average distance of 621 meters in between (BRT Data, 2016), and the design of them differ, however the distance on the larger roads are significantly longer. Some stations are located as islands with buses accessing both sides, see Figure 20, while others have the running way passing the station in-between platforms, see Figure 21. The doors are located on the right hand side of the vehicles, and overtaking is possible at the stations. Some stations offer proper buildings while others are of simpler bus stop kind, and the platforms are constructed at a low level compared to the bus (Mucsi, 2016). Some of these stations are located next to the freeway with overpasses, see upper right part of Figure 20. These overpasses are closed and have a red color which is characteristic for the entire Transitway system and are around 200 meters. They provide a connection for people living on opposite side of the freeway as they can park their vehicle and pass over the freeway and enter the Transitway system. The stations have car parking facilities, more common in the outer parts of the city, and many stations also contain cycle parking. The reason for placing the BRT in adjacency to the freeway in many North American countries has to do with space availability, lower cost and ease of implementation rather than good urban and transportation planning (Mucsi, 2016). The same person states that noise and air quality have not been considered as major issues at these types of stations located in near contact of the freeway, but that the station placement cause long distances for pedestrian which is problematic.

Figure 20: Picture of the station configuration, the upper leftmost picture is from St Laurent Station (Ortiz, 2014), and the other two are from Place d'Orleans, Google Maps 2015.

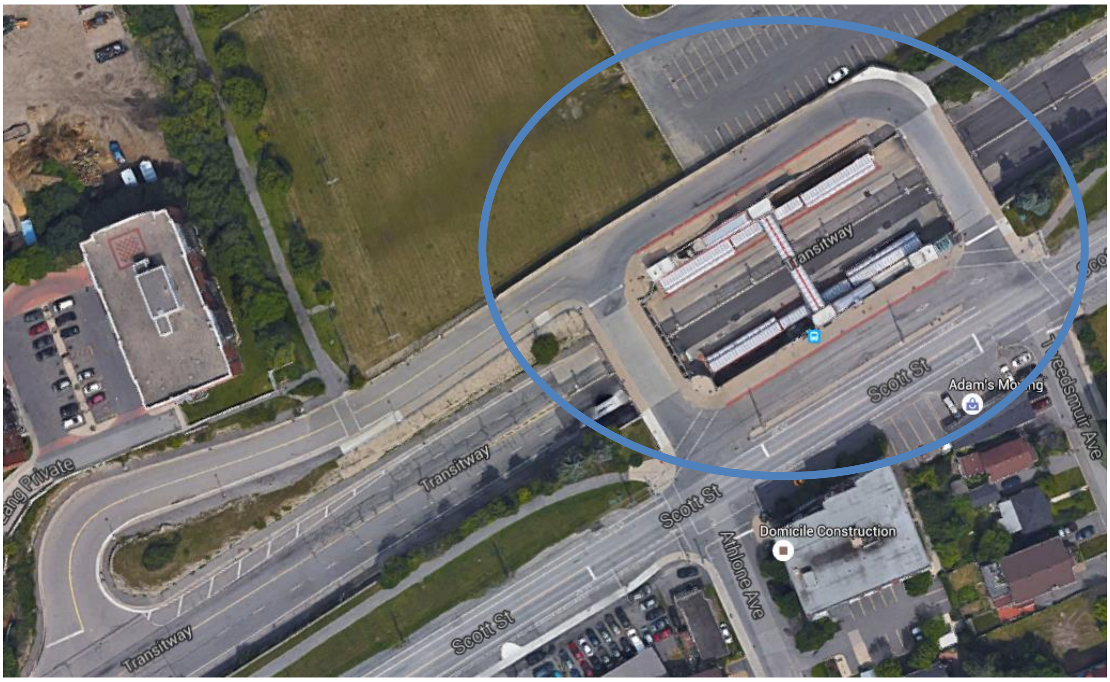

Figure 21: Station design on Westboro Station, from Google Maps 2015.

The stations offer transfers to destinations that is not located along the corridors of the Transitway (OC Transpo, 2016 b). After 9 pm night stops are used in some stations, which means that all routes are gathered and use the same stop at the station in question. The night stops are well lit and located in close connection to emergency call boxes and pay phones (OC Transpo, 2016 a).

