Design Standards for Bicycle Express-Routes

Implementation of design standards for a commuter route between Gothenburg, Partille and Lerum

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

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Master´s Thesis BOMX02-17-30
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Examensarbete BOMX02-17-30/ Institutionen för bygg- och miljöteknik,
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Department of Civil and Environmental Engineering
Göteborg, Sweden, 2017

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ABSTRACT

The need for space-efficient and environmentally friendly solutions in the transport system are increasing due to urban expansion and the growing threats towards the environment. The population of Gothenburg and its neighbouring municipalities is growing with more residential expansion than the existing transport system can handle. Therefore, strategies that include different commuting alternatives are of high priority within cities' future plans. Currently, a project is taking place in the Göteborg Region Association of Local Authorities (GR) on a cycle commuter network of long (>10 km) high-quality cycle routes. The cycle routes are intended to be designed and influenced by a recently developed concept, named in this thesis as *bicycle express-routes*, which have been implemented in countries leading within cycle infrastructure such as the Netherlands and Denmark. Bicycle express-routes are high-quality cycle routes which allow commuters to travel fast and direct with minimal distraction on long distances. The travel distance is typically from 5 to 25 km, connecting municipalities, neighbourhoods and working areas. One of the bicycle routes included in future plans for GR is a bicycle express-route connecting Gothenburg, Partille and Lerum.

The purpose of this master thesis is to investigate design standards for high-quality bicycle routes in other European countries and develop suggested design guidelines for bicycle express-routes in Sweden. The proposed design guidelines are based on design manuals and examples of bicycle express-routes in Europe and include the following parameters; type of bicycle infrastructure, crossings, markings, travel speed, lighting, width, horizontal curve radius, gradient, crossfall and surface material. Furthermore, a case study of implementing the suggested design guidelines on a bicycle express-route between Gothenburg, Partille and Lerum is carried out and required measures to achieve the design criteria for bicycle express-routes are pointed out. Results show that the 18 km studied route requires additional infrastructure on the existing bicycle network, including new construction where no bicycle infrastructure exists and improving the quality of the route to achieve the desired criteria. By implementing the proposed design standards on the route the estimated time-gain, in comparison to current route, is 15 minutes with an average travel speed of 21 km/h. The construction cost for the new route is estimated 106 million SEK and the biggest investment is on sections where currently no bicycle infrastructure exists, where difficult conditions require expensive and complex solutions. Conclusively, one of the most important features of bicycle express-routes is to minimise delays and waiting times which can be achieved by implementing bicycle priority crossings to ensure cyclists can uphold a sufficient flow.

Key words: Bicycle express-route, bicycle infrastructure, design standards, bicycle commuting, fast cycling

Designstandarder för Cykelexpressrutter
Applicering av designstandarderna för ett pendlingsstråk mellan Göteborg, Partille och Lerum

Examensarbete inom masterprogrammet Infrastructure and Environmental Engineering

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SAMMANFATTNING

Behovet av utrymmeseffektiva och miljövänliga lösningar i transportsystemet ökar på grund av urban expansion och växande hot mot miljön. Befolkningen i Göteborg och dess närliggande kommuner växer med mer bostadsutbyggnad än vad befintligt transportsystem kan hantera. Därför är strategier som innehåller olika pendlingsalternativ av hög prioritet inom städernas framtidsplaner. För närvarande pågår ett projekt i Göteborgsregionens kommunalförbund (GR) på ett regionalt cykelpendlarnät bestående av långa cykelvägar (>10 km) av hög kvalitet. Cykelvägarna är avsedda att utformas i enlighet med ett nyligen utvecklat koncept, som i detta examensarbete benämns som *cykelexpressvägar*, och som redan har implementerats i länder som är ledande på cykelinfrastruktur som exempelvis Nederländerna och Danmark. Cykelexpressvägar är cykelvägar av hög kvalitet som gör det möjligt för pendlare att resa snabbt och gent med minimal distraktion på långa sträckor. Stråken är vanligtvis mellan 5 och 25 km och förbinder kommuner, bostadsområden och/eller arbetsplatser. En av de cykelvägar som ingår i framtida planer för GR är en cykelexpressväg som förbinder Göteborg, Partille och Lerum.

Syftet med detta examensarbete är att undersöka designstandarder för cykelvägar av hög kvalitet i andra europeiska länder och utveckla förslag för designriktlinjer för cykelexpressvägar i Sverige. De föreslagna designriktlinjerna är baserade på designmanualer och exempel på cykelexpressvägar i Europa och inkluderar följande parametrar; typ av cykelinfrastruktur, korsningar, markeringar, hastighet, belysning, bredd, horisontell kurvradie, lutning, tvärfall och ytmaterial. Vidare utförs en fallstudie genom att utföra de föreslagna designriktlinjerna på en cykelexpressväg mellan Göteborg, Partille och Lerum där det krävs åtgärder för att uppnå designkriterierna för de berörda cykelvägarna. Resultaten visar att för att uppnå kriterierna för cykelexpressvägar på den 18 km långa studerade sträckan krävs ytterligare infrastruktur på det befintliga cykelnätet, inklusive ny infrastruktur där den idag saknas helt, samt förbättring av stråkets kvalitet. Den tid som uppnåtts i jämförelse med den nuvarande cykelvägen, tack vara uppgraderingarna, uppskattas till en tidsvinst på 15 minuter med en genomsnittlig färdhastighet på 21 km/h. Beräknad byggkostnad för den nya rutten är 106 miljoner kronor, varav den största investeringen är att bygga ny infrastruktur där den idag saknas helt, där svåra förhållanden kräver dyra och komplexa lösningar. Sammanfattningsvis är ett av de viktigaste dragen i cykelvägarna att minimera fördröjningar och väntetider genom att utföra cykelöverfarter, där cyklister har företräde, för att säkerställa att cyklisterna kan upprätthålla ett tillräckligt gott flöde.

Nyckelord: Cykelexpressväg, cykelinfrastruktur, designstandard, cykelpendling, snabbcykling

Contents

Preface

The thesis is intended for urban planners, students or people working in the field of traffic planning and the Swedish Transport Administration. This master thesis was carried out as a parallel study to the Göteborg Region Association of Local Authorities (GR) project about regional bicycle commuter-routes. This project was conducted through workshops led by consultants from Koucky and Partners AB and with urban planners from the municipalities within GR. The fieldwork was carried out during Mars and April year 2017. The study was conducted at the Department of Civil and Environmental Engineering, Road and Traffic Group, Chalmers University of Technology, Sweden.

The research was carried out in association with Michael Koucky, mobility management consultant, as a supervisor from Koucky and Partners. Gunnar Lannér and Claes Johansson were the supervisors from the Department of Civil and Environmental Engineering, Road and Traffic Group, Chalmers University of Technology. Additionally, it should be noted that urban planners from Gothenburg, Partille and Lerum municipality were helpful during the study and also colleagues at Koucky and Partners AB. This thesis was carried out at their office and we are very grateful for the welcoming environment and the support given to us during our work.

Göteborg June 2017
Arna Kristjánsdóttir and Agnes Sjöö

Wordlist

Bicycle express-route:	A high-quality bicycle route which allows commuters to travel fast and direct with minimal interference with other transport modes for long distances between point A and B.
Bicycle passage: *(Cykelpassage)*	A crossing between road and bicycle path where cyclists and drivers of mopeds class II must give way to motorised traffic. A bicycle passage consists typically of transverse surface markings indicating a crossing and can be guarded or unguarded.
Bicycle path:	A road or a part of a road separated from motorised traffic and intended only for bicycles and moped class II. Bicycle paths are often combined with pedestrian paths but it is common to separate them with road markings or barriers.
Bicycle priority crossing: *(Cykelöverfart)*	A crossing between road and bicycle path where motorised traffic must give way to cyclists or drivers of moped class II. The crossing must have transverse surface markings indicating a crossing, give way surface markings and bicycle crossing signs. Traffic environment needs to be designed in a secure way with traffic speed limited to 30 km/h.
Bicycle route:	A bicycle path with similar design criteria over the entire route and with continuous routing that takes a cyclist from point A to B.
Bicycle street:	A regulated shared road between cyclists and motorised traffic where bicycles are prioritised and traffic speeds should be adapted to the cyclists´ speed.
Crossfall	A road´s tilting in the cross direction, measured in percentage.
Delay factor:	A factor showing how much longer time the route from point A to B takes with stops than without them.
Detour factor:	A factor showing how much longer the chosen route from point A to B is in comparison with the shortest possible option between point A and B.
Electrical bicycle *(E-bike)*	A bicycle that has electrical power in addition to the normal mechanical power driven by the cyclist.
Green waves:	Signalised crossings which detect cyclists and change the light to green when cyclists approach the signal. Green waves occur when this happens at several signalised crossings in a row.
Longitudinal fall	A road´s tilting in the longitudinal direction, measured in percentage.
Pictogram:	Symbol, for example of a bicycle painted on the asphalt concrete surface.
Resulting fall:	The resulting fall of both cross and longitudinal fall of a path.
Rolling resistance:	The force that resists the motion of a body rolling on a surface.
Skid resistance:	The force developed when a tire that is prevented from rotating slides along the pavement surface.

Koucky and Partners AB	A consultant company with main focus on mobility management.
Region Västra Götaland *Västra götalandsregionen (VGR)*	VGR is ruled by politicians where the manager of the region is the person in charge of making sure the political decisions are implemented. Good healthcare, dental care, providing the prerequisites for good public health, a rich cultural life, a good environment, jobs, research, education and good communications are all tasks within VGR.
Swedish Association of Local Authorities and Regions (SALAR) *Sveriges Kommuner och Landsting (SKL)*	SALAR is an association for municipalities, county councils and regions. Their mission is to provide municipalities, county councils and regions with improved circumstances for local and regional self-government. The vision is to develop the welfare system and its services.
Swedish Transport Administration *Trafikverket*	The Swedish Transport Administration is in charge of planning of the transport system for all types of traffic, along with building, operating and maintaining public roads and railways.
Swedish Transport Agency *Transportstyrelsen*	The Swedish Transport Agency specifies rules and monitors how they are followed, grants permission, registers change of ownership and manages congestion and vehicle taxation.
The Göteborg Region Association of Local Authorities *Göteborgsregionens kommunalförbund (GR)*	GR is a co-operative organisation joining thirteen municipalities in western Sweden. The task of the association is to promote co-operation over municipal borders and provide an environment for the exchange of ideas and experience within the region. GR´s focus is issues regarding regional planning, environment, traffic, job market, welfare and social services, competence development, education, and research.

1 Introduction

In today´s society, transportation is of great importance and the need for space-efficient and environmentally friendly solutions are increasing due to urban expansion and the growing threats towards the environment. Cycling is a suitable option for commuting which contributes to sustainable development of cities and is additionally beneficial for both individuals and for society in terms of health.

In the last decades, bicycle commuting has attracted increasing interests by local authorities and politicians in Sweden where additional emphasis is placed on bicycle infrastructure. The population of Gothenburg and its surrounding municipalities is growing with more residential expansion than the existing transport system can handle. Therefore, strategies that include different commuting alternatives are of high priority within the city´s future plans. Gothenburg has a vision which includes making the city an attractive place for cyclists, where cycling is a competitive mode of transport and by 2025, the goal is to have a share of cyclists three times higher than recent years (Trafikkontoret, 2015). Another main goal is to make cycling a safe and fast way of commuting for short and long distances within the region.

To promote cycling as an alternative transport mode, attractive and well-functioning bicycle infrastructure needs to be in place. For long distances, high-quality bicycle routes are necessary in order to make commuting by bicycle an attractive alternative in comparison with other transport modes. In recent years, a concept has been developed in classifying specific bicycle routes that are intended for long distance commuting. The term for this concept varies within different countries and no internationally agreed on term has been established yet. For instance, *Cycle Highways* in London, *Supercykelstier* in Denmark, *Sykkelekspressveger* in Norway, *Radschnellweg* in Germany and *Snelle fietsroutes* or *Bicycle highways* in the Netherlands. In this thesis, these routes will be termed *bicycle express-routes*. The general definition of bicycle express-routes is that they are high-quality bicycle routes which allow commuters to travel faster and more directly than other bicycle routes, with minimal distractions on long distances between points A and B. Such routes have been opened in London and Copenhagen as well as in countries like the Netherlands, Germany and Norway with promising results (Sørensen, 2012). Sweden has taken special interest in the concept to improve the bicycle network of cities and their surrounding municipalities. However, no common design standards have been established for Swedish bicycle express-routes.

1.1 Background

CHIPS (Cycle Highways Innovation for smarter People Transport and Spatial Planning) is a project by partners in Belgium, Germany, the Netherlands and United Kingdom that aims to develop and promote bicycle express-routes with the purpose to decrease car usage and increase the number of people commuting by bicycles (European Cyclists´ Federation (ECF), n.d.). The number of electrical bikes are increasing and together with innovations within bicycle express-routes, the CHIPS project aim to demonstrate that it can be an effective way to change people´s commuting habits from travelling with motorised traffic to travelling with bicycles. Furthermore, the CHIPS project will work on establishing common standards and solutions for bicycle express-routes within North-West Europe. While the number of fast cyclists are increasing, particularly because of the increasing number of e-bikes, it is especially important to design the bicycle express-routes for safe over-taking and to take into account that differences in speed are to be expected.

Currently, a project is taking place in the Göteborg Region Association of Local Authorities (GR) on a regional commuter network of long high-quality bicycle routes (>10 km) which is supported by the Swedish Energy Agency. Koucky and Partners is a consultant company carrying out the project on behalf of GR to manage the project with workshops with urban planners from the municipalities within GR. The workshops are a first step towards developing regional bicycle express-routes in the Gothenburg region. Connecting the different municipalities with bicycle express-routes requires additional infrastructure on the existing bicycle network, including new construction where no bicycle infrastructure exists and improving the quality of the routes (see overview in Figure 1.1). One of the bicycle routes included in future plans for GR is a bicycle express-route connecting Gothenburg, Partille and Lerum. There are existing bicycle paths on parts of the route, but additional infrastructure is needed as well as improvements on the existing paths.

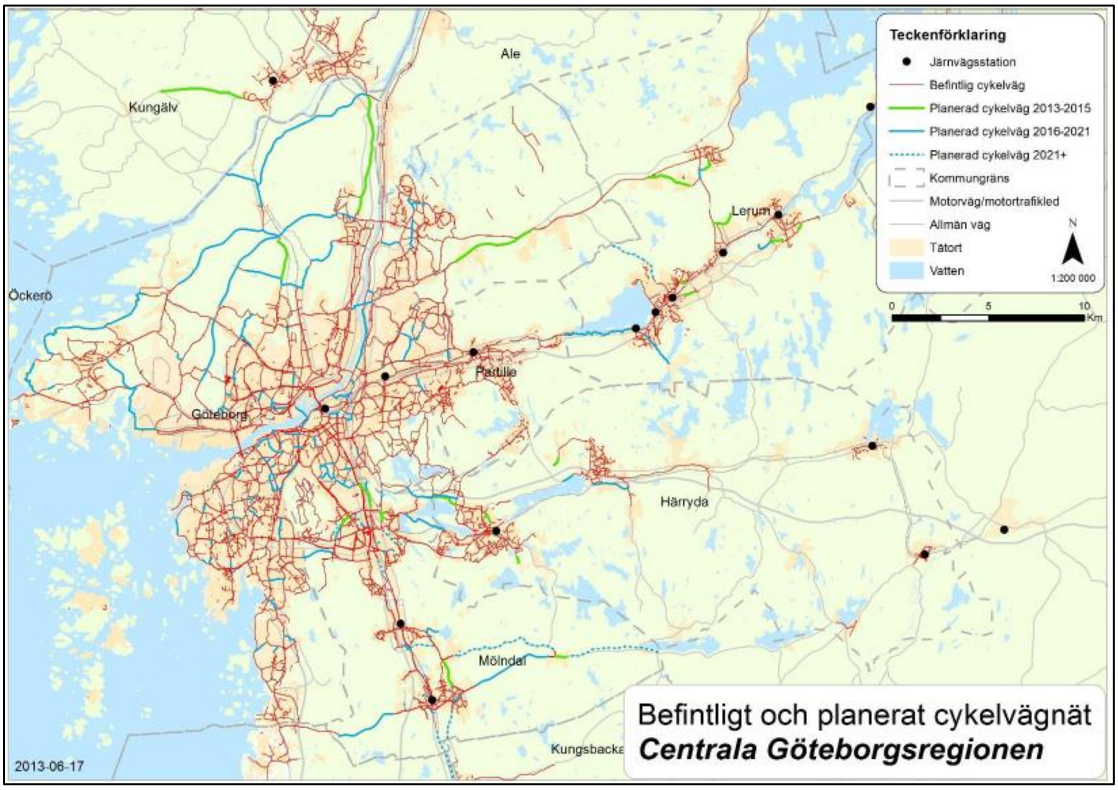

Figure 1.1 Overview of the existing and planned bicycle network in the central parts of Gothenburg region (Trivector, 2013).

1.2 Aim and objective

The purpose of this thesis is to gain better knowledge of the design standards for a high-quality bicycle route for long distance commuting. The main focus of the design is to suggest what type of bicycle infrastructure is suitable, lighting, road markings, crossings, travel speed, width, gradient, curve radius, crossfall and surface quality.

The study has three objectives. The first is to identify design standards for high-quality bicycle routes in other countries and review the research of existing bicycle express-routes. The second objective is to suggest design guidelines for bicycle express-routes in Sweden. The final objective of this study is to implement the proposed guidelines to a bicycle express-routes between Gothenburg, Partille and Lerum which is included in future plans for the Gothenburg region.

The following questions will be addressed in this study:

- What are the design standards for a high-quality bicycle route internationally?
- What are suitable proposed design guidelines for bicycle express-routes in Sweden?
- Which parts of the existing bicycle commuter-route between Gothenburg, Partille and Lerum meet the suggested guidelines and which parts need improvements? Which improvements are needed?
- What is the cost of establishing a bicycle express-route between Gothenburg, Partille and Lerum in accordance with the proposed design guidelines?
- What are the possible challenges of implementing the bicycle express-route between Gothenburg, Partille and Lerum?

1.3 Limitations

In order to keep the thesis within the scope, withhold a technical approach and to manage the time constraints, the following limitations are made:

- The important link between bicycle and public transport is not considered.
- Maintenance is not taken into consideration.
- Policies are not included.
- Promotions such as advertisement and campaigns are not considered.
- Effects on public health and environment are not included.
- The traffic safety perspective is not considered.

1.4 Method

The study was carried out in three blocks; literature review, assessment of guidelines and case study. Figure 1.2 illustrates an overview of the methodology which was used for this study.

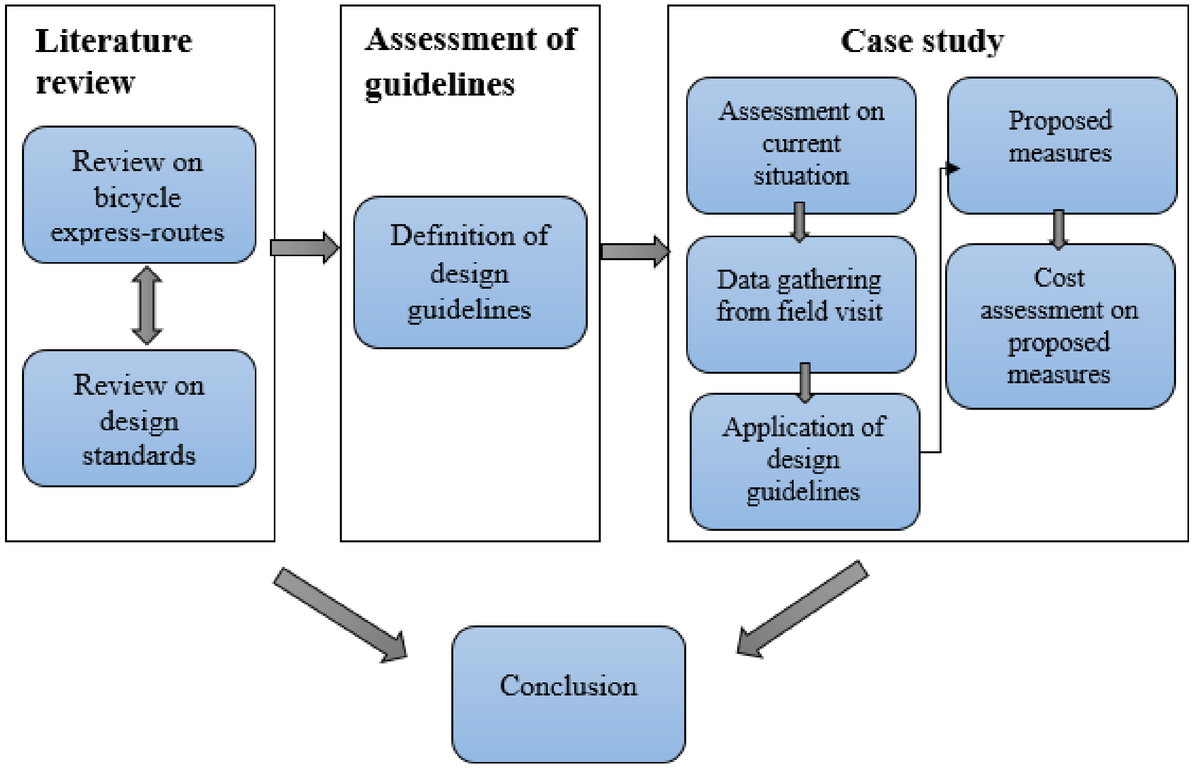

Figure 1.2 Flow chart describing the research model of the study.

Literature review
Several subjects concerning high-quality bicycle routes were reviewed in Chapters 2 and 3. First, a background to the subject of high-quality bicycle routes was looked into, followed by a review of experience from cycle leading countries where bicycle express-routes have been implemented or are in the design phase. The second subject includes a review of design standards used in different countries. The design standards in focus were the ones most relevant for high-quality bicycle routes connecting cities and suburbs. The reviewed countries include the Netherlands, Denmark, Germany, United Kingdom and Norway. Furthermore, practices and guidelines from Sweden were also examined. Literature reviewed included first design manuals and guidelines from countries with well-developed bicycle infrastructure, case studies on bicycle express-routes and papers on bicycle infrastructure. Secondly, design manuals and guidelines for design standards: *Design manual for bicycle traffic* by CROW (The Netherlands), *GCM-handbok* by SKL (Sweden), *VGU* by Trafikverket and SKL (Sweden), *Håndbog i Cykeltrafik* by Celis Consult (Denmark), *Håndbog Supercykelstier* by Vejregler (Denmark), *Empfehlungen fur Radverkehrsanlagen* by FGSV (Germany) and *Cycle infrastructure design* by TfL (UK).

Assessment of guidelines
The different design standards were evaluated and, in collaboration with Koucky and Partners, suggestions on design guidelines to use for bicycle express-routes in Sweden were made and presented in Chapter 4.

Case study

At an early stage of the research, an assessment of the current situation of the bicycle route between Gothenburg, Partille and Lerum was carried out. This was done in fieldwork by cycling the route before gathering the data for inventory purposes. The aim of the current situation assessment was to evaluate which parameters needed to be considered for the inventory and to determine the start and finish points for the studied bicycle route. The route´s alignment was based on suggestions from the three concerned municipalities and on visual inspection from the early assessment of the situation. Furthermore, the route was visually evaluated and divided into stretches based on their homogenous characteristics. Based on the suggested guidelines, a sheet with predefined design parameters was created in the GIS Cloud tool *Mobile Data Collection (MDC).* Further description of each evaluated parameter can be found in Appendix I. Later each stretch was walked and evaluated on the basis of the chosen parameters. The MDC-tool, which uses the smartphone´s GPS-signal, was used to easily combine the gathered data with a corresponding map. The gathered fieldwork data was compared to the suggested design standards for each stretch of the route to determine which sections already fulfilled the suggested standard, which needed improvement and which measures would be necessary.

A cost analysis for the case study was performed in Excel. The quantity of the proposed measures was estimated based on inventory data collected from site. Material and labour costs were estimated based on prices gathered from municipalities, manufactures and contractors. The case study is presented in Chapter 5.

2 Bicycle Express-Routes

The fast bicycle routes especially designed for commuting have become popular over the last years, however several names and different definitions are used for this type of bicycle infrastructure. The name used in this report is bicycle express-routes, which is based on suggestions from Löwing, Koucky, & Kleberg (2012). Common features identifying these commuter-routes are; high-quality standards, certain minimum length, exclusively for cyclists and designed for high speed.

2.1 Historical background

Bicycle express-route is not an entirely new concept. By the end of the 19th century, the California Cycleway was proposed by investor Horace Dobbins as a 10 km elevated bicycle commuter route between Pasadena and Los Angeles city centre. The cycleway was built as a flat and fast level-separated highway which towered over railways, road junctions and residents (Holder, 1900). Unfortunately, only about 2 km of the path were built and in the beginning of the 20th century the structure was taken down. This was mainly because of the increasing use of private motorised vehicles, and the structure was later rebuilt as an automobile freeway. Bicycle use decreased significantly after the introduction of automobiles globally and bicycle infrastructure was not considered a priority nor a necessity (Gally, 2005).