5.3.2 Transit Oriented Development

The Transitway stations are situated in near contact with shopping centers or employment areas (OC Transpo, 2016 c), and Figure 22 shows the location of the station in comparison with services and residential buildings in the area of Place d'Orleans, and there are several stations with similar design. The overpasses allow for pedestrians to reach the station when they originate from the other side of the freeway, and this way the barrier effect of the road is reduced.

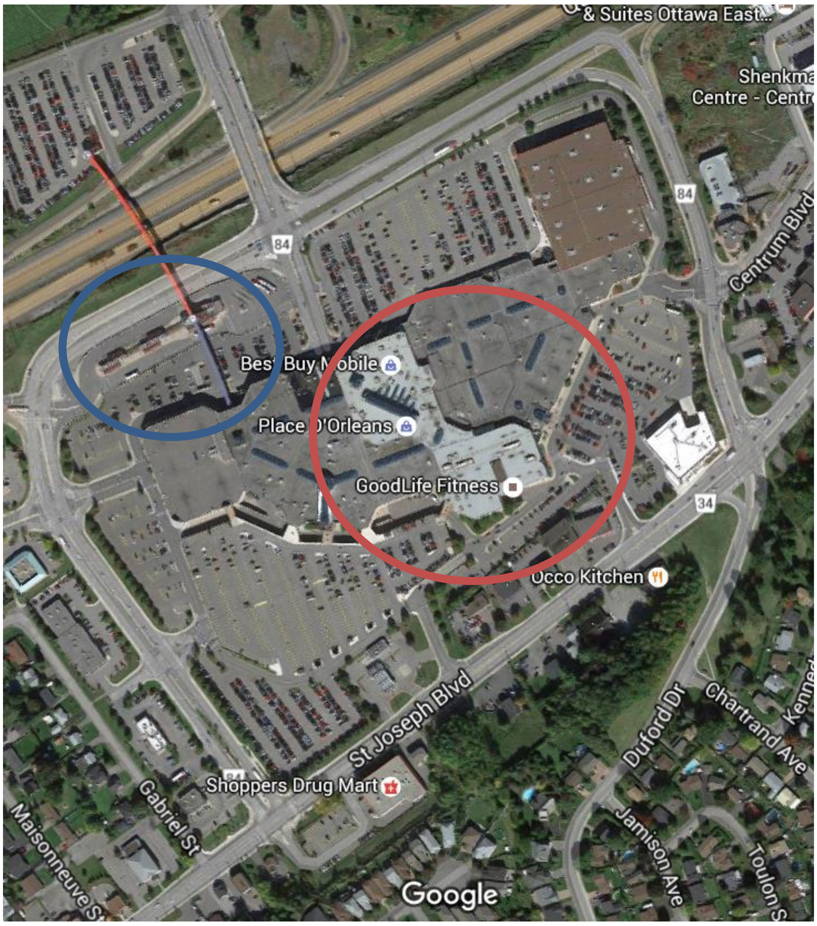

Figure 22: Photo from Google Maps illustrating the station in d´Orleans within the blue circle, closely connected to services within the orange circle. Residential buildings can be seen in the bottom of the picture.

In the transportation master plan (City of Ottawa, 2013a) a lot of effort is put into increasing the ridership of public transport, by turning the transit system more attractive by for example increasing the allowed height of the buildings and construct a dense city with higher buildings closer to the station, and increasing the accessibility for cyclists and pedestrian to the stations. This means giving cyclists priority in the surroundings of the station and allowing bikes on-board the vehicles of the transit system. By increasing the density and diversity in the surroundings of the stations the city aims to bring the origin and destination of trips closer towards each other and increase walking and cycling.

5.3.2.1 Accessibility features

The Transitway system contain 14 park-and-ride lots (City of Ottawa, 2013a) and had 20 bike and ride locations in 2013 (City of Ottawa, 2013b), which offer shelter for around 10-15 bicycles each (Mucsi, 2016) in near contact of the stations. According to the cycling plan the city will expand these shelters at stations with high demand. The bike and ride stations are reached by mixed pathways or local streets (City of Ottawa, 2015). Furthermore from mid-spring to mid-autumn Ottawa has a system for boarding bikes when travelling with the bus, which is called *Rack and Roll* where the bikes are stashed in front of the bus (City of Ottawa, 2015). On the light rail transit bikes are always allowed (City of Ottawa, 2015) compared to the buses where slightly more than half of the fleet (City of Ottawa, 2013b) are equipped with racks, and the number of spots on each racks is limited to two. The cycling plan brings up building cycling lanes to transit stations, securing proper parking facilities, and promoting multimodal travel as important factors that will receive a lot of attention the upcoming years in order to achieve the goals of increased modal share for cycling for 2031 (City of Ottawa, 2013b). Some further TOD aspects that are included in planning are no park and ride locations within the city center, and sidewalks on both sides on streets located here (City of Ottawa, 2016e).

There has been a decline in ridership during off-peak hours, which to some extent is analyzed in the assessment made by Al-Dubikhi and Meers (2010). It is mentioned that the system is designed with regards to peak-hours which brings large station areas. This is thought to be somewhat problematic during off-peak hours when transferring is necessary, and people have to walk relatively long distances that sometimes contain stairs, and this is considered to have an influence on the ridership.

5.3.3 Analysis Transitway

Some of Ottawa's districts are found on large distance from the city center, larger than the ones found in Gothenburg, but out of the three examples studied Ottawa has the most similar population size to Gothenburg. However Ottawa's goals for modal shares are very modest compared to Gothenburg's, and as can be seen when comparing Table 1 and Table 3, Gothenburg had larger shares for walking, cycling and transit in 2015 than Ottawa aims for in the year of 2031. Furthermore the goal for automobile is 59% in 2031 in Ottawa while Gothenburg had 41% in 2015, and the amount of cars in Ottawa is also a lot larger than in Gothenburg. Based on this Ottawa is seen as far less sustainable when it comes to transport than Gothenburg and many Swedish cities, and not as the environmental friendly success story the literature study stated.

However, the Transitway is overall a well-functioning system, apart from when it enters the streets downtown. The fact that the system does not perform well here is a significant problem since it limits the success of the system overall. It can be assumed that many public transport customers sometimes either start, end or pass through this bottleneck and therefore many people are affected by this poor design. This shows the importance of proper dedicated busways throughout the entire system. This issue is being dealt with by constructing the Confederation Line, which however is something that could be questioned based on the reasoning that light rail does not necessarily has to be superior to BRT. It is stated that the Confederation Line will better the air quality, increase ridership and save money, however these are things that should be questioned and most likely could have been achieved by a high standard BRT as well. It is reasonable to assume that the traffic jams could have been resolved by simply constructing higher BRT standard downtown as well, since that would increase the reliability of the buses in the same way that the construction of the Confederation Line aims at.

The simplicity of the BRT-system is a most important feature since it helps customers to identify and distinguish BRT from regular bus service. The Transitway is rather flexible in terms of differentiated running ways and stations, as well as containing not only trunk services but also express routes. This somewhat compromises the simplicity of the system, which is as previously described an important feature of public transport. The fact that the city considered air quality and noise levels as no great issues of the stations near the freeway such as d'Orleans, Blair and St. Laurent, is interesting. These are situated on one side of the road and it might become more of a problem when the Confederation Line is in use with some stations located in the median of the freeway.

The stations along the freeway are situated on the side which probably is easier to construct compared to the stations in Istanbul and some of the stations in Curitiba, but brings longer distances for pedestrians and cyclists as they will have to pass the entire road when coming to or from locations on opposite side. It also brings longer distances for the buses traveling on the lanes on the other side of the road. These buses have to exit and pass over the freeway for loading of passengers at the stations, and then go back on the freeway which is time consuming. Having stations integrated with urban development in adjacency to a freeway has turned out rather well on some locations where large shopping malls were developed. However it can be considered that there are less possibilities of having the stations close to intensive land use since the infrastructure in such places takes up much space, and as mentioned it brings challenges when it comes to having comfortable and accessible pedestrian roads to the station.

The idea of bringing the bike along on the bus is interesting and might increase the chances of using a sustainable mode when travelling to the station, but it reduces the efficiency of a BRT-system as it takes time to load and unload the bike. Furthermore the number of bikes a bus can take is restricted and therefore it might be difficult to promote a system that only can be used by a small portion of the customers and therefore is difficult to rely upon. Furthermore the size of the shelter for the bikes in the bike and ride system is quite small, and in order to fully offer the possibility to take the bike to the transit such facilities should be larger.