Close to a century later, engineers and designers proposed similar systems for cities around the world. The first recognised bicycle express-route was built in 2004 in the Netherlands, connecting the city of Breda and the town of Etten-Leur with a 7.5 km high-quality bicycle path. One of the aims of this construction was to demonstrate how good-quality bicycle infrastructure can increase bicycle commuting between cities (Ministry of Transport & Fietsberaad, 2009). Although Breda to Etten-Leur was known to be the first successful bicycle express-route constructed, another Dutch bicycle route built already in 1977 between Tilburg and Oisterwijk has similar quality standards. However, due to the number of non-prioritised crossings for cyclists, it has not been recognised as a bicycle express-route even though other standards seem to be fulfilled.

Subsequently, further development was made in the front runner country within cycling, the Netherlands, concerning bicycle express-route infrastructure and a number of routes have been built successfully in recent years. Another leading country in bicycle infrastructure is Denmark where increasing interest has been in bicycle express-routes and several routes have already been built. Other countries such as United Kingdom, Germany, Norway and Sweden have all shown great interest in the concept and planning for new bicycle express-route infrastructures is in motion in all of them, if not already built.

2.2 Bicycle express-routes in Europe

This chapter consists of reviews of bicycle express-routes in the Netherlands, Denmark, United Kingdom, Germany, Norway and Sweden. Each of the sub-chapters start with a short description of the country´s definition of bicycle express-routes and ends with examples of routes constructed or planned.

2.2.1 The Netherlands

According to the Dutch CROW manual, *Bicycle highway* is the term used for high-quality regional bicycle route which main purpose is to facilitate journeys by bicycle over distances from 5 to 30 km (CROW, 2016). The bicycle routes are constructed between important locations within a region such as cities, hubs, shopping districts and places of work. A bicycle highway needs special attention regarding design speed and prevention of delays where separation between traffic and cyclists is essential. The CROW manual states the following five main requirements for a bicycle-friendly infrastructure and bicycle express-routes:

Cohesion Bicycle highways are the fundamentals of a regional bicycle network and establish the highest level of commuter possibilities within a region. They contribute to both practical and recreational levels of service as a connection between city and country-side.

Directness The bicycle highway connects destinations on regional scale and allows commuters to travel directly between their target points without delay. The detour factor on a route should not exceed 1.2.

Attractiveness The implementation of a bicycle highway is done in an attractive way where cyclists and residents in surrounding areas should experience the added value that the route provides to the area. Personal safety is also perceived by good route selection, design and organisation of the bicycle highway such as lighting and distance between vegetation and path.

Safety The bicycle highway should allow cyclists to commute more or less undisturbed and conflicts with other road users should be kept at a minimum. The route´s surface must provide sufficient skid-resistance and good ride quality (no bumps, good curve radius and gradient). Furthermore, nuisance from fellow route-users, such as over-taking, speed difference and width variety, should be kept as low as possible. Safety at junctions and bicycle crossings should be in priority where adequate view of ongoing traffic should be present, which in principle must give priority to the bicycle highway users.

Comfort Width of bicycle highways should be adequate to enable safe and smooth over-taking. Moreover, the route should satisfy the highest quality requirements in regard to surface skid resistance and evenness**.** Special attention should be taken to the route´s delay factor, where maximum 0.4 stops/km is acceptable.

Examples of bicycle express-routes in the Netherlands

As mentioned, the Netherlands is considered to be a leading country within cycling and bicycle express-routes are becoming a popular type of bicycle infrastructure for connecting bicycle networks on a regional level. By 2014, 25 bicycle highways existed in the Netherlands and by 2025 the agenda is to establish a bicycle express-route network of total 687 km (Esch, Bot, Goedhart, & Scheres, 2013). The strategy, made by authorities, is to upgrade existing bicycle infrastructure to meet the requirements of bicycle express-routes and to implement new infrastructure where needed.

The longest bicycle express-route in the Netherlands, named F35, is a 62 km long route in the region Twente, connecting eight of the largest municipalities. Construction of the entire route is expected to be finished by 2020 (Province Overijssel, 2015). Out of the total distance, 15 km of the F35-route will be alongside existing roads, 16 km new bicycle routes will be constructed and 28 km will lie alongside the railway. F35 has the highest design standard requirements for bicycle express-route and some parts of the standards include:

- It is a two-way bicycle path with a minimum width of 4 m in rural areas and 4.5 m in built-up areas. The path is coated with red coloured asphalt concrete and has the signature logo painted on the surface at regular intervals and at distraction nodes such as crossings.
- Total separation from pedestrians and motorised traffic is required.
- Requirements at junctions:
    - At distributor roads, there should be total level-separation.
    - At district access roads, there should be level-separation or a roundabout.
    - At estate access roads, there should be rise of crossings with cyclists´ priority.
    - At major junctions, there should be traffic lights with a maximum red time of 30 seconds for cyclists.
- Delay time should not exceed 15 seconds per km.
- Surface must be smooth, lighting should be provided throughout the entire route and the inclinations must not exceed 4 %.
- Distance between railway and bicycle path must be at least 1.2 metres.
- The bicycle express-route should have sufficient connections to the local bicycle network (Region of Twente & Goudappel Coffeng, 2009).

Another existing bicycle express-route in the Netherlands, the *F325* or *RijnWaalpad*, connects the two cities Arnhem and Nijmegen with a 15.8 km long bicycle path that lies mostly alongside the A325 motorway. It is expected that around 2000 commuters in the surrounding areas along the route use the bicycle express-route daily. It took approximately 5 years to construct the route including two underpasses and one overpass. The cost was estimated to about 16 million Euros, or 1 million Euros per km which is around 9.5 million SEK per km. The F325 path is 4 metres wide and has smooth red asphalt concrete surfacing. The route is provided with specific lighting where light-posts are placed with 8.5 m intervals. The bicycle express-route gets priority at junctions as much as possible, but depending on the traffic situation other traffic modals could be prioritised (Bicycle Dutch, 2015).

2.2.2 Denmark

The Danish handbook on bicycle express-routes or *Supercykelstier*, as called in Denmark, describe them as a high-priority bicycle route intended for commuting over longer distances (Vejregler, 2016). The suggested quality goals for bicycle express-routes are according to Vejregler (2014) suggestions regarding; *directness, accessibility, safety, comfort and experience and familiarity and identity.*

Directness A bicycle express-route should be a direct and logical route, connecting residential areas with workplaces and educational institutions. It should also connect to other cycle routes and give access to public transport to support the combination tours between cycling and public transport.

Accessibility	When choosing between alternative routes on sections, the fastest route or a route that does not make the travel time much more than 20 percent longer should be chosen. The goal should be to minimize the number of stops. Overtaking should be possible.
Safety	Safety inspections of a route should be conducted when rebuilding existing routes and when constructing new ones, with respect to fast cyclists. The route should be illuminated and visible from the surroundings. Frequent follow-up operation and maintenance work should be made. The route should have the highest priority for winter service among cycle routes.
Comfort and experience	A bicycle express-route should have an even coating, preferably asphalt. The route should be inspected regularly to uphold an even surface. Service stations such as pumps and water could be incorporated. The path should have good drainage and climate protection if possible.
Familiarity and identity	Bicycle express-route should be marketed with a unique visual identity. The route should be marked repeatedly throughout the path to ensure cyclists never doubt that they are on a bicycle express-route or in direction of one.

Examples of bicycle express-routes in Denmark

Within Denmark´s capital region, a bicycle network of 28 routes has been planned and 14 routes will be built by year 2020 (Supercykelstier, 2016a). The bicycle network has similar structure to road and rail networks in the metropolitan area, starting in one point with direction in and out of the city and ring routes around the town.

The first bicycle express-route to be built in the network was *Albertslundsruten C99*, which was established in April 2012 (Supercykelstier, 2016b). With its´ 16.9 km, the route connects Copenhagen, Frederiksberg, Albertslund, Rødovre and Glostrup. The route has green waves for cyclists, even coating, bicycle pumps and foot rests to ensure easy accessibility along the entire route. In 2015, an additional water post was set up along the route. The budget for this project was 0.79 million DKK per km or 1.0 million SEK per km.

One of the new bicycle express-routes in Denmark is *Ishøjruten C77*, which connect Ishøj and Copenhagen (Supercykelstier, 2016c). The route is 13.8 km long and was completed in August 2016. Several measures have been made in order to improve the route and achieve a better standard which is needed for a bicycle express-route. Examples of these improvements are; green waves for cyclists in seven crossings, new asphalt concrete on some parts of the stretch, widening of the path on some parts, signs along the entire route and markings in the asphalt showing the way. The budget for this project was 0.98 million DKK per km or 1.25 million SEK per km.

2.2.3 United Kingdom

The Mayor of London has set out a comprehensive vision for cycling where the aim is to make London a "cyclist city" by building high-quality bicycle infrastructure to make cycling an attractive way to commute (TfL, 2013). *Cycle Superhighway* is the term used for bicycle express-routes in United Kingdom and they are described as fast, safe and direct bicycle routes that connect the outer districts with city centres. The Mayor´s Vision for Cycling will be achieved by ensuring the following six design outcomes (TfL, 2014):

Cohesion	The cycle network should be understandable, consistent, intuitive and well linked together. All kind of users should be able to use it and understand.
Directness	Cycle routes should be logical and continuous without hinders, delays and diversions. The routes should be designed in a holistic way as a part of a cycle network.
Attractiveness	Cycle infrastructure should be attractive and should not add to street clutters.
Safety	Safety for cyclists should be achieved by well-designed infrastructure and should address negative perceptions about safety, especially at junctions and crossings.
Comfort	The cycle route's surface should be of high quality, fit for purpose, well-designed transitions, smooth and well maintained.
Adaptability	The design of cycling infrastructure should accommodate all kind of cycle users and should add number of users over time.

Examples of bicycle express-routes in United Kingdom

The Mayor´s Vison for Cycling mainly includes the ambitious bicycle network project of the so-called Barclays Cycle Superhighways, introduced in 2008. The Cycle Superhighways are high-quality bicycle routes that run from outer London into central London. They are intended to improve cycling conditions in London and encourage new users to shift commuter habits from vehicles to bicycles. Initially, 12 Superhighways were planned that vary from 5 to 15 km in length and widths vary from 1.5 to 4 m. In 2017, seven routes have been constructed and one route has been cancelled (TfL, n.d.). The bicycle routes are designed to be aligned with existing streets as fully separated one-way or two-way bicycle lanes, identified with blue coloured surfacing. In the designing process of the Superhighway, special emphasis was made on junctions by implementing different strategies to ensure cyclists safety (TfL, 2014). Estimated costs for the project is 140 million Euros, or 1 million Euros per kilometre which is 9.5 million SEK per km (ECF, n.d.).

2.2.4 Germany

The German National Cycling Plan 2020 (BMVBS, 2012) mentions that one of their main strategies in order to reduce congestion and relieve pressure on the public transport system is the introduction of bicycle express-routes. In Germany, the term *radschnellweg* is most often used for bicycle express-routes and is defined as connections in the bicycle network of a city-region where long commuter distances are in focus (minimum 5 km). The routes are characterised by high-quality standards and the route should allow high speeds through a safe and attractive area (FGSV, 2016).

Examples of bicycle express-routes in Germany

Currently, there are only a few existing bicycle express-routes in Germany. However, discussions and planning strategies on the concept have high priority within municipalities and authorities.

The first bicycle express-route planned for Germany, named RS1, will connect 10 different municipalities between the towns Duisburg and Hamm with a 101 km long bicycle network. Construction has already begun and in 2015 the first 6 km section was opened between Mülheim and Essen and the entire route is expected to be completed in 2020. RS1 is expected to attract between 1000 and 4000 cyclists daily on each section and to have significant influence on solving congestion issues in the region. Main design requirements for RS1 are as follows:

- The width of two-way bicycle path should be 4 m. For one-way bicycle path the width requirement is 3 m.
- Total separation between cyclists and pedestrians. However, where pedestrians are present, an appropriate footpath, 2 m apart from bicycle path, should be implemented.
- Cyclists should have priority at crossings or level-separation if possible to prevent waiting time.
- Signage should be appropriate, informative and uniform throughout municipalities.
- Lighting in rural areas should be innovative with dynamic lighting. The route should be illuminated on all sections.
- Mid and edge markings should be provided on bicycle path surface. In particular, the edge markings are to increase the cyclist´s visibility and improve the contrast of the path.
- Gradient of bicycle path should not exceed 6 %.
- Service points which include pumps, resting places and parking should be placed along the bicycle route (Ruhr Regional Association, 2014).

Cost for RS1 is expected to be 183.7 million Euros, or 1.8 million Euros per km which is around 17 million SEK per km.

2.2.5 Norway

The Norwegian National Cycling strategy for 2014-2023 outlines the importance of bicycle express-routes to ensure a functional bicycle network (Statens vegvesen, 2012). It refers to bicycle express-routes as *sykkelekspressveger* and are described as bicycle paths in the bicycle network with higher quality standards than usual. They are continuous, separated bicycle paths connecting large cities, with wider paths and therefore increased possibilities for modal shifts for commuters. Moreover, Sykkelhandboken V122 describes bicycle express-routes as high-standard bicycle paths that enable commuters to cycle longer distances (5-20 km) between residential areas, job areas, educational areas and public transport nodes without having to experience delay and discomfort (Statens vegvesen, 2014a).

Examples of bicycle express-routes in Norway

Planning and constructions of a new bicycle express-route is taking place to connect two towns, Stavanger and Sandnes, in South-West of Norway (Sørensen, 2012). The main goal of the new bicycle route is to make it attractive for cyclists to commute by bicycle instead of private car. The bicycle express-route is planned to be a separated, high-standard, 13 km bicycle route which is aligned alongside the E39 motorway. The main characteristics of the designed route are:

- The bicycle path is fully separated from motorised traffic and pedestrians.
- Width of the path is 4.5 m, with 4 m of asphalt concrete paved material and 0.25 m of gravel as shoulder on each side.
- Distance from E39 motorway will vary, typically between 8 to 20 m.
- Maximum gradients for routes longer than 200 m, between 100 and 200 m and less than 100 m should be 3.5 %, 5 % and 7 % respectively.
- Crossings should be prioritised.

Construction is estimated to be completed by 2020 and the estimated cost is between 330 and 550 million NOK, 25 to 42 million per km which is around 26.5 to 45 million SEK per km (Sørensen, 2012).

2.2.6 Sweden

In Sweden, several studies have been made on the subject of high-quality bicycle routes. In year 2012, Koucky and Partners conducted a report with a review of knowledge and proposed definition of bicycle express-routes at the request of the project *Öresund som cykelregion* (Öresund as a bicycle region). The report reviews the definitions of bicycle express-routes in some chosen countries (Löwing, Koucky, & Kleberg, 2012). These definitions are used as foundation for the suggested criteria for the bicycle express-routes. The criteria for functional design should be for the entire route from A to B, which makes it possible to have varying infrastructure on different sections of the route as long as the functional criteria are achieved. The included aspects concerning the functional design are; travel time between target points, priority, easy orientation, accessibility, comfort, safety and experienced security. The following is a summary of the most important suggestions. A bicycle express-route should:

- Be direct and connect target points with the least possible detour.
- Make it possible for an experienced bicycle-commuter to achieve an average speed of 20 km/h including stops.
- Give distinguishable advantages within speed and comfort in comparison with other bicycle routes.
- Give cyclists priority. Occasional exceptions could be done if it does not result in too long stopping times.
- Minimise number of stops and waiting periods. Maximum one short stop (10-15 seconds) per km or one longer stop (30-40 seconds) every other km.
- Be separated from car- and pedestrian traffic.
- Be easily orientated, with distinct signage and marking.
- Inclination kept at minimum. Steep parts should be short and the gradient should never exceed 7 %.
- Be wide enough to ensure safe over-taking. Minimum 2.5 m wide for two-way bicycle paths, but the width should be adjusted in accordance with the traffic flow.
- Be designed for a speed of 30 km/h or more.
- Have a high-quality coating without disturbing unevenness, for example potholes.
- Have priority within maintenance.
- Avoid areas with loud noises or other direct disturbance factors like splash from cars driving in puddles.

- Be designed in a way that offers security for the users, including good illumination (Löwing, Koucky, & Kleberg, 2012).

The Swedish Transport Administration is currently investigating the possibility to construct a bicycle express-route between Malmö and Lund. In the planning process, it was examined where and how the road should be built, number of needed examinations, if there are alternative routes, available budget and the input from affected organisations and individuals (Structor Mark Malmö, 2017). The plan is to build the bicycle express-route before year 2023.

At beginning of 2017, a study on alternative alignments for the planned route was published at the request of the Swedish Transport Administration (Structor Mark Malmö, 2017). Two different alignments were reviewed, one along the railway, called *the railway corridor*, and the other located further west, called *the west corridor*. Three standard sections are suggested and the design speed is 20 km/h in urban areas and 40 km/h in rural locations. Standard section 1 is for rural areas. Suggested width is 4.5 m for a two-way bicycle express-route, but could be 3.5 m if the traffic flow is low. Pedestrians are allowed on the bicycle path. Standard section 2 is for urban areas and here a separated path for pedestrians is suggested. Width should be 4.5 m for two-way bicycle express-route and the pedestrian path should be 1.5 m. Standard section 3 should be used where the space in an urban area is limited. The bicycle path could be 2.5 m and otherwise the same as standard section 2.

The municipality of Gothenburg has made a vision for cycling 2015-2025, where they identify three levels of bicycle networks; *commuter bicycle-network* – connect large target points and can be on a regional level, *overall bicycle-network* – makes connections to the commuter bicycle network, *local bicycle-network* – takes the cyclists to their target point. The highest functional requirements are described for a commuter bicycle-network. A route within the commuter bicycle-network should be designed for a speed of 30 km/h between crossings and with a minimum average speed of 20 km/h on a stretch of 2 km (Trafikkontoret, 2015). The detour factor should not exceed 1.25 between important target points and the surface quality should allow a bicycle with well-pressured wheels to roll without disturbances. Safe overtaking should always be possible, the network should be free from fixed obstacles and the crossings should be secured. The signage should be distinct and the cyclists should always have a sense of security while using the commuter bicycle-network.

3 Design Standards

In this chapter, a review of design standards, based on several countries´ bicycle design manuals and experience, are presented. The reviewed countries are all front runners in bicycle development and bicycle infrastructure. Furthermore, reviews on existing Swedish guidelines are also presented. The chapter is divided into sub-chapters, where every sub-chapter represents one design parameter. The reviewed parameters are; diverse types of bicycle infrastructure, crossings, travel speed, markings, lighting, width, horizontal curve radius, gradient, crossfall and surface material.

3.1 Types of bicycle infrastructure

The bicycle network comprises of several types of bicycle infrastructure. In this chapter, a review will be presented on bicycle paths, bicycle lanes and bicycle streets that will support design guidelines for bicycle express-routes.

3.1.1 Bicycle path

A separated bicycle path is defined by the Dutch manual as a bicycle path physically separated from motorised traffic, parking lanes and pedestrian sidewalks (CROW, 2016). Separated bicycle paths are intended exclusively for bicyclists. In built-up areas, bicycle paths are typically located along the carriageway or the sidewalk where separation strategies involve for example, painted line, vegetation, raised curb, barriers or different colouring or material. In rural areas, bicycle paths are typically separated from the carriageway since traffic speeds are too high (>60km/h) to maintain safety for cyclists. Separation strategies in rural areas include verges that require a specific width, depending on traffic volumes. Similar definition of a bicycle path is described in the Swedish GCM handbook, with the difference that the pedestrians are usually on the same path and only separated with a painted line from the cyclists (Sveriges Kommuner och Landsting & Trafikverket, 2010). Two-way bicycle paths are typically chosen for rural areas and when connecting districts, where the frequency of junctions is kept to a minimum and bicycle traffic is relatively low. Inevitably, on two-way paths where cyclists approach each other, collision is at stake and it is therefore essential to maintain high design standards regarding width and markings.

3.1.2 Bicycle lane

Bicycle lane is a lane with surface markings showing where the cyclists should ride, located on a carriageway with vehicle speeds ≤80 km/h (Trafikverket, 2015a). However, bicycle lanes are mostly used when the traffic speed is 40-50 km/h (Sveriges Kommuner och Landsting & Trafikverket, 2010). They are separated from the carriageway with a painted line and/or a different coloured surface. Bicycle lanes are generally intended for bicycle traffic in one direction, with a bicycle lane on each side of the carriageway. Bicycle lanes should only be used on residential streets where the flow of motorised traffic is low and the carriageway has sufficient width to safely accommodate the bicycle lane. (Sveriges Kommuner och Landsting & Trafikverket, 2014).

3.1.3 Bicycle Street

Bicycle Streets are shared-space streets in residential areas which are designated to give cyclists priority from motorised traffic and form parts of the main bicycle network or bicycle express-route. They are generally implemented in areas where traffic flows are low and space is limited. Bicycle Streets can be identified by their design and layout with signage, surface markings and speed management measures (Sveriges Kommuner och Landsting & Trafikverket, 2010).

Bicycle Street is a relatively new concept and they are rarely seen in Sweden but have been increasing in other European countries. In Gothenburg, Bicycle Streets have been implemented in several places; along Västra Hamngatan and Redbergsvägen are two examples and even more are in the planning process. The standard section used in Gothenburg is limited for one-way traffic of both cyclists and motorised traffic. (Göteborg stad, Trafikkontoret, 2017).

The Swedish GCM handbook mentions that no design standards are established yet for Bicycle Streets in Sweden, however there are recommendations on design criteria (Sveriges Kommuner och Landsting & Trafikverket, 2010). The Swedish recommendations are for most parts in line with the design standards for Bicycle Streets in the Dutch manual, *CROW*. The main outputs from the standards are that a Bicycle Street with two-directional traffic for both motorised traffic and bicycle traffic should have a minimum width of 4.5 m including 0.50-0.75 m wide border strips on both sides of the carriageway. Furthermore, no parking is allowed on the carriageway but can be accommodated along the carriageway, speed reduction measures should be in place and coating should preferable be coloured asphalt concrete. An addition on traffic speed is mentioned in the CROW manual where Bicycle Streets in rural areas can uphold maximum speeds of 60 km/h and not only 30 km/h as in urban areas (CROW, 2016).

3.2 Bicycle crossing infrastructure

Accident statistics show that great attention is required where interactions with cyclists and motorised traffic occurs (European Commission, 2016). Junctions and crossings are spots where interactions between motorised and bicycle traffic occurs, entailing a risk of collision and limiting the safety. The Dutch *CROW design manual* lists safety at junctions and crossings as one of the key factors in achieving a functional bicycle network where minimising and avoiding conflicts with crossing traffic is crucial (CROW, 2016). Introduction of uniform guidelines is essential for bicycle crossing facilities when designing a bicycle-network to minimise the confusion between cyclists and drivers (SWOV, 2010).

The following chapters will firstly define four different types of bicycle crossings according to Swedish regulations; Bicycle priority crossing, bicycle passage, signalised crossing and level separation. Secondly, a review of crossings on bicycle express-routes from international standards and guidelines will be carried out.

3.2.1 Bicycle priority crossing

A bicycle priority crossing is a place where cyclists can cross a carriageway and the motorised traffic should give way (Transportstyrelsen, 2016). The crossing must comprise transverse surface markings indicating a crossing, give-way surface markings and bicycle crossing signs, see illustration in Figure 3.1.

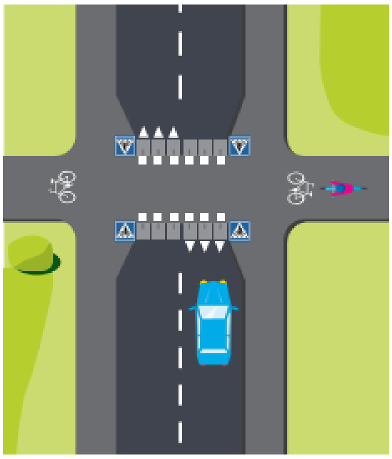

Figure 3.1 Illustration of a bicycle priority crossing in Sweden (Transportstyrelsen, 2016).

The traffic environment should be designed in a secure manner to ensure the understanding of yielding requirements. There should be sufficient distance from a bicycle crossing that is crossing a feeder road and to the main road so that one car can be stationed there. These criteria will create space and time for a turning vehicle driver to notice a cyclist crossing the road. Speed reduction measures should be in place to reduce traffic speed. Bicycle crossings should be designed in accordance with local laws and regulations.

The Swedish Traffic Law describes a bicycle crossing as:

> "*A part of a road which is intended to be used by cyclists or mopeds to cross a carriageway or bike path and is laid out with road markings and road signs. At a bicycle crossing the junction should be designed to secure a speed of vehicles to maximum 30 km/h.*" (SFS 2001:651 Vägtrafikdefinitioner)

In 2014, the Swedish traffic law changed the right-of-way so that motorised traffic should yield for bicycle traffic at crossings marked with a new sign, B8 bicycle priority crossing (see Figure 3.3a), for bicycle crossings. According to (SFS 2007:90 Vägmärkesförordning) the rules applied where the sign B8 is located are described below.

The Swedish Traffic Law states in 3 chapter 61 a § that:

> *"Motorised traffic must give way for cyclists and moped drivers which are on or just about to pass the bicycle crossing."* (SFS 1998:1276 Trafikförordning)

The Swedish Traffic Law states in 6 chapter 6 § that:

> *"Cyclists or moped drivers which are about to enter a bicycle crossing should decrease the speed and take approaching vehicles into account, and are only allowed to cross the road if it can be done without any danger. Cyclists or moped drivers which are about to enter a bicycle crossing should consider the speed and the distance to vehicles approaching the crossing."* (SFS 1998:1276 Trafikförordning)

3.2.2 Bicycle passage

A bicycle passage is a place where cyclists can cross a carriageway, but cyclists should give way for motorised traffic (Transportstyrelsen, 2016). Illustration of bicycle passages in Sweden are presented in Figure 3.2.

The Swedish Traffic Law describes a bicycle passage as:

> "*A part of a road which is intended to be used by cyclists or mopeds to cross a carriageway or bicycle path and can be laid out with road markings"* (SFS 2001:651 Vägtrafikdefinitioner)

Figure 3.2 Examples of design of bicycle passages (Transportstyrelsen, 2016).

The outdated version of bicycle crossings is now included in the definition of bicycle passages. This means that if a bicycle crossing is not a bicycle priority crossing or signalised, it is considered a bicycle passage as from the new addition of bicycle priority crossings in 2014.

There are no Swedish laws that regulate the design of a bicycle passage but they are usually identified with a simple surface marking (Sveriges Kommuner och Landsting, 2015). A bicycle passage can be unguarded or guarded. A guarded bicycle passage is either equipped with bicycle signals or a police officer controlling traffic, if none of these exists the passage is unguarded.

3.2.3 Signalised bicycle crossing

Signalised bicycle crossings are bicycle crossings or bicycle passages where traffic is controlled with signals (Trafikverket, 2015b). Same priority rules apply as for bicycle crossings and bicycle passages, using the same signs and surface markings. Bicycle signals are normally placed low for visual purposes and to avoid confusion with motorised traffic signals. To ensure short waiting times and non-stop possibilities, bicycle detection measures can be implemented. Bicycle detection can include push button by signal or a detection device earlier on the path such as green wave.

3.2.4 Level separation at crossings

Level separation at crossings is usually achieved with implementing an underpass or an overpass. The purpose of level separation measures is to ensure safety at crossings where traffic is high and/or fast. However, level-separation is not always a recommended solution since implementation costs are high and they are not particularly space efficient. To increase the safety and security at level separation infrastructures, specific measures need to be in place such as additional lighting, drainage and comfortable inclination when approaching/leaving the crossing (Sveriges Kommuner och Landsting & Trafikverket, 2010).

3.2.5 Crossings on bicycle express-routes

Among measures to obtain a safe bicycle crossing, the Dutch *CROW design manual* suggests that bicycle express-routes along main carriageway, crossing a feeder road, should be placed 2-5 m away from the main carriageway. On streets with low traffic flow and low speed limit, a speed bump is recommended since it will reduce the speed of approaching traffic, resulting in lower collision risk for cyclists. Minimum standards state that at crossings where traffic speed is more than 50 km/h or if the Passenger Car Unit (PCU) exceeds 500 PCU per day, there should be level-separated bicycle facilities. Furthermore, adequate sight of all traffic should be ensured when approaching crossings and motorised traffic should always give-way for cyclists on the bicycle express-route (CROW, 2016).

In the Norwegian *Sykkelhåndboka V122*, it is recommended that the number of junctions with motorised traffic on bicycle express-routes should be kept at an absolute minimum. Furthermore, crossings between motorised and bicycle traffic should be either level-separated or cyclist should have priority (Statens vegvesen, 2014a). A report done on bicycle express-routes in Norway suggests measures should be implemented, on large signalized junctions, in order to ensure safety and minimise the waiting time for cyclists. The measures include green waves, green time extensions, signs warning the motorised traffic about cyclists in the junction and other standard bicycle signals (Sørensen, 2012).

Design guidelines in United Kingdom, *London Cycling Design Standards* (TfL, 2014) and *Cycle Infrastructure Design manual* (Department for Transport, 2008), state that bicycle priority crossings should be applied where appropriate and possible. Furthermore, bicycle priority crossings should only be applied where there are road bumps or raised crossings and the path coloured with high skid-resistance surfacing together with appropriate markings to enhance the driver´s awareness Additionally, multiple design speed reduction measures at bicycle priority crossings are suggested, for instance, raised crossings, entry treatments and reduction of corner radius. At T-junctions, a 5m setback from the main carriageway should be in place for two-way bicycle paths and appropriate signs to indicate cyclists´ priority (TfL, 2014).

The Danish *Håndbog om Supercykelstier* states for bicycle express-routes that new development of solutions is required at bicycle crossings to maintain safety and accessibility. Similar to the Norwegian suggestions, level-separation at crossings is always recommended if possible and if not, crossings should be designed with priority for cyclists. Level-separating infrastructure is typically expensive and is therefore important to account for in the design process of new bicycle infrastructure. For bicycle priority crossings, special focus should be made on distinct and understandable signage and markings as well as sufficient sight for both cyclists and motorised traffic. In cases where sufficient traffic volume and speed reduction is not possible, the cyclists must give-way to drivers to ensure safety. Further, it is stated that another solution for bicycle crossings on bicycle express-routes, where bicycle priority is not possible, is signalised crossings. Different measures to ensure minimum waiting time include green waves, guiding light in the asphalt surface or dynamic tables along the path showing the required speed in order to minimise number of stops. Furthermore, comfort measures at stopping areas such as footrests, shelters or information boards on remaining waiting time can be applied to add the cyclist´s experience of high quality (Vejregler, 2016).

3.3 Markings

Establishing rules for bicycle paths ensures consistency in design and municipalities do not need to integrate different design manuals for themselves. Markings on bicycle paths, such as bicycle express-routes, should be applied according to the country´s law. Swedish law for markings and signs on bicycle paths are as follows:

According to 4 chapter 8 § the transverse marking M16 for bicycle passage or bicycle crossing, should be used as follows:

> *"The marking indicates a bicycle passage or a bicycle crossing, where the sign B8 for bicycle priority crossing is installed. If the marking designates a bicycle priority crossing, it should be combined with the marking M14 for give-way."*(SFS 2007:90 Vägmärkesförordning)

In 2 chapter 10 § the following signs are described; D4 bicycle path, D6 pedestrian and bicycle path, D7 pedestrian and bicycle paths separated (SFS 2007:90 Vägmärkesförordning). The sign D4 marks a bicycle path designated for cyclists and moped drivers class II, whereas D6 indicates a shared path for pedestrians, cyclists and moped class II. D7 also indicates a shared path, but cyclists and pedestrians are separated with a straight line marked on the surface. For all three signs a supplementary sign could be added to exclude the moped class II drivers from the path. In Figure 3.3 the described signs and markings used in Sweden are presented.

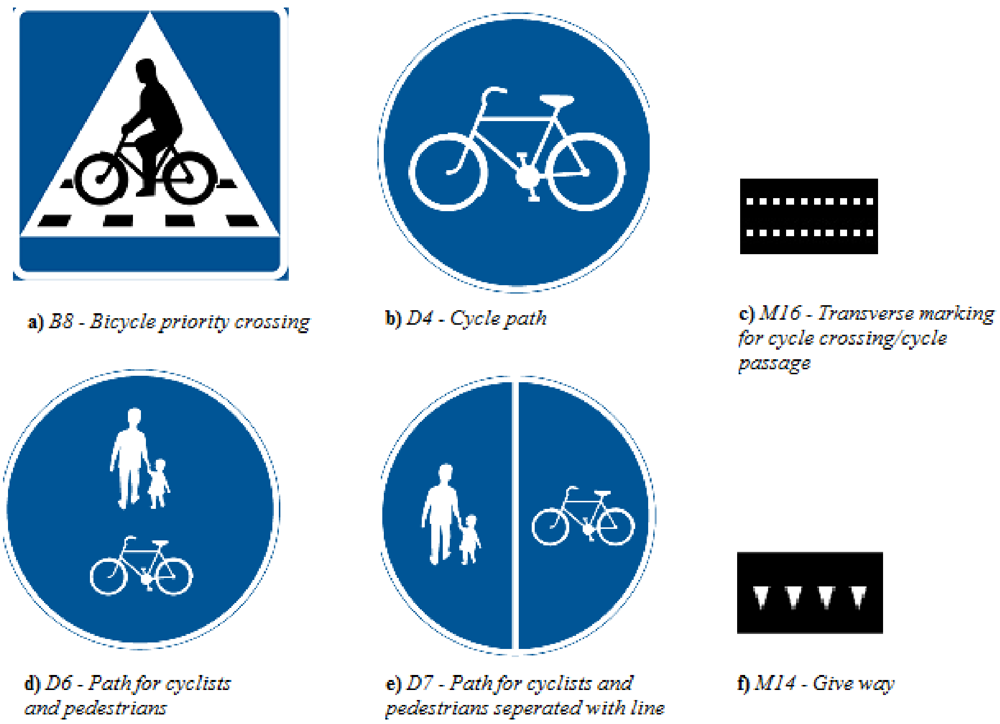

Figure 3.3 Signs and markings for cyclists in Sweden (Transportstyrelsen, 2017)

Many of the existing bicycle express-routes in other countries have some sort of identity which make them distinct from other routes such as a common logotype or symbol, special road markings or signs or a chosen colour scheme for the route (Sørensen, 2012). Markings include signs, surface markings and coloured surfacing that should provide information on using the bicycle path as well as providing cyclists with additional security.

Signs
Signs are important to indicate rules on the bicycle paths, who is allowed on the paths and to support wayfinding. Common signs associated with bicycle paths are a bicycle symbol, cycling times indication, route number and any branding or colour associated with bicycle routes (TfL, 2014). In Figure 3.4, different logotypes used for bicycle express-routes are presented used to underline the routes identity. Local and long-distance bicycle signage assists in linking different bicycle facilities and it is therefore essential that signs are uniformly designed to keep the path users well informed (CROW, 2016).

Figure 3.4 Identity logo signs for bicycle express-routes in the Denmark, Netherlands, UK and Germany. (Supercykelstier, 2016a), (Region of Twente & Goudappel Coffeng, 2009), (Sørensen, 2012), (Ruhr Regional Association, 2014)

Surface Markings
Surface markings are regulatory markings used to control traffic and provide directional information for cyclists. Therefore, it is important for road markings to be well situated, recognizable and visible (CROW, 2016). Bicycle path surface markings can be classified into lane markings, give-way markings and symbol- and direction markings. Bicycle symbols (pictograms) should be provided with a directional arrow at the start of the path and then at each decision point after that; at crossings, underpasses, overpass and after each distraction node on path. In the Netherlands, edge markings in the form of white lines were introduced in 2015 as standards on bicycle paths in rural areas. By applying edge markings on bicycle paths, more contrast to the path will be added, resulting in enhanced visibility in darker conditions (CROW, 2016).

Coloured surface
Coloured surfacing is widely used for bicycle-specific infrastructure such as bicycle express-routes. In most countries, surface colouring has no legal meaning but is used as an identification tool for safety purposes especially where motorised traffic meets bicycle traffic. In London, a blue identification colour is used for the Barclays Cycle Superhighway. On large sections of the path it is used to cover the entire surface but in areas where that is not required it is used selectively to emphasise road markings like the bicycle symbol (TfL, 2014). Authorities in the Netherlands typically identify their bicycle express-routes with a reddish colour throughout the entire bicycle path along carriageways. A fully coated coloured surface is most relevant when bicycle paths are close to motorised traffic and/or at crossings but is less relevant in the case of separated bicycle paths with few crossings (CROW, 2016). Another solution for colour surface identification is to go by the Danish initiative and have a 30 cm wide coloured stripe marking the bicycle path as a bicycle express-route and making the path less expensive but still maintaining a distinguished identity (Sørensen, 2012). Three different executions of coloured surfaces are demonstrated in Figure 3.5.

Figure 3.5 Examples of different executions of coloured surface. (Bicycle Dutch, 2015), (London Cyclist, 2011), (Sørensen, 2012)

3.4 Travel speed

Norway, Denmark and the Netherlands have established speed design standards for bicycle express-routes. However, Sweden, Germany and United Kingdom only have design speed standards for bicycle commuter routes in cities. The following design speeds for the 6 countries are presented in Table 3.1.

Table 3.1 Suggested maximum travel speeds for commuter routes/ bicycle express-routes for the reviewed countries (Sveriges Kommuner och Landsting & Trafikverket, 2010), (Department for Transport, 2008), (Statens vegvesen, 2014a), (Vejregler, 2016), (FGSV, 2016), (CROW, 2016).

Country	**Sweden**	**United Kingdom**	**Norway**	**Denmark**	**Germany**	**The Netherlands**
Design speed [km/h]	30 km/h	32 km/h	40 km/h	35 km/h	40 km/h	Urban area: 30 km/h Rural area: 40 km/h

3.5 Lighting

The studied manuals all state the importance of illuminating the bicycle path and its surroundings to maintain high security and safety. The main selections on lighting from the different manuals are presented in Table 3.2.

Table 3.2 Lighting requirements from the studied manuals for 6 different countries.

Country	**Lighting requirements**
Sweden	It is stated that the lighting should be designed for the environment with the requirements of security, availability and energy efficiency. Different lighting classes are described depending on different traffic volumes and visibility. Recommended distance between light posts varies between 30-40 m, depending on different factors such as lighting class and light post type (Vägverket, 2004). Special attention should be given to lighting at obstacle areas such as crossings, underpasses, stairs, bus stops, and direction change of path. Furthermore, light posts should be located 0.3 m from the actual path (Trafikverket, 2015a).

United Kingdom	In order to maintain safety, lighting should always be provided on separated bicycle paths. However, designers should consider the electricity source, energy use and light pollution (Department for Transport, 2008).
Norway	Lighting on bicycle paths should be chosen according to bicycle traffic where low and medium traffic should use a different lighting class than in areas with heavy traffic. Special illumination should be at underpasses, junctions and overpasses (Statens vegvesen, 2014a).
Denmark	Good lighting improves accessibility, safety and security, where cyclists can orientate themselves sufficiently by having vision of the path and its surroundings. Emphasis should be taken on lighting at junctions, crossings, underpasses and overpasses. An overall lighting plan for the designed bicycle express-route should be available (Vejregler, 2016).
Germany	Special emphasis is made on lighting as a tool to increase the cyclist´s security. Locations considered to need extra illumination such as; narrow spots, obstacles on path, junctions and underpasses should be secured with lighting. Recommended dimensions of the light posts are 4-5 m high and a 3-5 lux horizontal light beam. These dimensions will provide approximately 30-40 m lighting sight (FGSV, 2010).
The Netherlands	Lighting is always recommended on high-quality bicycle routes used as connections between villages, towns, neighbourhoods and districts. Particularly since it is proven that a higher design speed requires a longer sight distance. Recommended distance between lamp posts to secure sufficient uniform lighting is 30 m. It is mentioned that for bicycle paths in rural areas, it is not always desirable to have lighting permanently on full power especially during evenings and night. Consequently, dynamic lighting is recommended in rural areas where the level of lighting is adaptable depending on presence or absence of cyclists on the path (CROW, 2016).

3.6 Width

The design targets for width are presented in Table 3.3. Width design standards for bicycle express-routes only exist for United Kingdom, Denmark and the Netherlands. Therefore, width standards for two-way bicycle paths intended for commuting were revised for Sweden, Norway and Germany.

Table 3.3 Width standards for two-way bicycle path/bicycle express-route for the reviewed countries (Trafikverket, 2015a), (Trafikverket, 2015b), (TfL, 2014), (Statens vegvesen, 2014b), (Vejregler, 2016), (FGSV, 2010), (CROW, 2016).

Country	**Sweden**	**United Kingdom**	**Norway**	**Denmark**	**Germany**	**The Netherlands**
Minimum width [m]	2.5-3.0	3	2.5-3.5	3-4	3	4

Other literature than the design manuals state different recommendations for bicycle express-route widths. A feasibility study carried out in Germany states that for a two-way bicycle express-route, the recommended width is 4 m (Ruhr Regional Association, 2014). Furthermore, a study performed by Sørensen (2012) suggests that the minimum width for a two-way bicycle express-route in Norway should be 4 m.

3.7 Horizontal curve radius

The requirements for minimum horizontal curve radius vary between the countries studied. The minimum horizontal curve radius depends on the design speed, since higher speeds require larger curves to minimize the risk of accidents. In Table 3.4 the design speed with the corresponding minimum horizontal curve radius for each country are presented. For Denmark and the design speed recommended in rural areas in the Netherlands, no requirements for horizontal curve radius were found in the design manuals.

Table 3.4 Summary of horizontal curve radius design standards for the reviewed countries (Trafikverket, 2015a), (Department for Transport, 2008), (Statens vegvesen, 2014b), (FGSV, 2010), (CROW, 2016).

Country	Sweden	United Kingdom	Norway	Denmark	Germany	The Netherlands
Design speed [km/h]	30	32	40	35	40	Urban area: 30 Rural area: 40
Minimum curve radius [m]	30	25	40	-	30	Urban area: 20 Rural area: -

3.8 Gradient

The design standards for a bicycle path´s gradient is expressed in percentage and described in relation to either height difference or length of the slope. The Swedish and the Dutch manuals express their gradient in relation to the paths height difference but the remaining countries express the gradient in relation to the length of the slope. The 6 countries have different requirements on acceptable gradient and a summary is provided in Table 3.5.

Table 3.5 Summary of gradient design standard for the reviewed countries (Trafikverket, 2015a), (Department for Transport, 2008), (Statens vegvesen, 2014b), (Celis Consult, 2014), (FGSV, 2010), (CROW, 2016).

Country	Gradient	
Sweden	**Difference in height [m]**	**Maximum gradient [%]**
	< 1 m	7 %
	1-2 m	6 %
	2-4 m	4 %
	4-6 m	3 %
	6-8 m	2.5 %
	8-10 m	2 %
United Kingdom	**Length of slope [m]**	**Maximum gradient [%]**
	< 30 m	7 %
	30-100 m	5 %
	> 100 m	3 %
Norway	**Length of slope [m]**	**Maximum gradient [%]**
	< 3 m	8 %
	3-35 m	8 %
	35-100 m	7 %
	> 100 m	5 %
Denmark	**Length of slope [m]**	**Maximum gradient [%]**
	50 m	5 %
	100 m	4.5 %
	200 m	4.0 %
	300 m	3.5 %
	> 500 m	3.0 %
Germany	**Length of slope [m]**	**Maximum gradient [%]**
	20 m	10 %
	65 m	6 %
	120 m	5 %
	250 m	4 %
	> 250 m	3 %

The Netherlands	Difference in height [m]	Maximum gradient [%]	Target gradient [%]
	< 1 m	10 %	7.5 %
	1-2 m	10 %	5.75 %
	2-4 m	7 %	3 %
	4-6 m	4 %	2 %
	6-8 m	3 %	1.75 %
	8-10 m	2.5 %	1.75 %

3.9 Crossfall

Crossfall is the horizontal gradient of a path that is required to obtain sufficient drainage. The requirements for crossfall varies somewhat between the reviewed countries as can be seen in Table 3.6. The Dutch design manual states that the drainage should be sufficient using crossfall, however no limits are given (CROW, 2016).

Table 3.6 Summary of minimum and maximum crossfall for the reviewed countries (Trafikverket, 2015a), (Department for Transport, 2008), (Statens vegvesen, 2014a), (Celis Consult, 2014), (FGSV, 2010).

Country	Sweden	United Kingdom	Norway	Denmark	Germany	The Netherlands
Crossfall [%]	0.5-2.5	1-2.5	2-3	2-4	2.5-4	-

3.10 Surface material

Design recommendations for type of surface material are presented separately for each country in Table 3.7 based on the different design manuals.

Table 3.7 Recommended surface material according to design manuals.

Country	Surface material
Sweden	The surface area for bicycle infrastructure should be even, firm and non-skid for the cyclists´ safety (Trafikverket, 2015a).
United Kingdom	The recommendation is to use asphalt concrete as surface material (Department for Transport, 2008).
Norway	Recommends coating to be of good quality, firm and smooth (Statens vegvesen, 2014a).
Denmark	The coating should be firm, smooth and have sufficient friction. The recommendation is to use asphalt concrete as surface material, since

	experience indicate that it gives the best result in terms of smoothness (Vejregler, 2016).
Germany	The surface should be smooth with minimum rolling resistance. It should have good grip even in wet conditions. It should be suitable in all weather, i.e. have good dewatering properties to prevent puddling and dirt-spraying and it should prevent from dust formation during dry conditions. All the requirements are met with the usage of a surface layer made of asphalt concrete which is distributed by a paver to achieve a smooth surface (FGSV, 2010).
The Netherlands	Requirements for skid resistance and evenness of the surface material is necessary. The recommendation is to use asphalt concrete or continuous concrete (CROW, 2016).

Dense asphalt concrete (AC)
One example of surface coating which is suitable for bicycle express-routes is dense graded asphalt concrete (AC). Dense graded asphalt concrete (AC) is a mix consisting of mineral aggregates and bituminous binder and is produced at temperatures over 120 °C (Parhamifar, 2016). The aggregates in the mix have a continuous gradation to make the asphalt dense. The material gives good stability, small friction and relatively good abrasion resistance, i.e. resistance for wearing due to friction.

4 Suggested Design Guidelines for Bicycle express-routes

Based on findings in Chapter 2 and 3, suggestions of design guidelines for bicycle express-routes were made. The suggestions are intended for Swedish design and were evaluated with international standards, Swedish regulations and similar practices in other European countries, as guidelines. Each suggestion for the design parameters are discussed and argued for in the following text and then summarised in a table.

Types of bicycle infrastructure

Separated bicycle paths are chosen to maintain safety, prevent interaction with motorised traffic and pedestrians and to uphold fast travel speed. Separate bicycle paths for bicycle express-routes are ideally fully separated from pedestrians and motorised traffic and are only intended for bicycle users. However, conditions do not always allow fully separate paths and coordination with other types of traffic need to be present. In those cases, separation measures need to be implemented with clear distinction between the different user facilities. However, it is important that these measures do not influence the travel speed of the cyclist or decrease the value of the bicycle express-route. Examples of coordination with motorised traffic are bicycle lanes which should typically be used in built-up areas. Bicycle Streets are recommended in low traffic residential areas. Rules for implementing Bicycle Streets do not exist in Swedish law, however they are widely used internationally and they have been introduced as a part of bicycle express-routes, for example in the Netherlands. In recent years, Gothenburg has implemented several one-way Bicycle Streets in the city centre (*cykelfartsgata*) and more are expected to be implemented, so users should become familiar with the concept. Shared paths with pedestrian should be kept at minimum but is inevitable at some sections. In those cases, it is important to keep the sections short and to implement relevant information signage in order to make all users aware of the shared space.

Two-way bicycle paths are suitable where traffic flows are low to medium but one-way bicycle paths are a better choice in built up areas and in city centres where traffic flows are high. Copenhagen and London have implemented one-way bicycle express-routes aligned along motorized vehicle roads where bicycle traffic is high in the city centres. Nevertheless, bicycle express-routes intended for commuting between municipalities or neighbourhoods are generally designed as two-way bicycle paths as in the Netherlands, Germany and Norway. In Gothenburg, two-way bicycle paths are more commonly used than one-way paths. The alignment of the bicycle express-route should be through attractive areas where wind and noise protection is taken into consideration.

Crossings

One of the main characteristics of bicycle express-routes is to be able to commute fast without delays. Subsequently, stops should be avoided for cyclists at crossings and they should have priority to minimise delay. To obtain safety at bicycle priority crossings, signage and markings need to be correct and visible for all road-users. Furthermore, good visibility for cyclists and motorised traffic at crossings is crucial so that they can be aware of the upcoming situation and prevent collisions. A bicycle crossing that is crossing a feeder road should be far enough from the main road so that at least one car can be stationed there. Accident statistics show that most bicycle accidents are single accidents. However, data shows that accidents involving motorised vehicles are more likely to result in severe or fatal injuries and therefore it is essential to keep the motorised traffic speed low (Kröyer, 2015). Where it is not possible to have bicycle priority crossings, different measures need to be taken, for instance level-separation or signalised crossings. Comfort measures at crossings will add value to the cyclist´s experience of the bicycle express-route where delay can occur.

Markings

Use of signage and surface markings on bicycle express-routes depends on local regulations. Therefore, Swedish regulations were examined to determine the appropriate signage and surface markings. Informative markings and signage on the bicycle express-route improves the quality of the route and adds value for the users. Fully coloured surface coating should be applied in built-up areas and at crossings to enhance the identity and visibility of the bicycle express-route. In rural areas, fully coloured surface is not required. In rural areas, edge marking in the bicycle express-route´s identity colour is suggested along the path as well as coloured surface behind the route´s pictogram at regular intervals. A common identification logotype for each bicycle express-route should be designed with a certain colour scheme. Special emphasis should be made on making the markings as uniform as possible throughout different municipalities.