6 Suggestions and analysis regarding Express-BRT on Söderleden

The global BRT examples Istanbul, Curitiba and Ottawa were investigated in order to gather information and gain knowledge about BRT as well as to examine if there were ideas and solutions from these examples that could be applied in the case of Gothenburg. In general, the examples' station configurations were not considerd to have a high enough standard to create a successful system if constructed in Sweden, yet rather high standards of TOD were found. Moreover the idea of replacing BRT with LRT was found in the case of Ottawa. This analysis aims at bringing together the knowledge of Express-BRT that was gathered through literature studies and case studies together with the research questions, with the final purpose of making suggestions in case of implementation on Väster and Söderleden as well as general recommendations of Express-BRT.

6.1 Station aspects concerning noise levels, air quality and traffic safety

As mentioned the aspects of noise, air quality and traffic safety have in this thesis been considered to be of extra importance when implementing a BRT on highly trafficked roads, and these aspects are analyzed below. Station characteristics are also further analyzed under the TOD chapter.

As presented in the thesis, Ottawa has not considered noise and air quality a problem, and no information was found that Istanbul and Curitiba have worked specifically with prevention of these issues either. Yet the literature study shows that these aspects are important to recognize and this thesis suggest a fully closed station including potential overpasses in order to reduce the noise to a level that could be considered acceptable for a station. In a closed station, ventilation could be installed to improve the station air quality for instance through air cleaning procedures or through ventilation pipes that collects air from a distance away where the air is cleaner. The fact that many emissions will likely decrease to 2035 is taken into account, yet the aspect of air quality is still assumed to be important due to particles and increased awareness of costumers. The literature study suggest several possible noise reducing measures, however to have barriers surrounding the station or a partly closed station was considered too poor in terms of noise as well as air quality. A closed station would enhance traffic safety, which is important due to the high speeds, and something that is noticed as a problem in both Istanbul and Curitiba. The station should only be open when there is a bus outside, keeping people from entering the running way and additionally preserving good air quality and reduced noise levels inside. Furthermore this would prevent people from entering the regular road to make shortcuts to reach the station, which happens in Istanbul and can be considered a serious drawback with the BRT's placement on the freeway. A closed station could be assumed to have additional benefits in terms of strong branding and comfort, which also are important features of a BRT system. Furthermore it would provide weather shelter and possibilities for a comfortable indoor climate, which is a noteworthy benefit with concern to the Swedish climate.

As stated earlier the station safety issues in Istanbul has partly to do with crowding and this could be somewhat solved through additional lanes so that buses access the station more efficiently and can overtake. It is understood that Metrobüs was competing with space and was not granted more than one lane for each direction due to the importance of the D100 freeway. This is something that should be taken into account when contemplating the study area, which also is a road of high importance with expansion needs and a surrounding area that is to undergo development leading to higher needs of available space. This could cause conflicts of space and between the different modes that need to use the road. The need of extra lanes, especially in the station areas, should be carefully investigated to not make similar mistakes as was made in Istanbul. As demonstrated in the case study there are large differences between Gothenburg and Istanbul and the risks of crowding in Gothenburg might be a lot smaller. However, besides from reducing passenger overloading, extra lanes at stations provide possibilities for differentiated services and faster operation thanks to takeover opportunities. If further analysis would show that additional lanes are needed but not possible to gain as a median configuration on the road, it can be considered if a fully separate busway is a better option if this means more space. It is furthermore reasonable to assume that the amount of passengers during night time will be a lot smaller than during day time, and therefore a setup similar to the one in Ottawa where all boarding and alighting are gathered to one section of the station during night time could be worth contemplating. This increases the security since people are gathered instead of being scattered over the station, but might however not be necessary if the stations is small.

6.2 Transit Oriented Development

Transit oriented development is considered an important subject in this thesis as the BRT is suggested to use an already existing transport corridor where the built environment and features of accessibility normally is less suitable for public transport.