Travel speed

Bicycle express-routes are intended for fast cycling and therefore the design speed should be high. It is likely that additional faster bicycle types other than the conventional bicycle, such as electrical bikes and mopeds, will become more prevalent in the future of bicycle culture and therefore higher speeds will occur on the bicycle express-routes. However, very high design speed is not reasonable in urban areas since the bicycle express-route is more likely to be exposed to disturbances from pedestrians and slow cyclists. According to literature, the design speeds from the examined countries varies from 30 km/h to 40 km/h for bicycle express-routes. Therefore, two distinctive design speeds are suggested for urban and rural areas respectively.

It is important to mention that the design speeds above are not representing the actual journey speed of the route. The actual journey speed is practically always lower than the design speed since it is highly affected by the number of stops and delays along the route. Limiting stops, by for example giving priority at crossings, will increase the actual journey speed.

Lighting

It has been proven that higher speeds require greater sight distance. Hence, there should be sufficient lighting throughout the route. A bicycle path and its nearest surroundings which are fully illuminated will enhance the route´s attractiveness. In addition, the cyclist´s security is enhanced, making the use of the route at any time of the day and year possible. The Swedish suggestions state that light posts should be located 0.3 m from the bicycle path to ensure enough space so that the lighting posts do not disturb the users. As mentioned in literature, light posts are typically located at 30-40 m intervals but that depends on lighting class and type of lighting. For a bicycle express-route to be environmental and bicycle friendly, new lighting solutions can substitute the typical light posts. Solutions involving dynamic lighting have been shown to be effective where the level of lighting is adaptable to the presence of cyclists on the path.

Width

The bicycle path´s width should be sufficient to ensure safe over-taking and safe encounter with oncoming traffic. The width requirements are chosen with respect to all the reviewed countries´ design standards and the bicycle express-routes already built internationally. Since these guidelines are suggested for Sweden, it is important to take into account the suggested design for the planned bicycle express-route Malmö-Lund. For rural areas, the Swedish Transport Administration suggest designing the path as a separated bicycle path and it should be marked in a way that it is intended for bicycle traffic only. However, pedestrians will also be allowed on the path and should share the space with cyclists. Our suggestion, however, is always to have the pedestrians separated from the bicycle express-route. If pedestrians are also present on the path it will slow down the speed significantly and it is also not safe since the route should be built for high bicycle speed. The chosen standard sections are similar to the ones suggested by the Swedish Transport Administration except for the separation of pedestrians from the bicycle path. Figure 4.1 illustrates the classified standard sections chosen for the suggested guidelines.

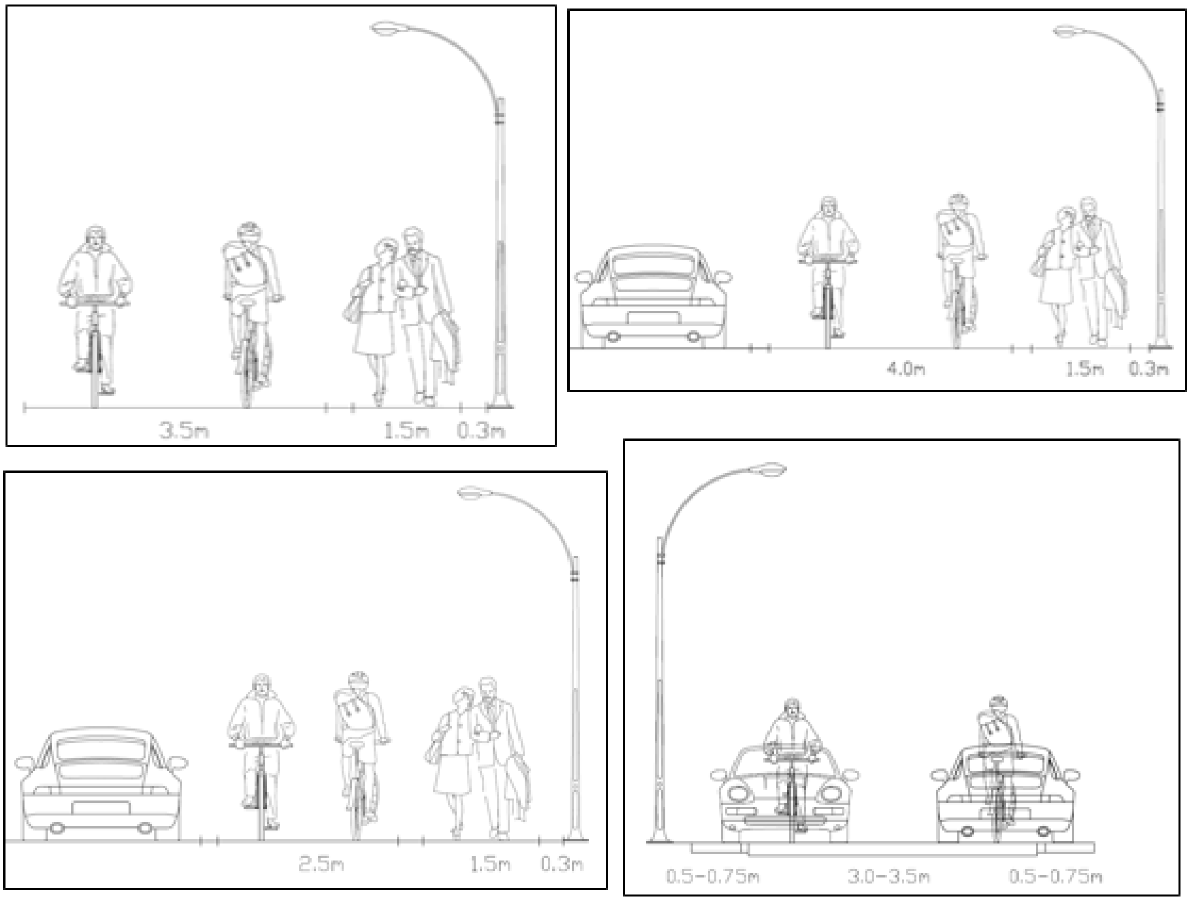

Figure 4.1 Cross-sections; upper left is section A, upper right is section B, lower left is section C and lower right is section D.

Standard section A should be used in rural areas, the width being based on examples of bicycle express-routes reviewed in the literature study. The reason standard section B for urban areas is wider is that larger traffic flow is expected and also larger likelihood of pedestrians on the bicycle path. Standard section C is to be used where there is not enough space or in another way problematic to implement the other standard sections. Standard section C is based on the minimum width for bicycle paths in Sweden. Standard section D is a Bicycle Street and should be used in residential areas with low motorised traffic where space prevents implementation of a separated bicycle path.

Horizontal curve radius

The requirements for horizontal curve radius vary between the reviewed guidelines presented in previous chapter. For a design speed of 30 km/h the minimum horizontal curve radius varies between 20 to 30 m, whereas it varies between 30 to 40 m for a design speed of 40 km/h. A reasonable option is to go with Sweden´s requirements, 30 m for 30 km/h. The lower limit for a path with design speed 40 km/h should then reasonably be 40 m. Another motivation to use the higher values as lower limits is that the minimum curve radius stated in the reviewed standards are for standard bicycle paths and not for bicycle express-routes, meaning the curve should be wider to uphold a high-quality standard. Since more and more electrical bikes are used and even faster electrical bikes with speed up to 45 km/h are expected to become more popular, this should be considered when designing a bicycle express-route.

Gradient

The target is to have as little inclination as possible to provide the cyclist with an effortless bicycle route for commuting purposes. The gradient span gathered from manuals from the reviewed countries is between 3 and 10 %. It is crucial to keep the gradients low in order to make the bicycle express-route user-friendly and attractive. Therefore, 5 % seems a reasonable limit. Both the Netherlands and Denmark have rather low limits for gradients, but considering the typology of the landscape, Sweden has more hills and the lowest limits are not reasonable in the context. Due to unavoidable hills or steep gradients at for instance over and underpasses, a steeper gradient is accepted on short distances. The route should be possible to bicycle without too much effort, which in terms of inclination means that the slopes should not be too steep and not too long.

Crossfall

The requirements for crossfall varies between 0.5 and 4 % over the different design manuals. The crossfall should be large enough to ensure good drainage. If it is in a slope it is the resulting fall of both cross and length that should be big enough to lead water away from the path. The suggested limits are in the higher span since the required crossfall should uphold good drainage at all times.

Surface material

All of the reviewed countries recommend either asphalt concrete or continuous concrete as surface material for bicycle express-routes. In Sweden, asphalt concrete, gravel and paving stone are the primarily surface materials used for roads. Gravel does not fulfil the comfort and safety requirements of bicycle express-routes and is not favourable for maintenance. Additionally, gravel has large friction which is not recommended for a bicycle express-route since users should be able to bicycle with little effort and still uphold a high travel speed. Furthermore, paving stone is not comfortable to bicycle on and is besides that also expensive. Hence, the coating should be made of asphalt concrete in order to achieve a good quality bicycle path.

Table 4.1 lists the suggested guidelines for bicycle express-routes in Sweden based on literature review and the reasoning above.

Table 4.1 Proposed design guidelines for bicycle express-routes in Sweden.

SUGGESTED DESIGN GUIDELINES FOR BICYCLE EXPRESS-ROUTES	
TYPE OF BICYCLE INFRASTRUCTURE	- Separated bicycle path intended solely for bicycle traffic. - Separation measures should be in place to separate pedestrians and motorised vehicles from bicycle path. - Exceptions including shared paths with pedestrians or carriageway should be kept short and well indicated that it is a shared path. - Two-way bicycle paths can be implemented both in rural areas and urban areas where bicycle traffic is relatively low. - One-way bicycle paths are suitable in urban areas and city centres where the traffic flows are very high.
CROSSINGS	- Bicycle traffic should always have priority at crossings when possible and motorised traffic should not exceed 30 km/h at those crossings. - Level separation should be implemented where bicycle priority crossings are not an option. This applies to crossings over roads with large traffic volumes and high traffic speed. - Signalised crossings should be in place if bicycle priority crossing or level separation is not an option. - Bicycle passages can be implemented if no other crossing solution is an option. - Bicycle crossing that is crossing a feeder road should be placed 5 m from the main road. - Bicycle crossings should have coloured surface.
MARKINGS	- Signs and surface markings should be implemented according to Swedish regulations on usage. - Common identity established for the bicycle express-routes: ▪ Common logotype. ▪ Surface colouring: Fully coloured surface for urban areas and coloured identity edge markings in rural areas. - Markings should be uniform throughout the entire route. - Distinguished midline, directional arrows and edge markings should be in place. - Pictograms indicating the route´s logotype should be applied on the paths surface at equal intervals as well as after each distraction.
TRAVEL SPEED	- 40 km/h design speed in rural areas. - 30 km/h design speed in urban areas. - 20 km/h actual journey speed is required.
LIGHTING	- Bicycle express-routes should always be fully illuminated, both the path and its nearest surroundings. - Light posts should be located 0.3 m from the path. - Distance between light posts should be 30-40 m. - Additional lighting should be considered at crossings, underpasses and overpasses. - Dynamic lighting is recommended in rural areas.
WIDTH	- Standard section A: minimum 3.5 m in rural areas. - Standard section B: minimum 4 m in urban areas. - Standard section C: minimum 2.5 m is recommended if the cross-sectional space is limited or if other factors make it problematic to implement section A or B. - Standard section D: Bicycle Street with minimum carriageway of 4.5 m, where 3-3.5 m is the vehicle path and 0.50-0.75 m border strips on each side of the path.

	- An illustration of the 4 different standard sections is shown in Figure 4.1.
HORIZONTAL CURVE RADIUS	- Curve radius should depend on design speed: ▪ Design speed 30 km/h -> minimum curve radius 30 m. ▪ Design speed 40 km/h -> minimum curve radius 40 m.
GRADIENT	- Inclination should generally not exceed 3 %. - Maximum inclination is 5 %. - Short distances (<100m) should never exceed 7 % incline.
CROSSFALL	- 2-4 % crossfall to ensure sufficient drainage.
SURFACE MATERIAL	- Even and firm. - Good skid-resistance even in wet conditions. - Dense asphalt concrete (AC). - Coloured asphalt concrete coating in urban areas.

5 Case Study

The suggested design guidelines listed in Chapter 4 were used as criteria for the study on a chosen route within the Gothenburg region. The case study was carried out in an area from Gamlestaden, Gothenburg, through Partille to Lerum´s new travel centre. In this chapter, the case study is described further with an overview of the studied area and a description of the route´s division into stretches. Furthermore, a description of the current situation of each stretch is presented along with proposed measures required to achieve the standards for a bicycle express-route. Lastly, a cost analysis on the suggested bicycle express-route is presented.

5.1 Studied area

Partille and Lerum are neighbouring municipalities to Gothenburg as seen in Figure 5.1. All three municipalities are within the Gothenburg region and it is common that people commute between the cities in the region. The distance between Gothenburg centre and Partille centre is roughly 10 km and further to Lerum centre is additional 12 km.

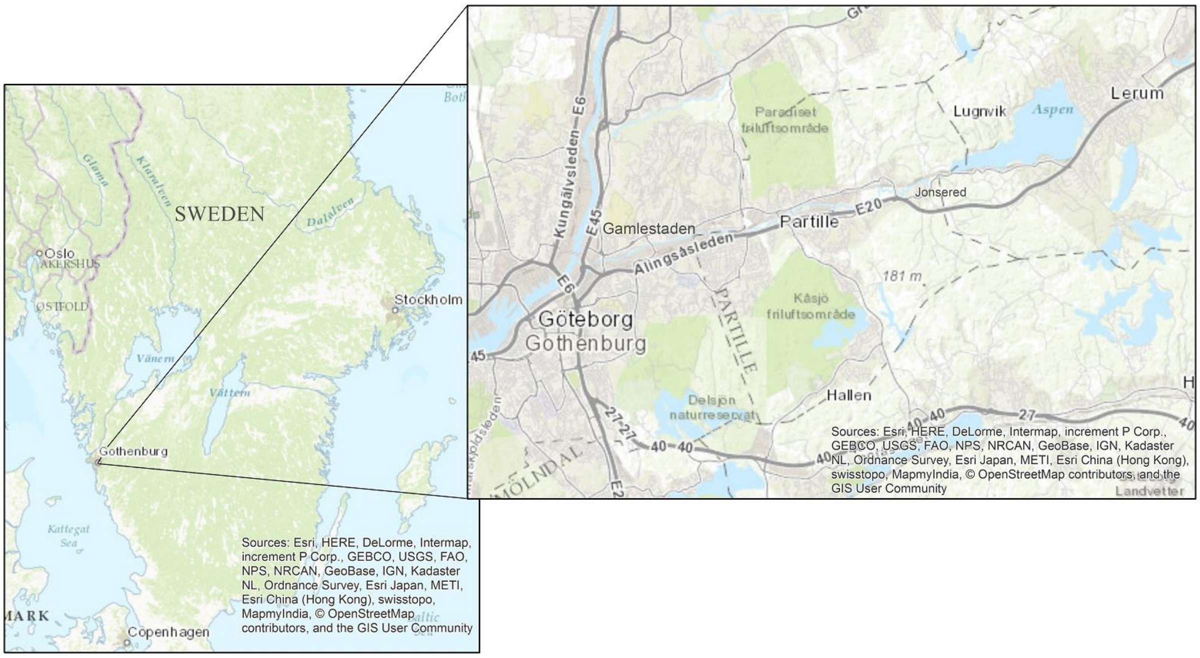

Figure 5.1 Overview map of the studied area around Gothenburg.

Region Västra Götaland (VGR) made a population prognosis for the municipalities situated in Västra Götaland stating that Gothenburg, Partille and Lerum will all have a significant population growth. Gothenburg was estimated to increase its population with 14 % from 2013 to 2025, Partille 16 % and Lerum 11 % (Althoff, 2014). By the year-end of 2016, the population was 556 640 in Gothenburg, 37 316 in Partille and 40 692 in Lerum (SCB, 2017). According to statistics from 2014 for Gothenburg municipality, approximately 110 000 people commute out of Gothenburg and 51 000 commute into Gothenburg (SCB, 2014). Around 13 600 people commute from Partille and 7 300 people commute into Partille for work (Partille kommun, 2015). In year 2014, there were 13 370 people commuting from Lerum municipality and 3 780 commuting from other municipalities to work in Lerum (SCB, 2016).

In the area Kviberg in Gothenburg, several new residential areas are planned with around 1500 residents with varying forms of ownership (Göteborg stad - Stadsbyggnadskontoret, 2015). Moreover, in the city of Partille there are around 1100 new residences planned whereof approximately 500 will be finished before year 2020 (Partille kommun, 2016b). Additionally, 1000 residences are planned to be constructed before year 2020 in the rest of the municipality of Partille.

There already exists bicycle infrastructure between the municipalities and several choices came up when searching for bicycle routes, both on Google maps and Gothenburg municipality´s bicycle travel guide. Through the physical assessment of the area early in the project phase, a choice was made of which route to investigate in more detail and which of the existing infrastructure could be used for the bicycle express-route. For instance, the assessment resulted in going along the river Säveån through most of Partille instead of along Utbyvägen and Lexbyvägen. However, in Jonsered, a section where no bicycle infrastructure is present, referred to as the "missing link", was found. In an interview with a transport planner of Lerum municipality R. Greek (1 mars 2017), she mentioned the municipality of Lerum has already made some preliminary studies on the "missing link" looking at three different options for the route´s alignment. One lies along the carriageway E20, one along Jonseredsvägen and one along the railway.

5.1.1 Start and target points

The proposition is to have Gamlestaden as a target point on the planned bicycle express-route since the municipality of Gothenburg plans to build a bicycle commuter-route between Gamlestaden and Gothenburg city centre. In an interview with a transport planner of Gothenburg municipality L-E. Lundin (3 mars 2017), he agreed with the proposition to have Gamlestaden as a target point. Additionally, a new travel centre with bus, tram and train connections is planned for Gamlestaden and it should be finished in year 2018 (Platzer Fastigheter, 2017). The target point at the other end of the route is the planned new travel centre in Lerum. Lerum´s new travel centre is expected to be finished during year 2019 (Västtrafik, n.d.). The travel centre will be located close to the old bus station and train station, with both old and new bicycle infrastructure connecting different parts of the centre (Lerum kommun, 2015). Furthermore, it is important to implement the bicycle express-route where many people have access, not only at start and end points but also along the route. In Partille, the planned route goes through the city centre with good connections to the local bicycle network and with easy access to both bus and train station. Going through Jonsered and into Lerum, the route´s alignment will be along the railway, passing both Jonsered and Aspen train station.

5.1.2 The chosen route and its division into 12 stretches

A preliminary field study was performed early to evaluate the route between Gothenburg, Partille and Lerum and to choose the most feasible route. A goal was to observe existing bicycle infrastructure and document which sections could be used for a bicycle express-route.

With the information gathered from field and map observations, the route was divided into 12 stretches, with a total length of 18 km, see Figure 5.2. The division of the route was chosen according to similar characteristics of the existing bicycle infrastructure.

1. *Gothenburg, Gamlestaden - Gothenburg, Kvibergsvägen/Kvibergs broväg (km 0/000-1/500)*
2. *Gothenburg, Kvibergsvägen/Kvibergs broväg - Gothenburg, Lemmingsgatan (km 1/500-3/000)*
3. *Gothenburg, Lemmingsgatan - Partille, Tunnel under railway (km 3/000-4/500)*
4. *Partille, Tunnel under railway - Partille, Gamla Kronvägen (km 4/500-5/500)*
5. *Partille, Gamla Kronvägen - Partille, Kung Göstas väg (km 5/500-6/000)*
6. *Partille, Kung Göstas väg - Partille, Yllegatan (km 6/000-6/800)*
7. *Partille, Yllegatan - Partille, playground area (km 6/800-7/100)*
8. *Partille, playground area - Partille, Åbrinken (km 7/100-9/200)*
9. *Partille, Åbrinken - Partille, Kåhögsvägen (km 9/200-10/000)*
10. *Partille, Kåhögsvägen - Lerum, Lake Aspen (km 10/000-11/800)*
11. *Lerum, Lake Aspen - Lerum, Aspen station "Missing Link" (km 11/800–15/300)*
12. *Lerum, Aspen station - Lerum station (km 15/300-18/000)*

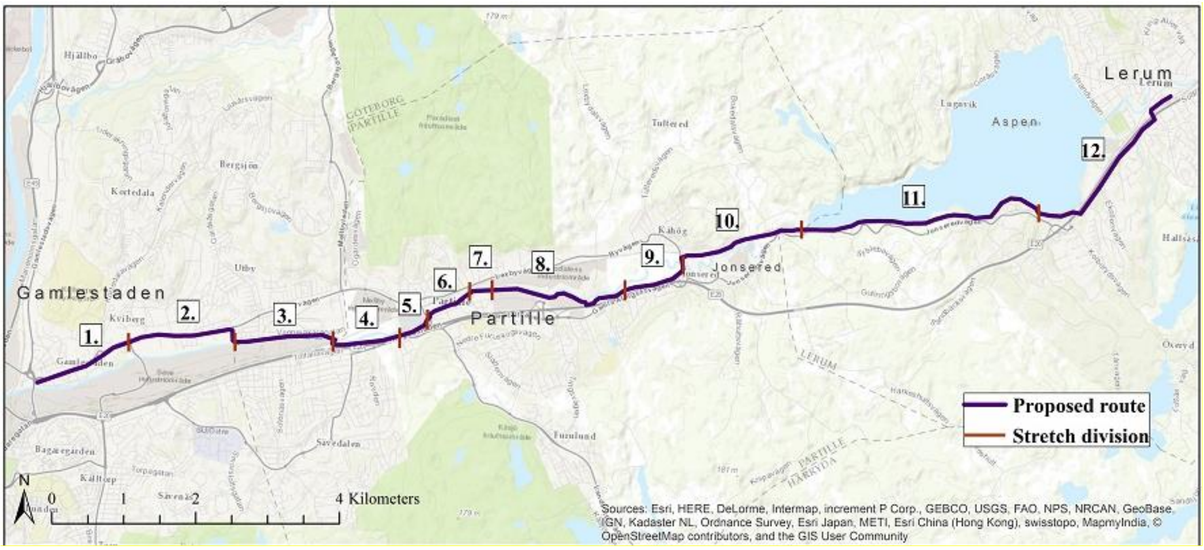

Figure 5.2 Overview of the proposed bicycle express-route and the division of the 12 stretches.

5.2 Results: Bicycle express-route from Gothenburg to Lerum

In this chapter, findings from the field study are listed for the selected bicycle route between Gothenburg, Partille and Lerum. Furthermore, suggested measures to achieve the design standards for a bicycle express-route are presented separately for each of the 12 stretches. The stretch between Jonsered and Aspen, which contains the "missing link", is presented differently than the other 11 stretches.

5.2.1 Gothenburg, Gamlestaden - Kvibergsvägen/Kvibergs broväg (km 0/000-1/500)

The stretch begins at Gamlestadstorget tram stop and ends at the crossing Kvibergsvägen/Kvibergs broväg. The existing bicycle path is two-way and separated from pedestrians with three different separation measures; raised sidewalk, separation with 15 cm of paving stone and fully separated with vegetation. The stretch is located in a residential urban area with several distractions such as pedestrians and motorised traffic. The characteristics of the path were identified during the field study and then compared with the proposed design standards, presented in Table 5.1.

Table 5.1 Summary of stretch 1.

Stretch 1 1.5 km 6 min	**Current situation**	**Required standards**	**Proposed measures**
Crossings	- 3 signalised crossings - 7 bicycle passages (3 of them are raised with speed bumps)	- Bicycle priority crossings - Level separation - Signalised crossing - Bicycle passage	- Upgrade 7 bicycle passages to bicycle priority crossings - Raise 4 crossings with a speed bump
Markings	- Midline and separation line between cyclists and pedestrians - Bicycle passage markings	- Midline and edge surface markings - Signs and markings at crossings - Surface colouring - Pictogram of logo - Identity signs	- Repainting of mid- and edge lines - Implement sign B8 and markings M16 and M14 at 7 bicycle priority crossings - Pictogram of route´s logo after each disturbance - Full surface colouring (see Surface material)
Lighting	- Appears sufficient	-	- No actions required
Width	- Path is 2.5 m wide for 1300 m - Path is 3 m wide for 200 m	- Standard section B: min width 4 m (urban) - Standard section C: min width 2.5 m (exception)	- Path requires 1.5 m widening for 1300 m
Curve radius	- No significant curve	-	- No actions required
Gradient	- No significant gradient	-	- No actions required
Surface	- Consists of asphalt concrete - Good quality for most of the stretch - OK quality at beginning of the stretch (500 m)	- Surface material should be dense asphalt concrete - The asphalt concrete should be coloured - 2-4 % crossfall for sufficient drainage	- 80 % of the stretch requires new construction including roadbed for widening (1950 m^2) - The entire stretch requires coloured asphalt concrete coating (5800 m^2)

Comments on proposed measures

The bicycle path should be designed as two-way and separated from pedestrians with separation measures. Since space was limited throughout the stretch, separation measures should include space-efficient barriers.

Three signalized bicycle crossings were present on the existing path where motorised traffic was controlled with signals at these points. These three crossings should remain signalised due to high traffic on the connecting street, Artillerigatan, and bicycle detection measures are recommended to be installed to provide the cyclist with a continuous flow throughout the crossings. Bicycle detection measures include speed detection boards to inform the cyclist what speed is required to fulfil to be able to follow the green wave. A bicycle passage was located by one of the signalised crossings, crossing the road for turning cars from Ryttmästaregatan to Artillerigatan. The bicycle passage was aligned with a pedestrian priority crossing and should be upgraded to a bicycle priority crossing with relevant signs and markings. Additionally, the 6 following bicycle passages should also be upgraded to bicycle priority crossings. Two pedestrian crossings, which were crossing the bicycle path on either side of the SKF tram stop, should be upgraded by making them more visible and make it more distinct where pedestrians should cross the bicycle path. The actual speed expected on the stretch is 15 km/h due to number of distractions along the stretch and the open possibilities of disturbance from pedestrians. A sketch of the proposed measures is presented in Figure 5.3.

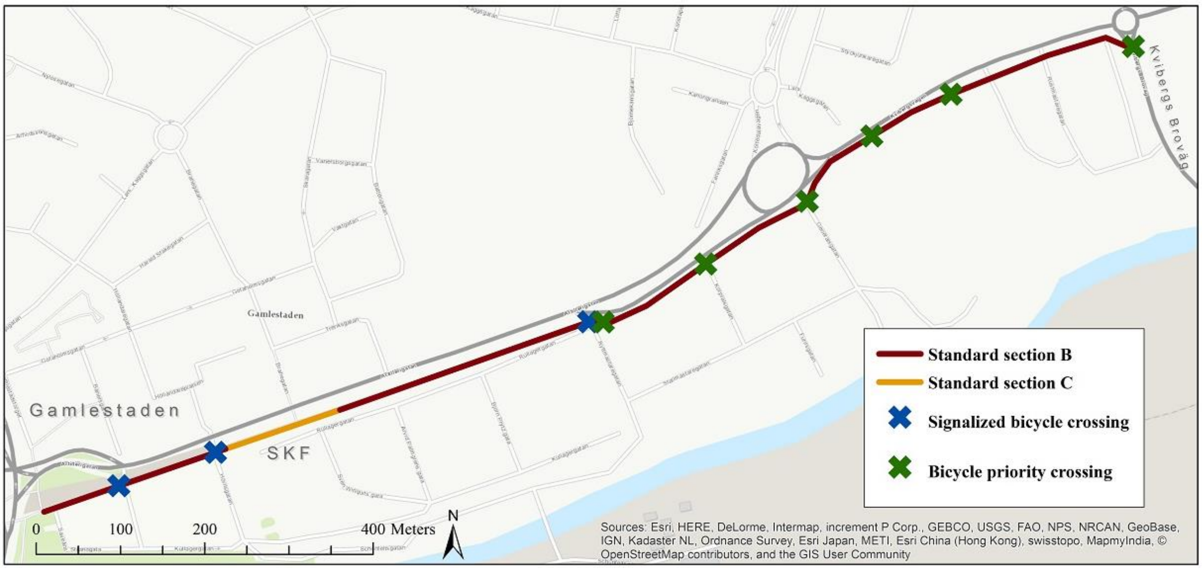

Figure 5.3 Overview of proposed measures for stretch 1.

5.2.2 Gothenburg, Kvibergsvägen/Kvibergs broväg - Gothenburg, Lemmingsgatan (km 1/500-3/000)

The stretch begins after the roundabout Kvibergsvägen/Kvibergs Broväg and ends before a bridge over Säveån at Lemmingsgatan. The existing bicycle infrastructure is a separate bicycle path, which is shared with pedestrians and without separation measures. The characteristics of the path were identified during the field study and then compared with the proposed design standards, presented in Table 5.2.

Table 5.2 Summary of stretch 2.

Stretch 2 1.5 km 4.5 min	**Current situation**	**Required standards**	**Proposed measures**
Crossings	- 5 bicycle passages (1 of them raised crossing) - 1 crossing without bicycle infrastructure	- Bicycle priority crossings - Level separation - Signalised crossing - Bicycle passage	- Change 5 bicycle passages into bicycle priority crossings - Implement 1 bicycle priority crossing at Lemmingsgatan - Raise 2 crossings with a speed bump
Markings	- No existing markings	- Midline and edge surface markings - Signs and markings at crossings - Surface colouring - Pictogram of logo - Identity signs	- Painting of mid- and edge lines. - Implement sign B8 and markings M16 and M14 at 6 bicycle priority crossings - Pictogram of route´s logo after each disturbance - Full surface colouring
Lighting	- Appears sufficient	-	- No actions required
Width	- Path is 2.3-2.8 m wide along Kvibergsvägen and Utbyvägen (1.3 km) - Path is 3.2 m wide along Lemmingsgatan (200 m)	- Standard section B: min width 4 m (urban) - Standards section C: min width 2.5 m (exception)	- Path requires on average 1.5 m of widening for 1.3 km - Path along Lemmingsgatan requires 0.8 m widening for 200 m
Curve radius	-1 curve not OK	- Minimum curve radius 30 m	-Widening of path and adjusted alignment should make the curve smoother
Gradient	- 1 slope along Lemmingsgatan is 150 m long	- Gradient should be kept under 3 % - Max inclination is 5 % - On short distances (<100m) the inclination should never exceed 7 %	- The gradient is not considered to be more than 5 %. Therefore, it does not require actions
Surface	- Consists of asphalt concrete - Poor quality for 30 % of the stretch - OK quality for 70 % of the stretch	- Surface material should be dense asphalt concrete - The asphalt concrete should be coloured	- 30 % of the stretch requires new construction including roadbed (2000 m^2) - The entire stretch requires new

Stretch 2 1.5 km 4.5 min	Current situation	Required standards	Proposed measures
	- Several potholes and cracks in the surface	- 2-4 % crossfall for sufficient drainage	construction including roadbed for widening (1360 m^2) - The entire stretch requires coloured asphalt concrete coating (6000 m^2)

Comments on proposed measures

The stretch should be designed as a two-way separated bicycle path, with a distinct barrier between cyclists and pedestrians. The cross-sectional space was limited and therefore space-efficient separation measures were recommended. There was an existing bicycle path on the north side of the road and therefore it was recommended to shift the carriageway for motorised traffic sideways up north in order to make space for the new bicycle express-route on the south side.

Currently, most of the feeder roads were connected to small residential areas or working sites and therefore the crossings consist of very low traffic. However, there are plans for constructing a new residential area along this stretch in the near future that will possibly increase traffic at several crossings (Göteborg stad - Stadsbyggnadskontoret, 2015). This new residential area is expected to attract more pedestrians and cyclists who will use the suggested infrastructure. The non-existing crossing over Lemmingsgatan should be designed as a bicycle priority crossing. The crossing should be oblique over the street to achieve a comfortable curve radius. Furthermore, speed reduction measures for motorised traffic should be implemented since speeds could be expected to be higher than regulated 30 km/h. Since the stretch is in an urban area and includes several crossings, the actual travel speed is estimated to be 20 km/h. However as mentioned, the crossings were crossing low traffic feeder roads and disturbance from pedestrians were not considered to be a problem for this stretch. A sketch of the proposed measures is presented in Figure 5.4.

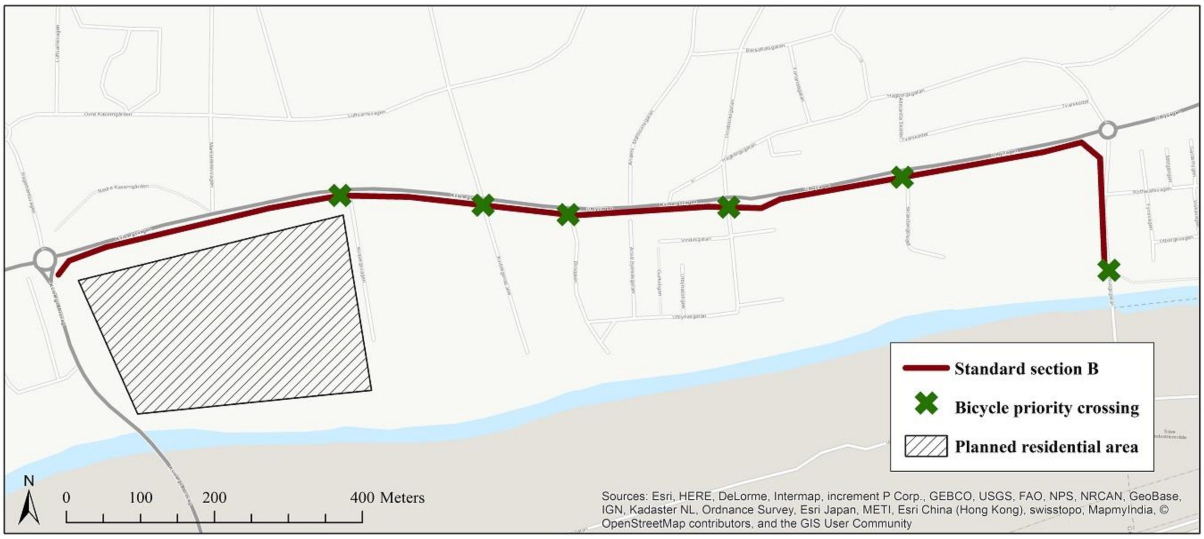

Figure 5.4 Overview of proposed measures for stretch 2.

5.2.3 Gothenburg, Lemmingsgatan - Partille, Tunnel under railway (km 3/000-4/500)

The existing path on the stretch is a two-way separated bicycle path which is shared with pedestrians and it is located along Säveån´s north side. The characteristics of the path were identified during the field study and then compared with the proposed design standards, presented in Table 5.3.

Table 5.3 Summary of stretch 3.

Stretch 3 1.5 km 4 min	**Current situation**	**Required standards**	**Proposed measures**
Crossings	- No crossings	-	- No actions required
Markings	-No existing markings	- Midline and edge surface markings - Coloured edge markings - Pictogram of logo - Identity signs	- Painting of mid- and edge lines. - Edge lines should be painted in the route´s identity colour - Pictogram of route´s logo at beginning and end of the stretch - Route identity sign
Lighting	- No existing lighting	- The path and its surroundings should be fully illuminated - Light posts should be located 0.3 m from the path at 30 m interval	- Implement 50 new light posts, preferably dynamic lighting technologies
Width	- Path is 2 m wide	- Standard section A: min width 3.5 m (rural)	- Path requires 1.5 m widening for 1500 m - 1.5 m wide pedestrian path is also required for 1500 m
Curve radius	-Small and relatively smooth curves along the stretch	- Minimum curve radius 40 m	- By widening the path, curves will mostly be eliminated. Therefore, no additional actions required
Gradient	- Hills and valleys giving a “rollercoaster feeling”. However, the inclinations are not significant and never longer than 20 m	- Gradient should be kept under 3 % - Max inclination is 5 % - On short distances (<100 m) the inclination should never exceed 7 %	- To minimise the gradients, it is recommended to remove material from hills and placing it as filling in the valleys

Stretch 3 1.5 km 4 min	Current situation	Required standards	Proposed measures
Surface	- Consists of unbound material (gravel) - Poor quality	- Surface material should be dense asphalt concrete - 2-4 % crossfall for sufficient drainage	- The entire stretch requires new construction including roadbed and asphalt concrete coating for widening and reconstruction (7000 m^2), bicycle + pedestrian path

Comments on proposed measures

The stretch should be designed as a two-way separated bicycle path, with a distinct barrier between cyclists and pedestrians. Physical separation in the shape of a width barrier in another material, for example vegetation, should be implemented.

The entire path needs to be reconstructed providing fixed gradients, sufficient width and high-quality surface material. Since the existing path was somewhat hilly, it was suggested to cut the top of the hills and use that material to fill the valleys in order to decrease the gradients. After upgrades, no distractions are anticipated on the path and high speeds should be reachable. Therefore, the expected travel speed for the stretch is 25 km/h. A sketch of the proposed measures is presented in Figure 5.5.

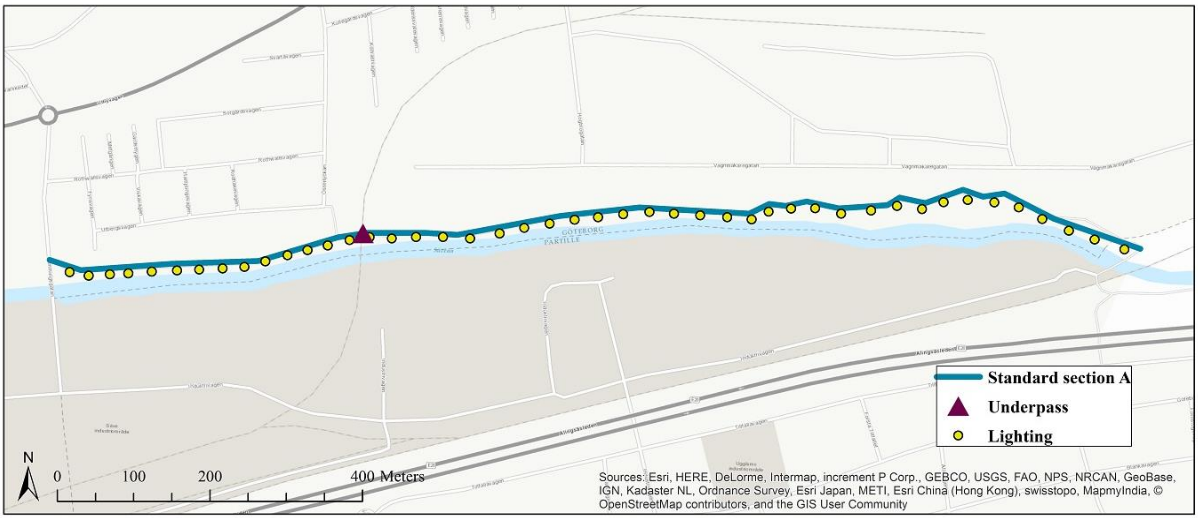

Figure 5.5 Overview of proposed measures for stretch 3.

5.2.4 Partille, Tunnel under railway - Partille, Gamla Kronvägen (km 4/500–5/500)

The stretch begins at an overpass, allowing cyclists and pedestrians to cross Säveån, and ends at Gamla Kronvägen in Partille. It is a separated two-way bicycle path which is shared with pedestrians. The stretch is parallel to E20 and is located approximately 20 m north of it. The characteristics of the path were identified during the field study and then compared with the proposed design standards, presented in Table 5.4.

Table 5.4 Summary of stretch 4.

Stretch 4 1 km 2.5 min	Current situation	Required standards	Proposed measures
Crossings	- 1 overpass, bridge over Säveån - 1 underpass, tunnel under railway	- Bicycle priority crossings - Level separation - Signalised crossing - Bicycle passage	- No actions required
Markings	- No existing markings	- Midline and edge surface markings - Coloured edge markings - Pictogram of logo - Identity signs	- Painting of mid- and edge lines - Edge lines should be painted in the route´s identity colour - Pictogram of route´s logo at beginning and end of stretch -Route identity sign
Lighting	- Lighting appears sufficient 90 % of the stretch - Last 100 m there is no lighting - No additional lighting at under- and overpasses	- The path and its surroundings should be fully illuminated - Light posts should be located 0.3 m from the path at 30 m interval	- Install 5 new light posts on a 100 m section - Install 2 new light posts at under- and overpass - Install 2 new light posts at blind spots - Preferably dynamic lighting technologies
Width	- Path is 2.5-3 m wide - Bridge is 3 m wide - Tunnel is 5.4 m wide	- Standard section A: min width 3.5 m (rural)	- Path requires on average 0.8 m of widening - Widths on bridge and tunnel will be kept the same
Curve radius	- Curve Not OK when entering the tunnel	- Minimum curve radius 40 m	- Signs and markings indicating a steep curve should be implemented
Gradient	No significant gradient	-	No actions required
Surface	- Consists of asphalt concrete - Poor quality for 90 % of the stretch - Good quality at under- and overpass (10 % of the stretch)	- Surface material should be dense asphalt concrete - 2-4 % crossfall for sufficient drainage	- 90 % of the stretch requires new construction including roadbed and asphalt concrete coating for widening and reconstruction (4050 m^2), bicycle + pedestrian path

Comments on proposed measures

The path should be designed as a two-way separated bicycle path with separation between cyclists and pedestrians. However, due to width constrains at the under and overpasses in the beginning of the stretch, separation measures between pedestrians have to be limited to a painted line or be completely shared. Following the tunnel, a 330 m section of the bicycle path should be fully separated from pedestrians since a parallel path exists approximately 8 m away which should be exclusively for pedestrians. When the two paths reunite, physical separation needs to be made, preferably with a width barrier such as vegetation.

Additional markings at under and overpasses including informative signs indicating shared space with pedestrians (sign D6) should be made along with measures that encourages the cyclists to slow down and show caution. These additional markings also contribute to reducing speeds in the narrow horizontal curve when entering the tunnel. Two maintenance houses were located beside the existing path and considered to be blind spots. To maintain high sense of security for cyclists, it is suggested that the maintenance houses are provided with additional lighting and mirrors, allowing cyclists to see around the corner. The stretch has minimal distractions and since it is in a rural area, the actual travel speed accounted for is 25 km/h. A sketch of the proposed measures is presented in Figure 5.6.

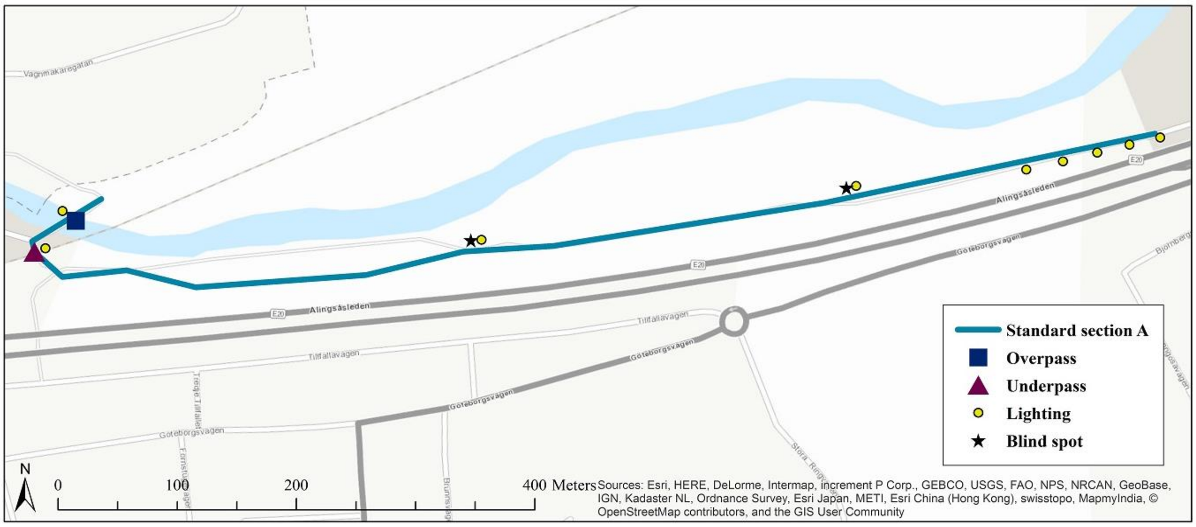

Figure 5.6 Overview of proposed measures for stretch 4.

5.2.5 Partille, Gamla Kronvägen - Partille, Kung Göstas väg (km 5/500–6/000)

The stretch is located on Gamla Kronvägen and can be divided into two sections. The first section has no existing bicycle infrastructure, and goes through an industrial area along E20 on an existing carriageway. The second section is a separated bicycle path, which is shared with pedestrians and along the carriageway. The characteristics of the stretch were identified during the field study and then compared with the proposed design standards, presented in Table 5.5.

Table 5.5 Summary of stretch 5.

Stretch 5 0.5 km 2 min	**Current situation**	**Required standards**	**Proposed measures**
Crossings	- No existing crossing infrastructure	- Bicycle priority crossings - Level separation - Signalised crossing - Bicycle passage	- No specific crossing infrastructure is required - Requires clear indications that Bicycle Street begins/ends - Insertion of 1 speed bump as speed reduction measure on section 1
Markings	- No existing markings	- Midline and edge surface markings - Coloured edge markings - Pictogram of logo - Identity signs	- Painting of mid- and edge lines - Edge lines should be painted in the route´s identity colour on section 2 - Pictogram of route´s logo on section 1 surface and beginning of section 2 -Route identity sign
Lighting	- No lighting on section 1 - Lighting appears sufficient on section 2	- The path and its surroundings should be fully illuminated - Light posts should be located 0.3 m from the path at 30 m interval	- Install 10 new light posts along section 1
Width	- Carriageway is 6.5 m wide (section 1) - Path is 2.5-3 m wide (section 2)	- Standards section C: minimum width 2.5 m (exception) - Standard section D: Bicycle Street, minimum carriageway width 4.5 m	- No widening required
Curve radius	- No significant curve	-	- No actions required
Gradient	- No significant gradient	-	- No actions required
Surface	- Consists of asphalt concrete - OK quality with bad drainage at some parts	-Surface material should be dense asphalt concrete - 2-4 % crossfall for sufficient drainage	- Section 1 requires recoating with coloured asphalt concrete (1050 m^2)

Comments on proposed measures

The first section of the stretch should be designed according to standard section D, a Bicycle Street, due to the limited cross-sectional space of 6.5 m. Speed-reducing measures need to be implemented, for example chicanes or speed bumps. The crossing at the end of this section, where there was no crossing infrastructure, requires a distinguishable indication that the Bicycle Street begins/ends and is connected to the bicycle path along the carriageway. The crossing should be designed in accordance with the design guidelines for horizontal curve radius and the surface markings should be distinct to ensure all road-users are aware of the circumstances.

The second section of the stretch should be a two-way bicycle path along the carriageway. Due to space constraints, the bicycle path must be shared with pedestrians as the space was too narrow to implement a separate pedestrian lane. However, the traffic flow of pedestrians was expected to be negligible and therefore it was considered sufficient to implement a shared space for this short section.

Speeds are not expected to be high on this section due to distractions from motorised traffic and pedestrians. Therefore, an actual travel speed for the stretch is expected to be 15 km/h. A sketch of the proposed measures for both sections is presented in Figure 5.7.

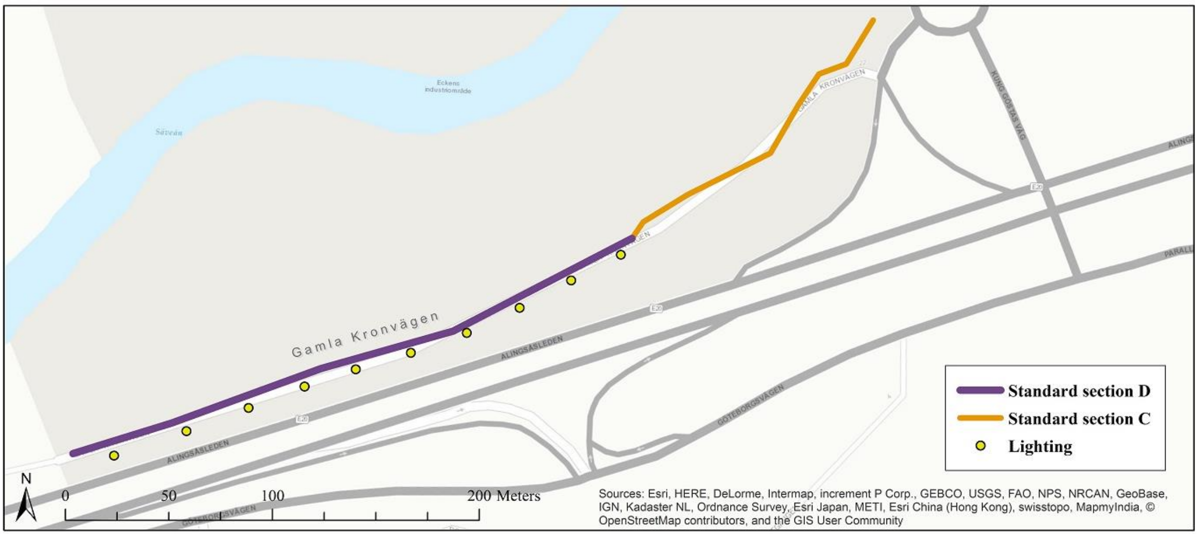

Figure 5.7 Overview of proposed measures for stretch 5.

5.2.6 Partille, Kung Göstas väg - Partille, Yllegatan (km 6/000-6/800)

The stretch begins at an existing bicycle and pedestrian path by Kung Göstas väg and ends at a junction by Yllegatan, next to a bridge for motorised traffic, cyclists and pedestrians which is currently under construction (Partille kommun, 2016a). The existing bicycle path is two-way and separated from motorised traffic but it is shared with pedestrians. The characteristics of the path were identified during the field study and then compared with the proposed design standards, presented in Table 5.6.

Table 5.6 Summary of stretch 6.