The case studies show a variation of TOD where Curitiba stands out with what can be considered an example of extraordinary planning. As previously mentioned the RIT system is considered hard to mimic for a mature city like Gothenburg due to the much different preconditions like growth, former plans and already existing transportation systems. Mimicking Curitiba would lead to an unrealistically extensive reformation of the city. Yet the case study can be used as an example of great implementation of TOD principles where for instance mixed development and density have been carefully designed.

The case of Ottawa presents some features that can be discussed when implementing BRT in Sweden. Carrying cycles in the front of the bus is seen as an unusual way to improve cycling and through reasoning it becomes apparent that this might cause a bottleneck due to loading time and insufficient capacity. This would compromise the BRT standard and it is therefore not considered a solution to bring to Gothenburg. However the possibility to bring cycles on the bus is something that should be encouraged, and perhaps cycles could be placed in the bus in a similar way strollers are today.

As explained in the thesis, the station's placement on the road is to some degree an implication of the running way configuration and the case studies show different setups. Common for all setups is that costumers preferably should be able to reach the station in a safe way and without walking too long distances. Having the station in the median, as in Istanbul, or having stations one side, as in Ottawa, leave people to walk significant distances because they have to cross a barrier, the road, unless they come from the same side as the station is located on. This can be considered a general drawback of BRT on large roads, which has been recognized as an issue in Ottawa. It is however worth noticing that the drawback with barriers in Express-BRT is also one of the system's strengths, as it utilizes an already existing barrier leading to no creation of a new one.

It could be discussed whether BRT in itself poses as an incentive for development of the built environment or if it is the other way around. It is ideally preferable to build infrastructure before development, but due to Gothenburg being a mature city it might be more feasible to establish infrastructure and urban development more integrated in time. There can be risks of putting construction of residential and commercial areas first and when a dense enough development exists construct the BRT, because then people are already used to using the car.

As is mentioned in chapter 2.1 a BRT should ideally run in the middle of urban development on smaller roads in order to reduce the distance between public transport and origin/destination for the customers. This is not the case with a BRT on Väster and Söderleden. In an ideal case 66% of the people who reside in the area should be living there, while 33% should be working. From the study of the area it appears that this ratio is somewhat reversed, with the majority of the development being non-residential, and therefore far from what TOD principles recommend. This may cause a large flow in one direction when the majority travels to work in Fässbergsdalen in the morning, and in the opposite direction in the afternoon, and therefore the system risk to become inefficient.

The 8600 inhabitants and 24 000 job opportunities in the area plus the goals of expansion and obtaining a mixed land use may however give a foundation larger than the 6000 inhabitants and job opportunities given as a demand in chapter 3.2. However these turned out to be located on a too long distance from the road, for instance in Järnbrott, which will be further described in chapter 6.2.2. Given the theories of TOD and the plans of Express-BRT in Gothenburg, it can be discussed whether there is a difference in how much TOD matters between regular BRT and Express-BRT. The Express-BRT investigated in this thesis has a purpose of transporting people fast in a tangential structure, which is a need that has been identified in the city. It is understood in literature that for regular BRT there should be a densification around the whole corridor and this is identified as something that could differ from Express-BRT since the stations are further apart. Concerning Express-BRT it is assumed that it could be reasonable to focus the densification on the station areas along Väster and Söderleden in a more radial structure, compared to planning for development along the whole road if this land is considered unattractive. This would be sensible considering the noise and air quality along the road. The idea of somewhat compromising the principles of TOD is further discussed in the Järnbrott chapter below.

6.2.1 Frölunda Torg

Since the studied road passes closely to Frölunda Torg the conditions for constructing a well-functioning station in close access to service and residential buildings are considered favorable here. There are different possibilities for the location of the station, it could be placed on the road either in the median or on shoulders, or adjacent to the already existing bus station, which has a waiting hall and the sort of service a

BRT should have. With a median setup and the station placed in near access to the already existing bus station the BRT running way would have to make a small detour which would not be in line with the aspect of a BRT occupying the closest and fastest way, though it would however connect the BRT with regular public transport and shorten the walking distance for passengers. If it on the other hand was to be constructed on the road there would have to be an overpass with proper shelter, for example with similar design as the one in Ottawa. If the ridership becomes large enough an overpass with rulling hoops such as the ones in the subway in Stockholm could be implemented in the future. The space in the area is however restricted and it may be difficult to fit the station on the road without taking existing lanes from other traffic. There is also a possibility of having the station underground, which would be expensive but favorable in terms of space availability.