Stretch 6 0.8 km 2.5 min	Current situation	Required standards	Proposed measures
Crossings	- 1 underpass, tunnel under Kung Göstas väg - 1 crossing, crossing another bicycle and pedestrian path	- Bicycle priority crossings - Level separation - Signalised crossing - Bicycle passage	- Implement 1 bicycle passage where the path crosses another bicycle and pedestrian path
Markings	- Markings seem sufficient at the underpass and its surroundings - Route identification signs present	- Midline and edge surface markings - Signs and markings at crossings - Surface colouring - Pictogram of logo - Identity signs	- Painting of mid- and edge lines. - Implement markings M16 at bicycle passage crossing - Pictogram of route´s logo after each disturbance - Full surface colouring (see Surface material)
Lighting	- Appears sufficient	-	- No actions required
Width	- Path is 3.2 m wide - Underpass is 2.5 m wide	- Standard section B: min width 4 m (urban) - Standards section C: min width 2.5 m (exception)	- Path requires 0.8 m widening for 720 m - Underpass width will be kept the same and shared with pedestrians
Curve radius	- 2 significant curves where cyclists have to slow down	- Min curve radius 30 m	- By widening the path and changing the alignment slightly, curves will become smoother
Gradient	- No significant gradient	-	- No actions required
Surface	- Consists of asphalt concrete - OK quality	- Surface material should be dense asphalt concrete - The asphalt concrete should be coloured - 2-4 % crossfall for sufficient drainage	- 90 % of the stretch requires new construction for widening (576 m^2 of roadbed) - The entire stretch requires recoating with coloured asphalt concrete (3080 m^2)

Comments on proposed measures

The stretch should be a two-way bicycle path, fully separated from pedestrians and motorised traffic along the south side of Säveån. Pedestrians have the opportunity to choose other paths; along Gamla Kronvägen or a path at the other side of Säveån. An exception from the fully separate bicycle path should be made at the beginning of stretch where the path goes under

Kung Göstas väg in a tunnel. In the tunnel, the path should be shared with pedestrians with only a painted line as separation.

A bicycle passage should be implemented at the crossing where two bicycle paths meet beside the church of Partille. Special priority should not apply for the bicycle express-route at the passage. However, markings indicating crossing pedestrian and bicycle traffic should be in place.

Two 90 degree turns were situated beside Kung Göstas väg when joining another path. The turns need to be redesigned in accordance with the proposed design guidelines in order to uphold a sufficient flow. This could be achieved by widening the path and aligning it slightly differently. Nevertheless, it was expected that cyclists must reduce their speed to some extent at these particular turns, but they should not need to stop. The actual travel speed expected on the stretch is 20 km/h. A sketch of the proposed measures is presented in Figure 5.8.

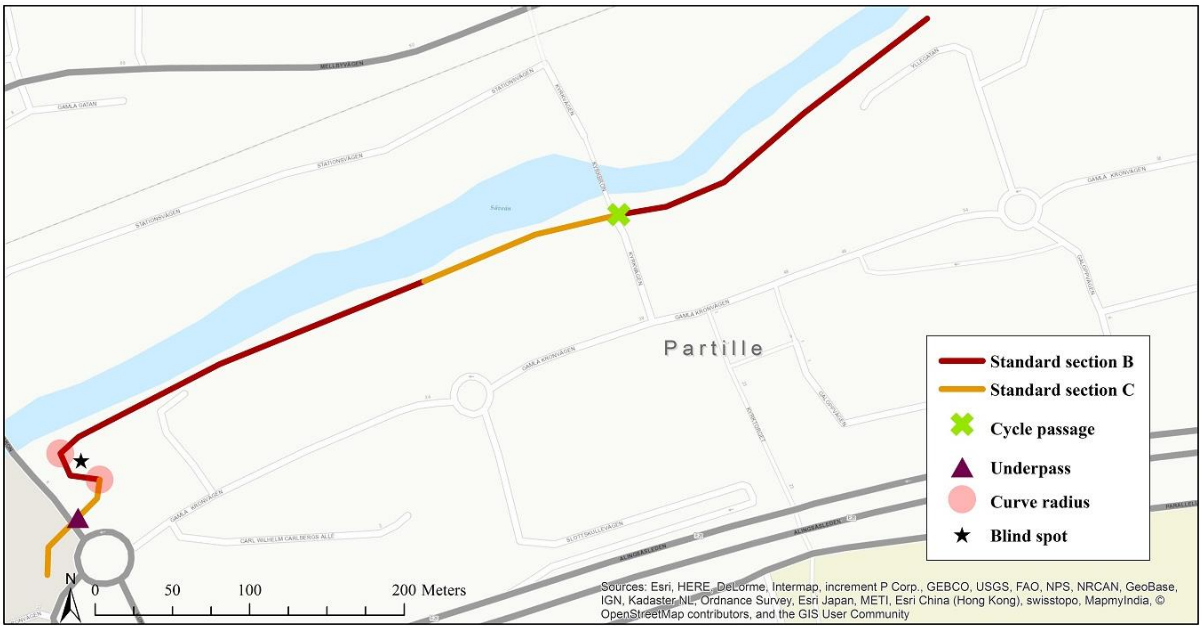

Figure 5.8 Overview of proposed measures for stretch 6.

5.2.7 Partille, Yllegatan - Partille, playground area (km 6/800–7/100)

The stretch begins where construction on a new commuter bridge is taking place by Yllegatan and ends at a pedestrian path junction. Currently, it is a separate two-way bicycle path which is shared with pedestrians and no separation measures. The characteristics of the path were identified during the field study and then compared with the proposed design standards, presented in Table 5.7.

Table 5.7 Summary of stretch 7.

Stretch 7 0.3 km 1 min	**Current situation**	**Required standards**	**Proposed measures**
Crossings	- 1 underpass, path under road bridge	- Bicycle priority crossings - Level separation - Signalised crossing	- Create 1 bicycle passage where the path crosses another bicycle and pedestrian path

Stretch 7 0.3 km 1 min	Current situation	Required standards	Proposed measures
	- 1 crossing, crossing another bicycle and pedestrian path	- Bicycle passage	
Markings	- No existing markings	- Midline and edge surface markings - Signs and markings at crossings - Surface colouring - Pictogram of logo - Identity signs	-Painting of mid- and edge lines - Put down markings M16 at bicycle passage crossing - Pictogram of route´s logo after each disturbance - Full surface colouring (see Surface material)
Lighting	- Appears sufficient	-	- No actions required
Width	- Path is 4 m wide	- Standard section B: min width 4 m (urban)	- Path requires 2.5 m widening for pedestrian path
Curve radius	- No significant curve	-	- No actions required
Gradient	- No significant gradient	-	- No actions required
Surface	- Consists of asphalt concrete - Good quality	- Surface material should be dense asphalt concrete - The asphalt concrete should be coloured - 2-4 % crossfall for sufficient drainage	- The entire stretch requires new construction including roadbed for widening (750 m^2) - The entire stretch requires coloured asphalt concrete coating (1200 m^2)

Comments on proposed measures

The path should be designed as a separated bicycle path with a distinct barrier between the bicycle and the pedestrian lane, preferably with vegetation. A bicycle passage should be implemented at the crossing where two bicycle paths meet after the playground. Special priority should not apply for the bicycle express-route at the passage. However, markings indicating crossing pedestrian and bicycle traffic should be in place. Furthermore, signs warning the cyclists about children playing was recommended since the path was located close to a playground area and the risk of them entering the bicycle path still exists even though separation measures were implemented. Due to possible distraction on the path from pedestrians along the playground area, actual travel speed is expected to be 15 km/h. A sketch of the proposed measures is presented in Figure 5.9.

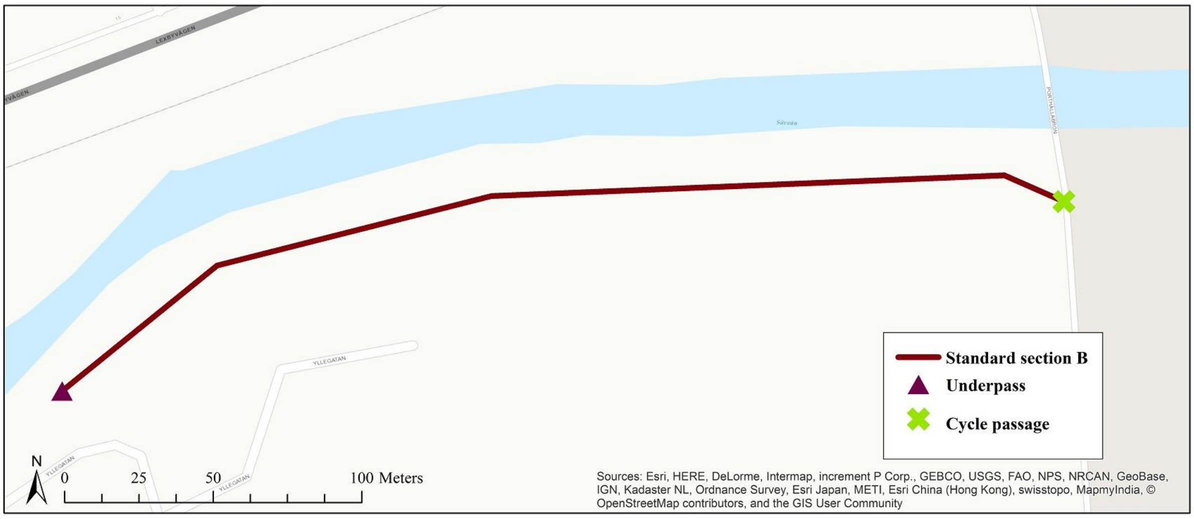

Figure 5.9 Overview of proposed measures for stretch 7.

5.2.8 Partille, playground area - Partille, Åbrinken (km 7/100-9/200)

The section begins after the playground area in central Partille and ends in a small residential area by Åbrinken. Currently, there is a separate two-way bicycle path present which is shared with pedestrians. The characteristics of the path were identified during the field study and then compared with the proposed design standards, presented in Table 5.8.

Table 5.8 Summary of stretch 8.

Stretch 8 2.1 km 5 min	Current situation	Required standards	Proposed measures
Crossings	- 1 underpass, path under road bridge	- Bicycle priority crossings - Level separation - Signalised crossing - Bicycle passage	- No actions required
Markings	- No existing markings	- Midline and edge surface markings - Coloured edge markings - Directional arrows - Pictogram of logo - Identity signs	- Painting of mid- and edge lines - Edge lines should be painted in the route´s identity colour - Pictogram of route´s logo at beginning and end of the stretch -Route identity sign
Lighting	- Appears sufficient the first 350 m of stretch - Remaining stretch consists of no lighting	- The path and its surroundings should be fully illuminated - Light posts should be located 0.3 m from the path at 30 m interval	- Implement 56 new light posts, preferably dynamic lighting technologies

Stretch 8 2.1 km 5 min	Current situation	Required standards	Proposed measures
Width	-First 350 m of path is 3 m - Remaining path is 2.7-3.2 m - Underpass is 2.6 m	- Standard section B: min width 4 m (urban) - Standard section A: min width 3.5 m (rural) - Standards section C: min width 2.5 m (exception)	- First 350 m requires 1 m widening + 1.5 m pedestrian path - The remaining path requires on average 0.6 m of widening (0.3-0.9 m) + 1.5 m pedestrian path - Width at underpass will remain the same
Curve radius	- 2 curves considered too narrow: one at a junction with a connecting path and another one 100 m before reaching Åbrinken residential area	- Minimum curve radius 40 m	- By widening the path and changing the alignment slightly at the bicycle path junction, the curve will be smoother - New proposed route alignment will eliminate the curve
Gradient	- 2 considerable inclinations: 75 and 55 m long before reaching Åbrinken residential area	- Gradient should be kept under 3 % - Max inclination is 5 % - On short distances (<100 m) the inclination should never exceed 7 %	- New proposed route´s alignment will minimise the gradients
Surface	- Consists of asphalt concrete - OK quality - First 350 m of good quality	- Surface material should be dense asphalt concrete - 2-4 % crossfall for sufficient drainage	- 1840 m of the stretch requires new construction of roadbed and asphalt concrete coating for widening (4000 m^2), bicycle + pedestrian path - New aligned path section requires new construction of roadbed and asphalt concrete coating (670 m^2) - 1450 m of stretch requires recoating of asphalt concrete (4350 m^2), bicycle + pedestrian path

Comments on proposed measures

The stretch should be designed as a separated two-way bicycle path where pedestrians should be separated from cyclists with a physical barrier such as vegetation. The last 260 m of the stretch include both the steep slopes mentioned, where the first one goes down into a valley and the other one up from it. Furthermore, a rather sharp curve connects these slopes making this section somewhat difficult to manoeuvre. Therefore, it was recommended to align the path differently and build a new separated two-way bicycle path through the vegetation and part of the residential area, connecting with Åbrinken. The existing path could be used by pedestrians and therefore a new pedestrian lane is not necessary. This new bicycle infrastructure will be 190 m and shortens the path by approximately 70 m. Moreover, the new infrastructure would eliminate the mentioned inclinations and curves. Actual speed for the stretch is expected to be 25 km/h since the stretch is in a rural area and distractions are limited. A sketch of the proposed stretch is presented in Figure 5.10.

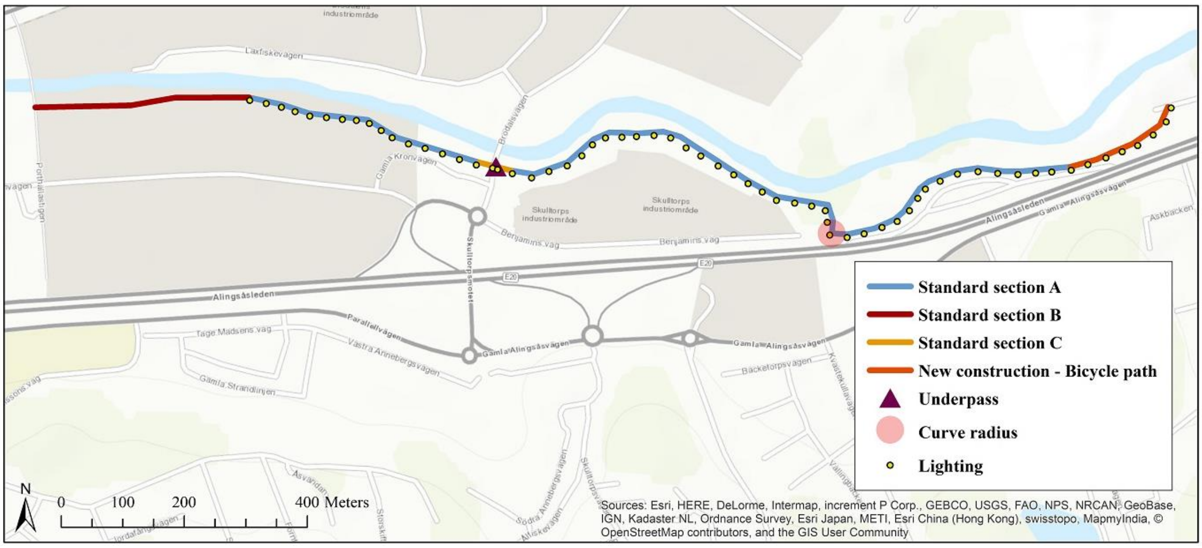

Figure 5.10 Overview of proposed measures for stretch 8.

5.2.9 Partille, Åbrinken - Partille, Kåhögsvägen (km 9/200 – 10/000)

The stretch begins in a small residential area by Åbrinken and ends by Kåhögsvägen. There is no existing bicycle infrastructure and cyclists and pedestrians share the carriageway with motorised traffic. Pedestrians and cyclists locate themselves at the edge of the carriageway and are vulnerable to motorised traffic. A 100 m long carriageway for motorised traffic, with a speed limit of 30 km/h, goes through a small residential area. The speed limit changes to 50 km/h on the remaining part of Åbrinken along E20. The characteristics of the stretch were identified during the field study and then compared with the proposed design standards, presented in Table 5.9.

Table 5.9 Summary of stretch 9.

Stretch 9 0.8 km 2.5 min	Current situation	Required standards	Proposed measures
Crossings	- 1 crossing without bicycle crossing infrastructure	- Bicycle priority crossings - Level separation - Signalised crossing - Bicycle passage	- Implement level separation -> Bicycle bridge
Markings	- No existing markings	- Pictogram of logo - Identity signs	- Pictogram of route´s logo on surface -Route identity sign
Lighting	- Appears sufficient in residential area, first 100 m - Remaining stretch has no lighting	- The path and its surroundings should be fully illuminated - Light posts should be located 0.3 m from the path at 30 m interval	- Install 23 new light posts along carriageway - Additional lighting required at bicycle bridge
Width	- Carriageway is 5 m in residential area (first 100 m) - Carriageway is 5.5 m outside the residential area	- Standard section D -> Bicycle Street, min carriageway with 4.5 m	- No widening required
Curve radius	- No significant curve	-	- No actions required
Gradient	- No significant gradient	-	- No actions required
Surface	- Consists of asphalt concrete - OK quality	- Surface material should be dense asphalt concrete - The asphalt concrete should be coloured - 2-4 % crossfall for sufficient drainage	- The entire stretch requires recoating of coloured asphalt concrete (2800 m^2)

Comments on proposed measures

Due to low flows of motorised traffic, the stretch at Åbrinken is recommended to be designed as standard section D, Bicycle Street. Speed-controlling measures need to be implemented to ensure traffic speeds do not exceed the legal speed for the carriageway, especially on the 50 km/h section. Special emphasis should be made to ensure that the measures only limit the speed of motorised traffic and do not affect the cyclists´ speed. The actual travel speed for the stretch is expected to be 20 km/h but motorised traffic is expected to be very low and therefore higher speeds for cyclists can be achieved.

Crossing infrastructure was needed at the end of the stretch where the path crosses Kåhögsvägen. Motorised vehicles tend to drive fast on this straight section of the carriageway.

Therefore, level separation in form of a bridge over Kåhögsvägen was recommended. A sketch of the proposed stretch is presented in Figure 5.11.

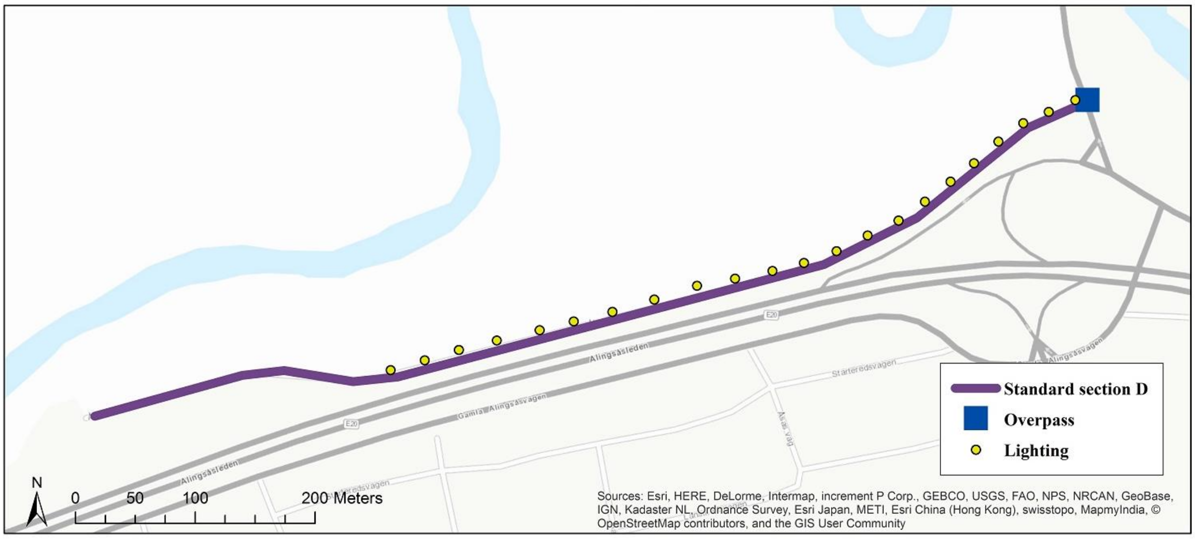

Figure 5.11 Overview of proposed measures for stretch 9.

5.2.10 Partille, Kåhögsvägen - Lerum, Lake Aspen (km 10/000-11/800)

The stretch begins at Kåhögsvägen and ends at the municipality border between Partille and Lerum at the south-east corner of Lake Aspen. A separate bicycle path shared with pedestrians exists, continuing north Kåhögsvägen and then turning into a fully separate shared path that lies along the railway in direction of Jonsered. The characteristics of the path were identified during the field study and then compared with the proposed design standards, presented in Table 5.10.

Table 5.10 Summary of stretch 10.

Stretch 10 1.8 km 4.5 min	**Current situation**	**Required standards**	**Proposed measures**
Crossings	- 1 underpass, path under road bridge by Jonsered station - 3 small bridges crossing water streams	- Bicycle priority crossings - Level separation - Signalised crossing - Bicycle passage	- No upgrades required
Markings	- No existing markings	- Midline and edge surface markings - Coloured edge markings - Directional arrows - Pictogram of logo - Identity signs	- Painting of mid- and edge lines - Edge lines should be painted in the route´s identity colour - Pictogram of route´s logo at beginning and end of the stretch -Route identity sign

Stretch 10 1.8 km 4.5 min	Current situation	Required standards	Proposed measures
Lighting	- Appears sufficient for 75 % of the stretch - No lighting on last 500 m	- The path and its surroundings should be fully illuminated - Light posts should be located 0.3 m from the path at 30 m interval	- Install 17 new light posts, preferably dynamic lighting technologies
Width	- Path is 2.5 m along Kåhögsvägen - Path is 3.5 m on a 100 m long section at beginning of path along railway - Path is 2-2.5 m along railway - Path is 1.7-2.2 m from Jonsered station to end of stretch	- Standard section A: min width 3.5 m (rural) - Standards section C: min width 2.5 m (exception)	- Path along Kåhögsvägen requires 1 m widening + 1.5 m pedestrian path - 100 m section along railway requires additional widening for 1.5 m pedestrian path - Path along railway requires 1-1.5 m widening + 1.5 m pedestrian path - Path from Jonsered station requires 1.3-1.8 m widening + 1.5 m pedestrian path
Curve radius	- 1 significant curve	- Minimum curve radius 40 m	- By widening the path and changing the alignment slightly, the curve radius will be better
Gradient	- 2 significant gradients: 95 m long slope along Kåhögsvägen and 100 m long slope on path along railway	- Gradient should be kept under 3 % - Max inclination is 5 % - On short distances (<100 m) the inclination should never exceed 7 %	- Length of slopes are both ≤100 m and are not considered to exceed 7 %. However, the slope along the railway should be redesigned to achieve a smaller inclination
Surface	- Consists of asphalt concrete and unbound material - OK and good quality for the first 300 m - Poor quality for the remaining stretch (1500 m)	- Surface material should be dense asphalt concrete - 2-4 % crossfall for sufficient drainage	- 80 % of the stretch requires new construction of roadbed and asphalt concrete coating (4900 m^2) for widening and reconstruction, bicycle + pedestrian path - 200 m of stretch requires recoating of

Stretch 10 1.8 km 4.5 min	Current situation	Required standards	Proposed measures
			asphalt concrete (500 m^2) - Implement new construction of 90 m long bridge, a width extension of the path

Comments on proposed measures

The bicycle path should be designed as a two-way separate bicycle path, with a distinguished barrier between cyclists and pedestrians. Due to width limitations at the bridge along Kåhögsvägen in the beginning of the stretch (note that this is not the new proposed bridge over Kåhögsvägen), separation from pedestrians must be limited to a painted line. High cycling speed is expected on the stretch with an actual speed of 25 km/h.

A 90 m section of the path, located on a narrow ridge between the railway and the river, will be difficult to widen. Possible widening techniques for that section could include a bridge that extends the existing path out onto the lake, standing on support beams. An issue that needs to be accounted for was that part of the area which the path goes through is environmentally sensitive and nature protected. Therefore, construction in the area might be challenging and require legal considerations. A sketch of the proposed stretch is presented in Figure 5.12.