6.2.2 Järnbrott

Even though the overall density in Fässbergsdalen might be sufficient there are no plans for exploitation nearby the actual road or around the junction of Järnbrott. The area around Järnbrott does not appear to have a sufficient density in distances lower than the 500 meters described as a requirement for transit oriented development. The distance from the outermost part of Pilegården is around 300 meter and other housing areas are more than 500 meters away. Järnbrott appears to have different conditions and future plans compared to what it is considered that BRT stations should have.

In the timeframe of GMP 2035 Järnbrott is only considered a node of transfer, referred to as an *important transfer station*, which is something that differs from conventional TOD theories where the nodes should be well integrated with urban development. Through reasoning, it is in this thesis considered that Järnbrott is not an ideal place for transit oriented development, mainly because residential areas are less suitable to be close to such heavy traffic. Even so, the area would benefit from basic infrastructural development such as proper walking and cycling paths for the ones that do have Järnbrott as their closest station. As mentioned, residential areas are rather unsuitable but commercial activities that have lower demands concerning the features of the close environment could be implemented to obtain a higher density and attractiveness. It remains unclear whether this way of looking at Järnbrott is destructive for the BRT. If Järnbrott only serves as a transfer node, and there is a foundation for such transfers, the junction will not be according to BRT and TOD principles but it might be reasonable anyways due to the nature of the neighborhood. With this said it is debatable to what degree there should be development made to support the BRT if an area is considered unsuitable. Through the work of this thesis it becomes apparent that the concept of BRT on heavily trafficked roads is more difficult to adapt to TOD principles than regular BRT.

The actual junction in Järnbrott takes a lot of space since two large roads are intersecting and to construct a station at this location is therefore a challenge. The idea of a station in Järnbrott is to enable transfers between BRT routes on Dag Hammarskjöldsleden and Söderleden. This could be made by constructing one station where all routes meet, and a mutual station would be preferable both in terms of providing a fast and efficient service. As mentioned previously in chapter 3.1.3 mutual station with joint platforms is also important in terms of safety since less movement of people would be necessary. Although space restrictions could cause the need for constructing two separate stations connected by some sort of path or bridge to enable passengers to transfer. There is also a possibility of constructing the station or stations grade separated, either above the road or below grade as an underground station. The rather difficult features of junction Järnbrott could be avoided by having a fully separate busway.

6.3 BRT versus LRT

Both BRT Guidelines and the work of GMP 2035 mention that BRT potentially can be used as a step for implementing LRT. This is not a specified suggestion for the studied stretch of Väster and Söderleden yet it is considered a relevant topic for discussion in this thesis.

According to the literature study the capacity of light rail are greater than buses, but BRT is cheaper and it is shown that it can provide more capacity per invested million which are in favor for constructing a BRT. BRT and LRT are becoming more alike each other, and in the future it is likely to assume that the only thing parting the two modes will be that a LRT runs on rails while BRT runs on rubber wheels. As previously mentioned there is an issue of capacity of BRT vehicles on freeways since they are recommended to provide seating for all passengers when travelling in speeds above 70 km/h, which has to do with the side movements that are greater for non-rail vehicles. It will be challenging providing vehicles that have as large a capacity as trams if all passengers need seating, as oppose to trams and trains or buses with lower speeds on urban streets where it is accepted to be standing. Going with a bus similar to the bi-articulated buses operating between Chalmers Lindholmen and Chalmers Johanneberg in 80km/h might not be considered achieving BRT standard in terms of comfort. This is something that is concluded in Ohnmacht's study as well; in order for a BRT to be successful it has to come with proper seating and space, therefore a BRT with a lot of standing capacity might not be preferable. There are also many psychological aspects that seem to be of importance when choosing a bus based mode, this could perhaps be achieved by constructing a more tram like design of the BRT, which also could help when mitigating the impacts the rail bonus is thought to have. Yet, when it comes to Gothenburg 2035, it should be questioned whether the demand is high enough to motivate a switch to LRT, and perhaps a BRT with a more frequent time table would be sufficient. Although the overall idea of switching to LRT is more sensible in Gothenburg since there already is a wide LRT system, compared to the example of Ottawa where LRT only make up for a fraction of the public transport system.

6.4 Additional aspects

Several aspects influence the choice of where to put the running way; median, shoulder or separate. There are pros and cons with each configuration as was briefly described in chapter 2.2. In general the APTA recommendations vary in standard and it is noted that there are options of shared running way and where the bus needs to leave the busway to reach a station. These types of features can be seen as making the system too flexible, which could potentially compromise the importance of an easy-to-understand and homogenous BRT system, and additionally the BRT vehicles' priority in relation to other vehicles. The idea of having counterflow is a further feature that can be considered compromising the clear identity of the system and therefore it is not assumed to be a reasonable option for Gothenburg.

One of the advantages with a median running way compared to shoulder is the possibility of having a shared platform instead of two separate, which is space efficient and also brings the possibility of straight alighting. Having a bus shoulder would require an isolated stop due to safety which would compromise the BRT speed. However as previously mentioned there are bridge pillars in the median of Väster and Söderleden that are placed in the spacing between the two directions at the junctions, which demands a small curve around the pillars or the need of bridge reconstruction. In order to not compromise speed and comfort, such a curve would require large geometry which requires even more space. Since several new lanes are to be constructed the road could become up to 8 lanes plus potential overtaking lanes. This would demand reconstruction of the junctions.

If instead a shoulder running way would be chosen the problems concerning the bridge pillars would go away but as mentioned this setup leads to the BRT being somewhat mixed with other traffic and thereby compromising the important BRT standard. Therefore it is considered that a shoulder running way setup is less suitable. The third option is to have a separate running way that uses the transport corridor and its land use features, leading to possibilities of high speed and comfort, rather than the actual road. This would create an additional barrier but bring larger possibilities in terms of taking consideration to TOD. A separate busway could be placed on the side of the corridor where satisfying connection to the built environment is most achievable, and it seems clear that such stations would have more possibilities of development since they can take up more space compared to if placed in the median of a road. The drawback is that as some people get closer to the station, people on the other side get a longer distance to walk. Therefore it should be carefully considered what side of the corridor to put the separate busway on. Based on the reasoning above, further investigations concerning for instance accessibility, cost and benefits from a separate setup should be carried through.

The overall purpose of all public transportation is to increase sustainability and decrease traffic jams. In this case Gothenburg has goals for increasing the modal share of not only public transport, but cycling and walking as well, and at the same time reduce the modal share for automobile. It might be difficult to promote public transport or cycling to some of the studied area since it contains shops and businesses, and the will for going by these modes when shopping might be smaller. However a lack of proper public transportation will clearly not help achieve the goals.

7 Discussion

Since the BRT-system is to be implemented in about twenty years there are many uncertain factors, for example what the built environment along the stretch actually will be like in the future. A further uncertainty in this thesis is that the noise levels in the median of the road were approximated based on levels on E20, but in order to obtain exact values measurements on Väster and Söderleden should be carried out. If the noise levels are higher than assumed investigation concerning materials and design that leads to even larger reductions should be carried out. Furthermore the increase of traffic flow until the year of 2035 is another uncertainty that will affect both noise levels and air quality, and these should therefore be taken consideration to. Road and vehicle development, such as new road surfaces and coats covering tires, are also aspects that to some extent could lead to reduced noise and possibly less particles originated from tires against road surfaces. This could ease the situation of BRT on highly trafficked roads. Both noise levels and air quality depend on the location of the station, and are lower if being placed beside the road.

As is mentioned in the scope no consideration was taken to economic aspects, apart from the approximated values when investigating BRT systems versus LRT systems. Economy is obviously a most vital part when investigating the feasibility of the different options concerning station location and design as well as running way options. Once economic circumstances are looked into the choice of stations, running ways and other aspects may be different than this thesis suggest.

Another shortcoming in the analysis is that no exact values of population in near access to the investigated potential stations were found. The values used are for the area of Fässbergsdalen and in order to obtain a more correct view upon how many people that will have close access to the station further studies should be carried out, for example in GIS. Such studies would provide the density near the stations and hence give a more accurate image of how transit oriented the station has the opportunity to become. Furthermore the values of people living in the area were not derived from the same area as the working opportunities were, which creates an uncertainty that should be further investigated.