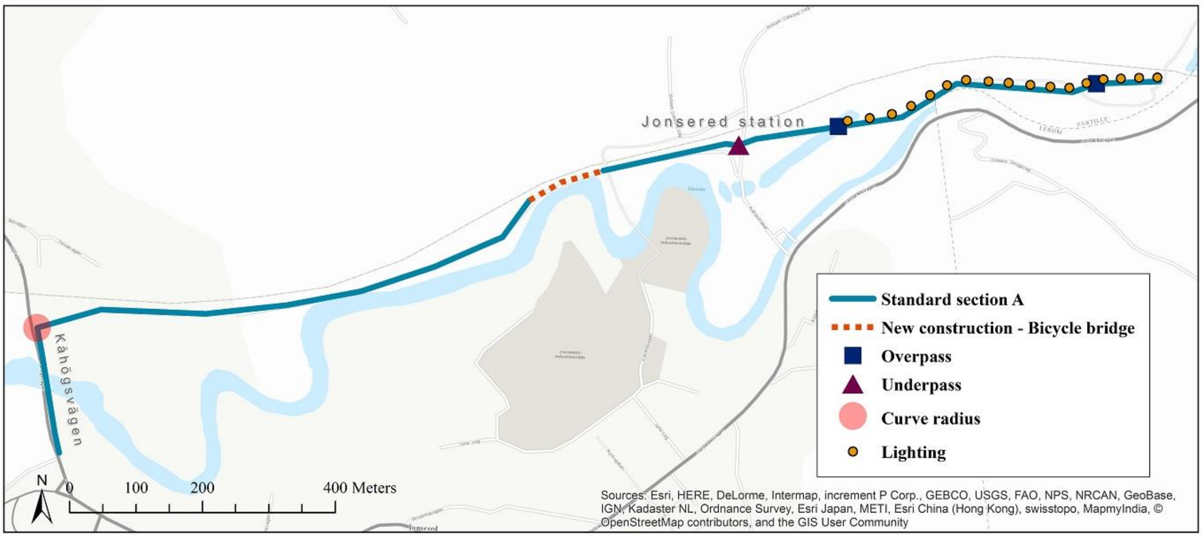

Figure 5.12 Overview of proposed measures for stretch 10.

5.2.11 The Missing Link (km 11/800–15/300)

Lerum municipality and the Swedish Transport Administration have made future plans on constructing a bicycle path connecting Lerum and Jonsered since bicycle infrastructure currently does not exist there. Preliminary studies have been conducted on the desired location of the planned bicycle path. Those studies indicate that a new bicycle path would be best aligned along Jonseredsvägen. The other option considered was along E20. However, that option was ruled out by Lerum municipality due to difficult conditions, lack of sense of security for cyclists and high altitude differences, according to Lerum´s transport planner R. Greek (interview 1. mars 2017).

During the field study, Jonseredsvägen was cycled and evaluated as a viable alternative for the new bicycle express-route. The conclusion gathered from the field study were that the carriageway causes dangerous conditions for cyclists due to its sinuous alignment and the high speed of motorised traffic. Furthermore, its changes in altitude was a huge drawback since it causes cyclists great effort and time delay. Therefore, it was considered that aligning the path along Jonseredsvägen does not meet the requirements for a bicycle express-route. Consequently, another alternative was considered which was along the railway and Lake Aspen. That alternative will be discussed in this chapter.

The stretch starts at Partille/Lerum municipality boarder by the south-west corner of Lake Aspen and ends by Aspen Station, a total of 3.5 km. If actual journey speed is assumed as 25 km/h then the stretch is expected to be cycled in 8.5 minutes. The following describes the new construction needed for the suggested bicycle express-route and is illustrated in Figure 5.13.

Figure 5.13 Overview of proposed measures for stretch 11, the "Missing link".

- **A.** A new bridge by the inlet/outlet of Lake Aspen, intended for the bicycle express-route along the existing railway bridge. The bridge will be 70 m long and should be 4.2 m wide, railing included. Other options were discussed for the area but they were discarded since space was restricted due to the lake, Jonseredsvägen and steep cliffs.
- **B.** A separate bicycle path along the maintenance carriageway next to the railway. The new bicycle path will be 650 m long and should be designed according to standard section A. The alignment for the section was straight and without inclination. The new path should be exclusively for cyclists.
- **C.** An overpass in form of a bridge should be built over the railway. An approximate length of 50 m was illustrated, but the length depends on the design of the bridge.
- **D.** A 110 m long bicycle path should be constructed on a small peninsula according to standard section A. One residence was present on the peninsula and special emphasis should be made ensuring that the new bicycle path does not disturb the residents.
- **E.** A 160 m long and 4.2 m wide bicycle bridge should be constructed. The bridge should be slightly elevated from the lake´s surface to allow for differences in water levels. However, inclinations at starting and end point of the bridge should be kept to absolute

minimum and it should be integrated with the connecting bicycle paths. Wind, precipitation and noise barriers should be considered on the bridge to protect the users.

F. A 400 m long bicycle path should be constructed according to standard section A. The path will be situated on a 25-40 m wide land strip along the railway which was considered a sufficient width to ensure a safe distance between the bicycle path and the railway. However, barriers surrounding the bicycle path are essential to prevent cyclists from going off the path.

G. A 225 m long and 4.2 m wide bicycle bridge should be constructed. The bridge should have similar design and characteristics to section E.

H. A new 750 m bicycle path that crosses through a small residential peninsula should be constructed. The path should be designed according to standard section A. Two residential houses are placed on the peninsula and conflicts could arise regarding land ownership when building the new bicycle path. Additionally, the peninsula is considered an exit point for the bicycle express-route since it connects with Jonseredsvägen.

I. A 170 m bicycle bridge should be constructed. The bridge characteristics and design should be similar to section E and G. The bridge ends at Aspen residential area on Skogshyddevägen.

J. A 720 m bicycle path going through Aspen residential area on Skogshyddevägen. An existing carriageway is used by a few residents in the area. Therefore, it was proposed this section was shared with motorised traffic and pedestrians and designed as standard section D. A 195 m existing pedestrian and bicycle path connects with the carriageway at the end of the residential area and continues to Aspen railway station. It was suggested that this section was upgraded to standard section A.

5.2.12 Lerum, Aspen station - Lerum station (km 15/300-18/000)

The stretch was divided into two sections. The first section is a 500 m fully separate pedestrian and bicycle path beginning by a tunnel under the railway and continuing along the railway from Aspen station until it reaches a tunnel under E20. From the tunnel, the second section begins where the path joins the existing local bicycle network in Lerum municipality. The path goes along Aspenvägen separated from pedestrians with a painted line. The local bicycle network is considered to be of good quality and it is reasonable to connect it with the proposed bicycle express-route. Therefore, a slightly less detailed inventory gathering was conducted on this part of the stretch and upgrade measures were mainly restrained to crossings and markings. The characteristics of the path were identified during the field study and then compared with the proposed design standards, presented in Table 5.11.

Table 5.11 Summary of stretch 12.

Stretch 12 2.7 km 8 min	Current situation	Required standards	Proposed measures
Crossings	- 2 underpasses: tunnel under Aspen railway station and tunnel under E20 - 9 bicycle passages	- Bicycle priority crossings - Level separation - Signalised crossing - Bicycle passage	- Tunnel under Aspen station does not require upgrading - Tunnel under E20 requires reconstruction

Stretch 12 2.7 km 8 min	Current situation	Required standards	Proposed measures
			(widening, lighting, surface) - Upgrade 1 bicycle passage to an underpass, connected with the tunnel under E20 - Upgrade 7 bicycle passages to bicycle priority crossings - Upgrade 1 bicycle passage to a signalised crossing - Raise 2 bicycle priority crossings with a speed bump
Markings	- No existing markings on section 1 - Markings not sufficient and poor visibility of separation lines on section 2	- Midline and edge surface markings - Coloured edge markings - Directional arrows - Signs and markings at crossings - Pictogram of logo - Identity signs	- Repainting of mid- and edge lines - Install sign B8 and markings M16 and M14 at 7 bicycle priority crossings - Pictogram of route´s logo after each distraction - Edge lines should be painted in the route´s identity colour -Route identity sign
Lighting	- Appears sufficient	-	- No actions required
Width	- Path is 3 m on section 1 - Path is 2.3-3 m on section 2 with an additional 1.5 m pedestrian path - Underpass is 3 m under Aspen railway station - Underpass is 1.5 m under E20	- Standard section A: min width 3.5 m (rural)	- Path on section 1 requires 0.5 m widening + 1.5 m pedestrian path - No widening is suggested for section 2. Bicycle express-route connects with Lerum´s municipality bicycle network and its current state is preserved
Curve radius	- No significant curve	-	- No actions required
Gradient	- No significant gradient	-	- No actions required

Stretch 12 2.7 km 8 min	Current situation	Required standards	Proposed measures
Surface	- Section 1 consists of unbound material and is of poor quality -Section 2 consists of asphalt concrete and is of good quality	- Surface material should be dense asphalt concrete - 2-4 % crossfall for sufficient drainage	- Section 1 requires new construction consisting of roadbed and asphalt concrete coating for widening and reconstruction (2500 m^2), bicycle + pedestrian path

Comments on proposed measures

The first section of the stretch should be designed as a separated two-way bicycle path with a distinguishable barrier, separating cyclists and pedestrians. A curve at the tunnel-opening by Aspen station was narrow and blocking vision, causing cyclists to slow down. Redesigning the surrounding of the tunnel should enhance the vision and allow cyclists to be more secure when entering/leaving the tunnel.

The second section of the stretch begins at a tunnel under E20 and shortly after the tunnel, the path crosses Aspenvägen as a bicycle passage. Aspenvägen is considered unsafe since traffic volumes are high at peak hours and although the speed limit is 50 km/h, it was noticed that higher speeds often occur. Therefore, it was recommended to implement an underpass, preferably linking with the other tunnel under E20.

The existing bicycle infrastructure along Aspenvägen should be kept in current state with minor improvements. To indicate that the path is part of the bicycle express-route and the local bicycle network of Lerum, surface colouring in the form of coloured edge lines is suggested in the bicycle express-route identity colour. Despite the fact that the guidelines suggested a fully coloured surface for bicycle express-routes in urban areas, the coloured edge lines are considered more relevant. Seven bicycle passages should be upgraded to bicycle priority crossings. One bicycle passage was recommended to be upgraded to a signalised crossing where the bicycle path crosses Södra Långvägen to enter Stationsvägen. Traffic speed and volumes on Södra Långvägen are high and it was therefore not reasonable to implement a bicycle priority crossing. The stretch is presented in Figure 5.14.

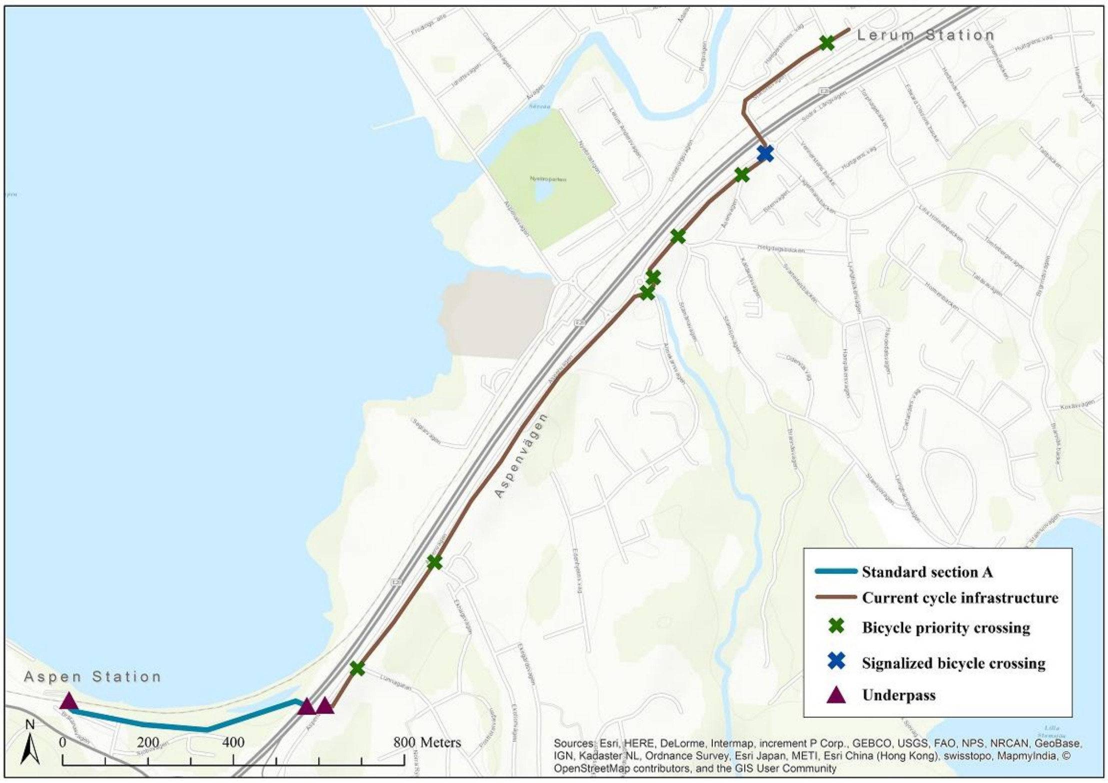

Figure 5.14 Overview of proposed measures for stretch 12.

5.3 Summary of results

Table 5.12 lists a summary of the required measures for the chosen route between Gothenburg, Partille and Lerum to fulfil the predefined standards for bicycle express-routes in Chapter 4.

Table 5.12 Summary of required measures to achieve the design standards for a bicycle express-route between Gothenburg, Partille and Lerum

	Proposed measures
Crossings	- Upgrade 18 bicycle passages to bicycle priority crossings. - Upgrade 1 bicycle passage to a signalised crossing. - Raise 8 crossings. - Implement 1 bicycle priority crossing where there is currently no crossing infrastructure. - Implement 2 bicycle passages at junctions with another pedestrian and bicycle path. - Implement 1 tunnel (upgrade of a bicycle passage). - Implement 2 bicycle bridges over road/railway.
Markings	All stretches require remarking, including: - Directional arrows, mid- and edge lines. - Additional markings and signs at crossings (bicycle priority crossings, bicycle passage, signalised crossing, under and overpass). - Pictogram of route´s logo after each disturbance. - Directional and route identity signs.

	Proposed measures
Lighting	- Implementation of new light posts where lighting is not sufficient. - Approximately additional 165 light posts in total.
Width	Existing path requires widening on all stretches to fulfil the desired standard sections, except when implementing Bicycle Streets. - *Stretch 1*: 1.5 m bicycle path widening for 1300 m. - *Stretch 2*: 1.5 m bicycle path widening for 1300 m and 0.8 bicycle path widening for 800 m. - *Stretch 3*: 1.5 m bicycle path widening for 1500 m and 1.5 m pedestrian path for 1500 m. - *Stretch 4:* 0.8 m bicycle path widening for 1000 m and 1.5m pedestrian path for 600 m. - *Stretch 5:* Bicycle Street (500 m). - *Stretch 6:* 0.8 m bicycle path widening for 720 m. - *Stretch 7*: 2.5 m pedestrian path for 300 m. - *Stretch 8*: 1 m bicycle path widening for 350 m, 0.6 m bicycle path widening for 1450 m and 1.5 m pedestrian path for 2100 m. - *Stretch 9*: Bicycle Street (800 m). - *Stretch 10*: 1-1.5 m bicycle path widening for 1300 m, 1.3-1.8 m bicycle path widening for 500 m and 1.5 m pedestrian path 1800 m. - *Stretch 11*: New construction. - *Stretch 12:* 0.5 m bicycle path widening for 500 m and 1.5 m pedestrian path for 500 m.
Curve radius	- Widening of path and slight change in alignment is expected to improve curve radius to at least *OK* where cyclists might have to slow down but not to a great extent. - Exceptions can be made at under- and overpasses. Clear indication with markings need to be in place. - One new proposed section with changed alignment should increase curve radius in accordance with the proposed guidelines.
Gradient	- One new proposed section with changed alignment should eliminate significant gradients. - One slope is considered to exceed 7 % and requires redesign.

	Proposed measures
Surface	Measures required on the route´s surface varies greatly between stretches: - *Stretch 1*: New construction for widening and coloured asphalt concrete coating for the entire stretch. - *Stretch 2*: 30 % of the stretch requires reconstruction due to bad quality, new construction for widening and coloured asphalt concrete coating for the entire stretch. - *Stretch 3:* The entire stretch requires reconstruction and widening consisting of roadbed and asphalt concrete coating. - *Stretch 4*: 90% of the stretch requires reconstruction consisting of roadbed and asphalt concrete coating due to bad quality, new construction for widening. - *Stretch 5*: Section 2 (300 m) requires coloured asphalt concrete coating. - *Stretch 6*: New construction for widening and coloured asphalt concrete coating for the entire stretch. - *Stretch 7*: New construction for widening and coloured asphalt concrete coating for the entire stretch. - *Stretch 8*: New construction for widening, recoating, 70% of the stretch requires recoating of asphalt concrete, 190 m new construction of new aligned path (roadbed+asphalt concrete coating). - *Stretch 9*: Coloured asphalt concrete coating for the entire stretch. - *Stretch 10*: 80 % of the stretch requires reconstruction consisting of roadbed and asphalt concrete coating due to bad quality, new construction for widening, 10% requires recoating of asphalt concrete. - *Stretch 11*: Complete new construction for 2.8 km (700 m bicycle bridge and 2.1 km bicycle path), coloured asphalt concrete coating for Bicycle Street (520 m). - *Stretch 12*: Section 1 (500 m) requires reconstruction consisting of roadbed and asphalt concrete coating due to bad quality, new construction for widening.

To obtain a better understanding of the required measures, the entire route was divided into three categories with different upgrade levels; minor upgrades, intermediate upgrades and complete upgrade, as shown in Figure 5.15. These three levels were assigned based on how much bicycle infrastructure exists, the quality of the existing infrastructure and the amount of improvements or reconstruction required.

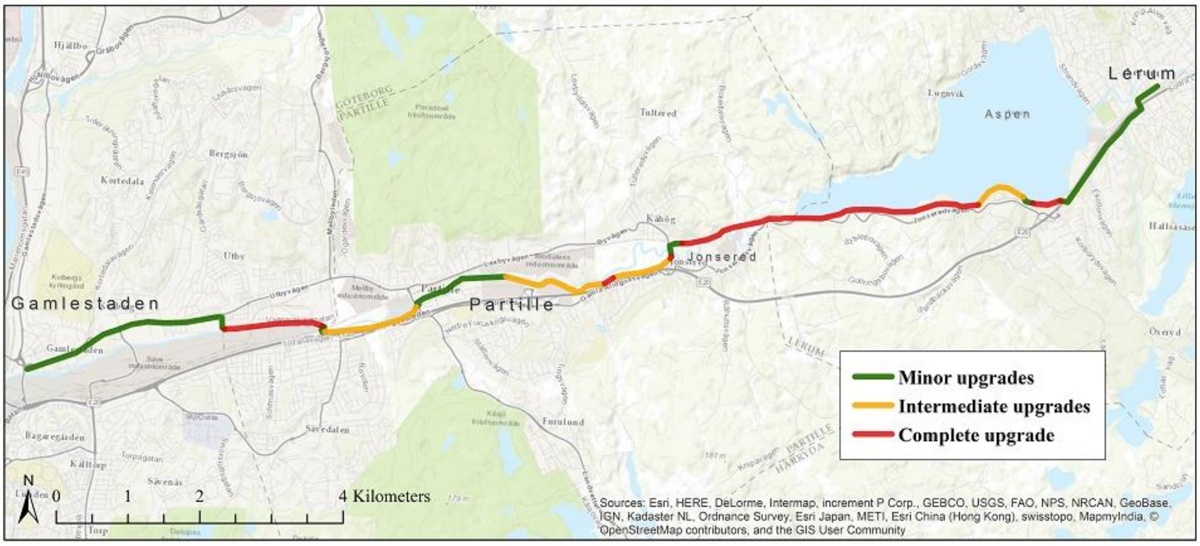

Figure 5.15 The route divided into three categories depending on the amount of upgrading necessary.

No part of the existing route fulfilled the proposed design standards of a bicycle express-route entirely. However, 40 % of the existing infrastructure was classified as being of good quality, only requiring minor upgrades. These minor upgrades consist of widening the existing path, recoating (typically with coloured asphalt concrete) and improving markings and signs. The sections classified for minor upgrades are all located within the built-up areas of Gothenburg, Partille and Lerum. For 25 % of the route, existing infrastructure could be used but more extensive upgrades were required, which was classified as intermediate upgrades. These sections are mainly located in the rural areas on both sides of Partille. The required upgrades were widening, recoating and additional reconstruction of the existing path. Within the intermediate upgrade class, implementation of two Bicycle Streets was suggested and they require additional design considerations. Approximately 35 % of the route was classified as bad quality and requires complete upgrades. This applies for the sections that consist of poor quality bicycle infrastructure such as stretch 3 and 10 or sections that are currently lacking bicycle infrastructure and require new construction such as stretch 11. The high percentage of complete upgrades could be derived from the 3.5 km "missing link" that requires new construction and design to connect the bicycle route between Jonsered and Lerum.

By upgrading a large number of bicycle passages to bicycle priority crossings, the travel time was expected to decrease significantly since both the frequency of stops and waiting time are minimised. By implementing the proposed measures, the number of stops was estimated to be reduced from 25 potential stops to 4 potential stops which roughly results in 3.5 gained minutes. More time will be gained when the time to increase the speed again after a stop is minimised, but since this was difficult to estimate this time was not included. Additionally, decreasing the number of stops results in saved effort for the cyclists who consequently do not have to start from zero speed at every crossing.

The actual travel time for the entire route from Gothenburg to Lerum was estimated to be 54 minutes if an average actual travel speed of 20 km/h was accounted for. However, actual travel speed was expected to be higher on sections in rural areas where there are few or no distractions, and lower in urban areas. Each stretch was evaluated based on its speed ability and assigned to a fitting actual travel speed, ranging from 15 to 25 km/h, obtaining an actual travel time of 50 minutes. Comparing these results with Google Map proposed time of 65 minutes, a 15-minute time gain was achieved by implementing the bicycle express-route between Gothenburg and Lerum. Calculations and estimates can be found in Appendix II.

5.4 Cost analysis

The construction cost for the 18 km long proposed bicycle express-route between Gothenburg, Partille and Lerum was evaluated. The cost includes new construction as well as upgrades of existing bicycle infrastructure required to meet the suggested design standards for bicycle express-routes. Inventory data was used to determine the necessary measures, presented in Chapter 5.3. The proposed measures were quantified and the cost for each measure was estimated to perform the cost analysis.

In Appendix III, a list of measures that were accounted for in the analysis is presented with their description and cost. Furthermore, inventory and cost calculations can be found in Appendix IV.

The total construction cost for the project was estimated at 106 million SEK, or approximately 6 million SEK/km. Figure 5.16 demonstrates the total construction cost within each concerned municipality.

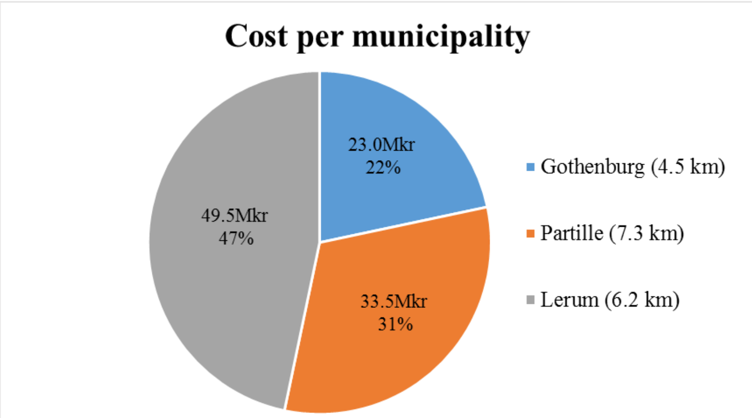

Figure 5.16 Estimated cost for the route in Gothenburg, Lerum and Partille.

The highest costs occur on the stretches within Lerum municipality. The suggested measures within this part of the route was estimated to cost 49.5 million SEK or 47 % of the total cost. The length of Lerum´s share of the route is 6.2 km which results in 8 million SEK/ km. These high-cost figures are mainly due to the additional infrastructure needed for the “missing link”. Difficult conditions for the new construction in the area aligned with the railway and Jonseredsvägen resulted in a costly solution. However, to maintain a high-quality bicycle express-route, this solution was considered to be the most feasible one. Measures required for the route located within Partille municipality were estimated to cost 33.5 million SEK and Partille has the longest segment of the route, 7.3 km, which resulted in a cost of 4.6 million SEK/km. These costs consist of upgrade measures which mainly include widening of the bicycle path and reconstruction of the surface due to poor surface quality. Lastly, the total cost for the required measures within Gothenburg municipality was estimated at 23 million SEK but Gothenburg has the shortest segment of the route out of the three municipalities, 4.5 km, resulting in a cost of 5.1 million SEK/km. Similar to Partille, the costs in Gothenburg mainly consists of upgrade measures of current infrastructure. A comparison of the costs for the different measures is demonstrated in Figure 5.17.