As is mentioned in the analysis there are space restrictions in the area, both on Frölunda Torg and generally on the entire stretch where more capacity is needed. The available space is one important factor when it comes to determining where the station will be placed, as well as the choice of running way. Therefore a more thoroughly investigation concerning what the physical conditions are needs to be carried out. Other significant factors when considering the choice of running way and location of stations are what the pros and cons are for making a detour from the running way to reach a location that is more integrated in the urban development, and more TOD friendly. In terms of TOD, the studied stretch shows how a BRT system could function on the specific part, not how BRT as a system could work all along Väster and Söderleden or in the whole of Gothenburg. However the issues at the two junctions investigated could probably be applied on other similar junctions across the city. When it comes to station design due to noise levels, traffic safety and air quality, these are aspects that are general and can be used on other routes along larger roads.

When looking at the studied examples some problems were assumed to be potential problems in Gothenburg, like people making shortcuts over roads in Istanbul, however this might not necessarily be a problem in Sweden just because it is a problem in Istanbul. This could be the case for other issues as well, and it is important to carefully consider different circumstances and not merely assume that a problem in one system will occur in another system. Another aspect when investigating the case studies is that it would be valuable to visit the cities and use the systems personally in order to obtain a better view of them. The described features from American guidelines concerning BRT on freeways were assumed to be applicable to Swedish circumstances even though there are differences in the characteristics of Swedish and US transportation policies, such as ambitions of reduced greenhouse gasses and modal share of public transport.

Finally, when it comes to BRT versus LRT the idea was to question the general assumption that LRT is superior to BRT and therefore the studied literature many times had the same kind of background. Therefore the result risk being somewhat in favor of BRT and might not at all times provide a neutral foundation for a comparative assessment. It is in this thesis concluded that BRT is cheaper but has less capacity than LRT, but in order to fully gain understanding of the two mode’s pros and cons, a deepened study should be carried out, where both angels of the subject are reflected upon.

8 Conclusion

When implementing BRT on a highly trafficked road with environment thereafter a station that is fully closed to the surrounding is recommended, as it could lead to acceptable levels of noise and air quality, and it would also increase satefy. Moreover it was found that there is a potential issue with people needing to cross the barrier of the road in terms of longer walking distance and the surroundings of the freeway is considered to be a general drawback with Express-BRT.

The studied area is not ideal in terms of preconditions of transit oriented developement, and Järnbrott was identified as a junction where TOD can be extra problematic. This is in line with the proposal of GMP 2035 that Järnbrott should only serve as a transfer node. This does not correspond to TOD principles or BRT Guidelines and it remains unclear whether this way of considering Järnbrott would compromize the BRT standard, a subject that therefore requires further studies. Frölunda Torg is however an example of where it would suit to have a node for the BRT.

Advantages of using corridors from large roads such as the one studied are that they already pose as a barrier and have features of geometry and built environment that enable high speed. A median running way is considered to be a more viable option than a shoulder due to possibilities of having a fully dedicated busway without interruption. Yet the idea of using already existing infrastructure is considered rather limited due to the need of reconstruction of junctions and additional lanes leading to widening of the road. This fact alongside what appears to be insufficient possibilities of implementing the BRT in accordance with TOD at Järnbrott leads to the conclusion that a separate busway could be a viable option that should be further analyzed. A separate busway could be placed in or adjacent to the transport corridor, using its features of geometry and sparse exploitation instead of the actual road, to obtain BRT standards of speed and comfort. This type of setup would have different preconditions for transit oriented development than a median, with possibilities of higher integration of the built environment as well as larger station areas. Yet it should be carefully considered on which side of the corridor the busway is implemented, as it leads to a significant walking distance for customers who come from the other side. A separate busway would also lead to somewhat lower exposure of noise levels and emissions due to the distance from the road, yet a closed station is still preferable since the reduction likely will not become large enough and traffic safety is secured through such a design.

From litterature there are indications that LRT provide higher capacity than BRT but BRT gives higher capacity per invested million. This along the fact that BRT aims to adopt rail like features leads to the conclusion that the BRT-system should not be replaced with a LRT-system unless there are significant capacity issues that cannot be solved with increased BRT frequency and larger vehicles. However the already existing LRT system in Gothenburg makes such a shift more reaonsble than if the city's public transport system was entiterly bus based.

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