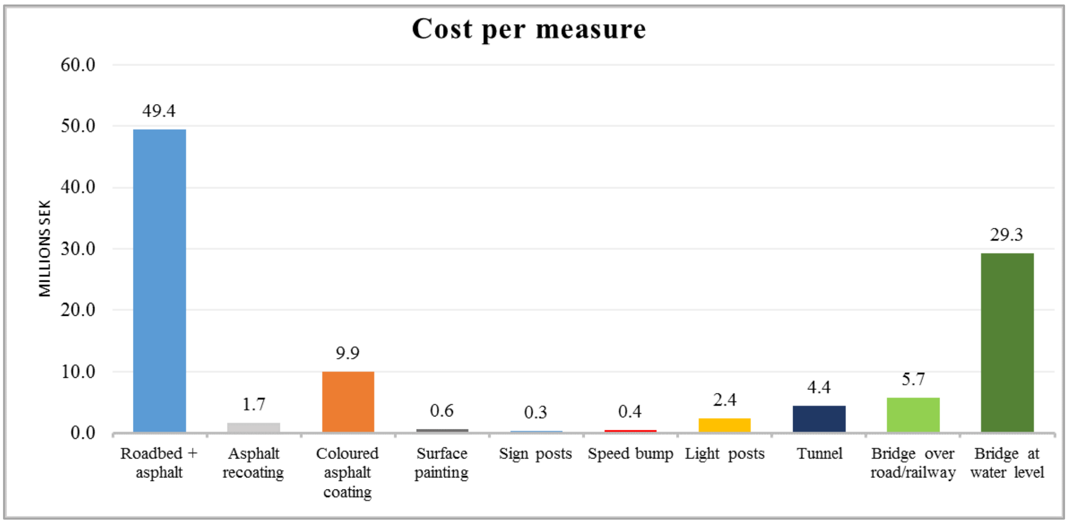

Figure 5.17 Cost estimation divided into measures.

The highest cost was for *roadbed + asphalt concrete*, with approximately 50 million SEK, for the entire route. These results were not unexpected since the majority of the route requires construction of some kind; widening of the path, new construction or reconstruction of existing infrastructure due to poor quality. New construction of bicycle bridges, both *for bridge over carriageway* and *bridge at water level*, were expected to cost 35 million SEK. However, costs for bridge infrastructure varies greatly and can be expected to change depending on material use and design. Furthermore, since the proposed guidelines state that fully coloured asphalt concrete should be in place in urban areas, the cost for *coloured asphalt concrete* was the third most expensive measure at 9.9 million SEK. Six out of the twelve stretches run through residential/urban areas and therefore it was expected that additional funding is required for coloured asphalt concrete. The remaining measures added up to a total of less than 10 million SEK for the entire route.

Figure 5.18 illustrates the division of measures for each stretch and the corresponding costs where the division of the stretch can be seen in Figure 5.2. Moreover, the number of stretches within each of the three concerned municipalities is presented. The analysis for Stretch 11, the “Missing link” is not included in Figure 5.18 but is presented separately in Figure 5.19.

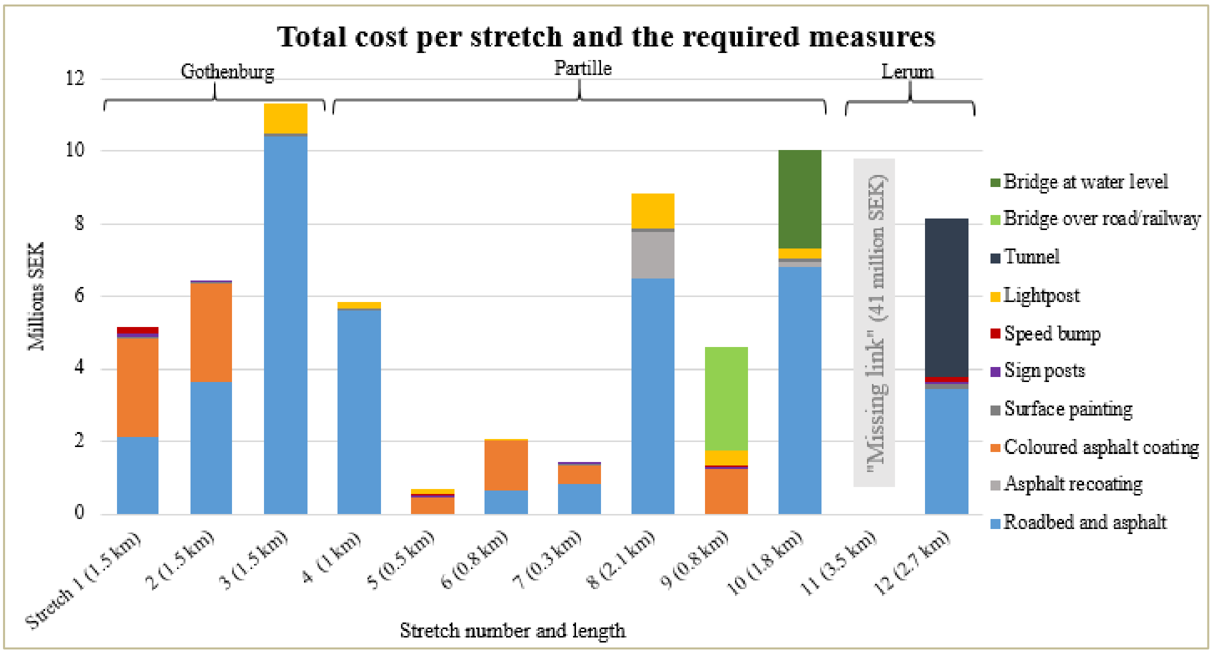

Figure 5.18 Total cost per stretch and measures required for each stretch.

With costs reaching around 11 million SEK, stretch 3 was the most expensive stretch, apart from stretch 11, the “Missing link”. Stretch 3 requires significant upgrades including new construction of path, both for cyclists and pedestrians. Therefore, *roadbed + asphalt concrete* was the dominant measure for that stretch, followed by new *light posts* for the entire stretch. Stretches 8 and 10 follow with costs up to 9 and 10 million SEK respectively. Cost for *Roadbed + asphalt concrete* is similar for both stretches since both paths need widening and reconstruction due to poor surface quality. Furthermore, stretch 8 requires additional lighting and asphalt concrete recoating at places. On stretch 10, a *bridge at water level* is suggested to widen the existing path which by itself contributed to a large part of the cost for the stretch. Level separation measures contributed highly to costs as can be seen for stretches 9, 10 and 12. Therefore it is essential to make logical decisions when deciding on implementing under- or overpasses. Stretches 1, 2, 5, 6, 7 and 9 all require recoating with coloured asphalt concrete and/or widening of the path which contributed to the high costs for roadbed.

Stretch 11 is expected to cost approximately 41 million SEK and with a length of 3.5 km, the cost is 11.8 million SEK per km. The cost for different measures required for the stretch is further described in Figure 5.19.

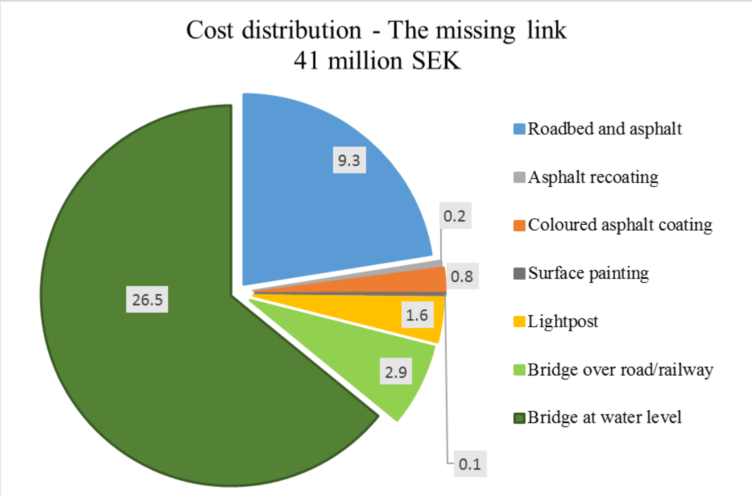

Figure 5.19 Cost distribution per measure for stretch 11, the "missing link".

As shown, the largest cost measure for stretch 11 was a suggested *bridge at water surface* which is estimated to cost 27 million SEK, followed by new bicycle path infrastructure consisting of *roadbed and asphalt concrete* for 9.3 million SEK. Other measures including *light posts*, *coloured asphalt concrete*, *surface painting* and *asphalt concrete* added up to around 5 million SEK.

Total cost varies greatly between stretches, from 0.7-11 million SEK. However, to be able to compare costs between the stretches it is necessary to look at cost per km for each stretch. Figure 5.20 illustrates the cost per km for each stretch resulting in a more even cost distribution between the stretches with price range between 1.5 and 7.5 million SEK per km.

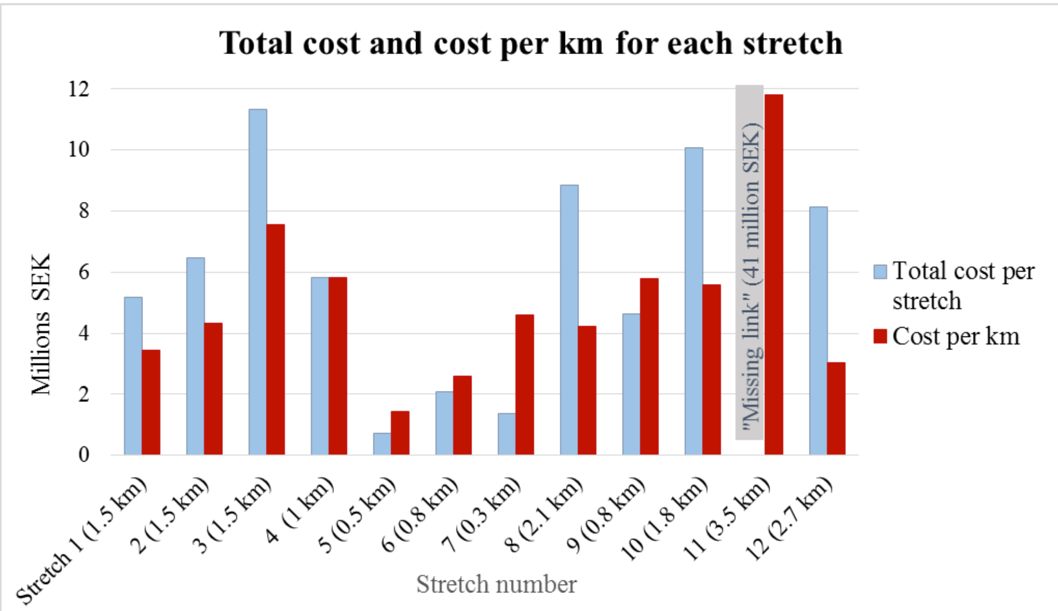

Figure 5.20 Cost per km for each stretch.

Comparing the total cost and the cost per km, it can be seen that for example for stretches 7 and 9, the costs shift from being low when looking at total costs but higher when looking at costs per km. The opposite can be seen for stretches 3, 8, 10 and 12, total cost was high but the km cost was relatively low.

6 Discussion

The following chapter addresses important measures required for the upgrade to a bicycle express-route, challenges with implementing a bicycle express-route from Gothenburg to Lerum and the conducted cost analysis including a comparison with other countries. Moreover, non-economic benefits gained from implementation of bicycle express-routes and sources of error are being mentioned.

Proposed measures

Measures minimising the number of stops and amount of times a cyclist must reduce their speed is key to achieving a high-quality commuter-route. The most important measure proposed for the concerned route in this perspective is upgrading bicycle passages into bicycle priority crossings in as many places as possible. In several cases, these priority crossings are also raised in order to reduce the speed of the motorised traffic on the road which the bicycle path is crossing, to make the crossing condition safer for cyclists. Another important measure to make the route attractive is to implement separation measures, separating pedestrians and motorised traffic from the bicycle path. This is mainly important in urban areas where grater traffic flows can be expected, compared to the country-side. In today´s Gothenburg, this problem is obvious for a cyclist since pedestrians are walking on or crossing a bicycle path at various places without looking out for passing bicycles. Additionally, coloured asphalt concrete on the bicycle express-route should also prevent pedestrians from accidently walking on the bicycle path. The goal is that the colour chosen for bicycle express-routes in Sweden should become a strong identity for these routes, resulting in less disturbance from pedestrians due to their knowledge about fast cyclists traveling there. In other words, similar respect for bicycle express-routes as for roads intended for motorised traffic. The bicycle express-route should be easy to recognise and in addition to coloured asphalt concrete it is also important to have pictograms and signs with the bicycle express-route´s logotype painted in the identity colour.

One important question to answer is what order measures should be taken to achieve improvements on the existing infrastructure and how to prioritise them. Three approaches could be considered; one that focuses on the minimum level of quality and start with upgrading the sections in worst condition, see Figure 5.15, one that is based on population by upgrading first in Gothenburg and then outwards through Partille and Lerum, and finally one upgrading crossings first to minimise the number of stops and delay.

The first option would result in prioritising new construction of the “Missing link” in order to connect the entire route from Gothenburg to Lerum. On the one hand, it would drastically improve the route and make it possible to bicycle almost the entire route without having to bicycle on the motorised traffic carriageway. On the other hand, the new construction might require additional funding from the Swedish Transport Administration and since the proposed design of the “Missing link” is rather new, it might take some time to investigate and design it in detail. Additionally, the “Missing link” is relatively far away from Gothenburg and therefore fewer commuters are expected on that section in comparison with the sections close to Gothenburg and Partille, situated closer to Gothenburg city. The second option would result in fixing the sections closest to Gothenburg city first and thereafter continue outwards towards Partille and Lerum. In regard to the number of expected commuters, this is a logical option since the short travel time most likely results in more cyclists. The third option, to upgrade crossings to bicycle priority crossing before anything else is done on the route, would be easily accomplished and also make a big difference in a bicycle-commuter´s perspective, especially in terms of gained time. However, since the law allowing bicycle priority crossings was recently added in 2014, they are not common and many people are probably not familiar with them yet. Hence, it would be preferable to implement bicycle priority crossings along the entire route at the same time in order to make them commonly known in the area, instead of a few first which possibly result in that no one knows which rules apply at the crossing.

Consequently, the third option is recommended, prior to further construction. Further, we propose to continue upgrading the red sections within the part between Gothenburg and Partille, which is mainly stretch 3. Continuously, the rest of the route between Gothenburg and Partille should be upgraded before construction on the “Missing link”.

Challenges of implementation

Bicycle express-route is a relatively new concept, especially in Sweden where planning on building them exists but none is built or is even under construction yet. Therefore, challenges can arise when planning and building the bicycle express-route between Gothenburg, Partille and Lerum. Conflict of interests might arise since giving the bicycle route priority at crossings can reduce the experienced accessibility for cars. Furthermore, conflict between different types of network and between different road-users may occur. For instance, it can be a challenge to handle pedestrians who walk on bicycle paths even though they should be aware of a bicycle only path. Consequently, it is important to make sure pedestrians have another option such as a path next to the route or somewhere else in the neighbourhood in order to keep them away from the bicycle express-route.

Another challenge is to ensure coherent maintenance standards along the entire route, which means that collaboration between the municipalities is needed. The reason for this is to avoid varying priority of for example snow removal, resulting in good conditions on the route in one municipality and then a snow wall at the boarder when entering the next municipality. One possibility to make that work is to employ one contractor who handles all maintenance throughout the entire route, regardless of municipality borders. It is of great importance that the municipalities manage a coherent maintenance strategy for the bicycle express-route. Moreover, coloured asphalt concrete coating could be a challenge, mainly because the concerned municipalities think it will be difficult to maintain. Their argument is primarily that it will be difficult for the maintenance staff to drive around with both regular asphalt concrete and coloured asphalt concrete for fixing for instance potholes. On the contrary, we believe this will not be a problem especially since there is at least one supplier of coloured asphalt concrete in Gothenburg and the municipality could have it in storage at the suppliers instead of in the maintenance trucks.

Cost analysis

The second feature obtained from results is the estimated construction cost for the chosen bicycle express-route. The estimated cost is 106 million SEK, or 6 million SEK/km. In comparison, the bicycle express-route implemented in Copenhagen, Denmark, was completed and the cost was around 1 million SEK/km. This relatively low cost was possible since the routes mainly consisted of existing bicycle infrastructure that required small upgrades. Furthermore, referring to the Netherlands and Germany, the routes mainly consist of new construction and the cost was 9.5 and 17 million SEK/km respectively. The high cost for Norway´s bicycle express-route, 24 to 45 million SEK/km, can be ascribed to the country´s topology and the expensive design for the route. Consequently, since the proposed route between Gothenburg, Partille and Lerum consists of both upgrades of existing infrastructure and new construction, 6 million SEK/km seems reasonable. To put the cost into perspective, the cost for building a new motorway in Sweden is estimated to be at least eight times higher than building the bicycle express-route. However, when comparing these different infrastructures, it is crucial to perform a cost-benefit analysis to determine the feasibility of implementing new infrastructure from an economic, environmental and social perspective.

An issue worth mentioning in regard to costs is the difference between standard asphalt concrete coating and coloured asphalt concrete coating. The price difference might seem substantial, 300 SEK/m^2 for standard asphalt concrete and 450 SEK/m^2 for coloured asphalt concrete. However, looking at the proposed route, only 3 million SEK would be saved for the entire route if coloured asphalt concrete would be discarded and replaced with standard asphalt concrete coating. That amount is not considered to be high enough to outweigh the benefits of coloured asphalt concrete as it increases the identity of the bicycle express-route and visually separates the bicycle path from other transport modes. Maintenance for coloured asphalt concrete is not believed to be any different from standard asphalt concrete. However, additional complexity and cost might arise if pedestrian paths running alongside the bicycle path require recoating or repair at the same time since the pedestrian path typically consists of standard asphalt concrete.

Two measures are noted to have the biggest influence on cost for the proposed route. First, under- and overpasses are expensive to implement. A number of under- and overpasses are already present on the existing paths, hence implementation of new infrastructure can be kept to a minimum. Nevertheless, there is one 3.5 km stretch, referred to as the “Missing link”, which goes along Jonseredsvägen and Lake Aspen that requires entirely new infrastructure. Due to difficult topology on Jonseredsvägen, implementing a bicycle bridge above the lake´s surface is considered the best option to maintain standards for the route. Costs for suitable bridge solutions for the stretch show great differences in costs due to different techniques, design and ground conditions. Therefore, it is difficult to estimate the price for bridge construction. In this case, the price includes high uncertainties and could either be over- or under estimated. The route requires over 700 m of new bridge construction and the cost for bridge infrastructure is 33 % of the total cost of the proposed bicycle express-route. Consequently, differences in bridge price will have considerable influence on the total price of the route and the concerned stretches. The most expensive measure is new path construction consisting of roadbed and asphalt concrete coating. The majority of the path construction involves widening of the existing path and new construction where there is no existing bicycle infrastructure. These measures are, however, inevitable if the standards for bicycle express-routes should be achieved and the cost estimates for them should be relatively correct. Therefore, these costs can be referred to as fixed costs

Funding

As the project must be funded the question is whether the economic responsibility should be on the concerned municipalities, on the Göteborg Region Association of Local Authorities (GR) or on the Swedish Transport Administration? On the one hand each municipality has best knowledge of their own municipality area. On the other hand if GR should succeed in making several bicycle commuter-routes it is reasonable that they carry the responsibility. Furthermore, if a municipality within a planned route do not want to build a bicycle express-route through their municipality, it would be preferable if the Swedish Transport Administration could interfere and decide to build it in order to get the regional bicycle network as planned without gaps or missing links due to opposing municipalities.

Additional advantages of bicycle express-routes and sources of error

The advantages of building an attractive commuter bicycle route, besides the economic, are the benefits for the environment and people´s health. Cycling is an environmentally friendly commuting choice and by implementing a bicycle express-route the need for private motorised vehicles would decrease and consequently also the emission from vehicles. Additionally, cycling has substantial health benefits and many commuters tend to use commuting on bike as their daily exercise. It is recommended here that a cost-benefit analysis be conducted in order to ensure that implementation of a bicycle express-route is benificial, but most importantly to convince city planners and politicians how beneficial these routes are. Previous cost-benefit analysis of bicycle routes for commuting have shown positive results and high rates of return for such investments.

In the early stages of the master’s thesis, the plan was to measure the altitude of the chosen route by using the phone´s GPS during field study and then calculate the gradient to be able to compare it to the proposed guidelines. Unfortunately, the GPS-signal turned out to be inconsistent and inaccurate. Thus, the gradients along the route had to be visually analysed instead, which can be a source of error since the severity of some slopes could have been misjudged.

7 Conclusion

A bicycle express-route is a high-quality bicycle route, which allows commuters to travel faster and more direct for longer distances than standard commuter routes and with minimal interference from other transport modes. Sweden has not yet established specific design standards for these types of commuter routes. In this thesis, design guidelines based on international experience, have been summarised as a basis for future Swedish standards.

A suggested bicycle express-route between Gothenburg, Partille and Lerum is an 18 km long high-quality commuter route connecting the three municipalities. Several conclusions are obtained from the results of a possible bicycle express-route between Gothenburg, Partille and Lerum and is presented below:

- The new route will require quality improvements and additional infrastructure such as widening on the existing bicycle network as well as new constructions to close the gaps to form a holistic route. 40 % of the existing infrastructure requires minor upgrades and 25 % requires intermediate upgrades. Due to a 3.5 km “missing link” along Lake Aspen and sections with poor quality infrastructure, complete upgrade accounts for 35 % of the route.
- Pedestrians are a challenge when it comes to controlling their behaviour in traffic situations. Therefore, separation measures and clear markings need to be in place to identify the bicycle express-route.
- Coloured asphalt concrete or coloured edge markings are important identity measures which compared to the total cost are a relatively small investment while they increase the value of the bicycle express-route in terms of the expected positive effect for the users.
- It is important to minimise the number of stops in order to achieve the bicycle express-route standards, preferably by implementing bicycle priority crossings.
- It is suggested that the upgrade of crossings into bicycle priority crossings is prioritised when starting the construction phase since it is a fast measure which will decrease the travel time. Furthermore, upgrades on the route should be prioritised by starting from Gothenburg and continuing to Partille since it is expected that more commuters will be commuting from Partille to Gothenburg than Lerum to Gothenburg. Another important upgrade is to close the gap on the “Missing link” since the current situation, cycling on the Jonseredsvagen carriageway, is not acceptable with regard to safety.
- By implementing the suggested design standards, the total travel time between Gamlestaden, Gothenburg, and Lerum travel centre is estimated to be 50 minutes if the actual travel speed accounted for is evaluated for each stretch, ranging from 15 to 25 km/h.
- The construction cost for the concerned bicycle express-route is 6 million SEK/km, which is within reasonable range in comparisons with routes in other countries. Moreover, a cost-benefit analysis of the investment, including health effects, is recommended as a further step.

8 Further studies

This thesis has considered the subject of bicycle express-routes with focus on design criteria. However, in order to successfully implement bicycle express-routes in Swedish society some further studies are necessary, concerning other perspectives of bicycle express-routes. A cost-benefit analysis should be conducted to make sure bicycle express-routes are beneficial for society and to present proof for politicians and urban planners that bicycle express-routes are an advantageous choice of infrastructure investment.

Furthermore, another important aspect is how to deal with the maintenance of bicycle express-routes since their purpose is to connect cities within a region and therefore they commonly cross municipality borders. Hence, it is suggested that maintenance work along a bicycle express-route and how to make the municipalities cooperate together is studied in detail. Another issue to study in detail is the “Missing link”, since this study only briefly looked at the area with visual inspection and any further investigation was not made.

Another important aspect to consider is the traffic safety on bicycle express-routes, since they should be designed for faster cycling than the existing bicycle networks in Sweden.

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Appendix I: Data gathering with MDC

Design parameters that were considered to influence the quality of the current bicycle infrastructure were classified in the GIS software Mobile Data Collection (MDC). The following parameters and their applications in the MDC software were used in a field observation study:

Type of bicycle facilities**:** A check-box selection sheet was created in MDC to be able to choose what type of bicycle facility exists at each point. As mentioned before, each section of the route was chosen based on the type of existing bicycle infrastructure.

Crossings: Type of crossings existing on each section was located and documented. A drop-down list including different crossing facilities was created in MDC.

Markings: Existing surface markings and signs were identified for each section by creating a check-box selection sheet in MDC.

Travel speed: The travel speed was evaluated in field by cycling, using the existing infrastructure along the route. The speed was not measured, instead it was assessed looking at parameters as stops, physical effort and wind protection. Number of stops was calculated after the inventory, using number of crossings resulting in stops. Additionally, physical effort and wind protection were assessed, as influential factors on travel speed, with check-boxes in the MDC application.

Lighting: Lighting for the route was evaluated by collecting inventory of the current lighting situation and to assess if it appears sufficient or not. A check-box selection sheet was created in MDC.

Width: The width of the existing infrastructure was measured with a measuring device and documented in the MDC application.

Horizontal curve radius: The horizontal curve radius was evaluated by visual inspection of the route. Simplifications to the suggested design guidelines were made in order to evaluate the horizontal curve radius in field. Since the radius is dependent on design speed, the curves were assessed based on how much a cyclist needs to slow down in order to safely ride through the curve. A drop-down list of different levels of needed speed reduction was created in MDC and presented below:

- Not OK - Cyclists have to slow down significantly or even stop.
- OK - Cyclists might have to slow down, but not to a great extent.
- Good - Cyclists do not have to slow down.

Gradient: The gradient was evaluated with a visual evaluation of the path´s gradient to determine which parts of the path would possibly not meet the gradient requirements. The plan was to measure the gradient with use of the altitude gathered from GPS, but unfortunately this did not work according to plan because of bad GPS reception.

Crossfall: The crossfall was evaluated briefly in field, since tools for measuring the crossfall was not available and visual estimations was very difficult. A check-box selection sheet was created in the MDC application including choices which indicate bad drainage.

Surface material: The type of surface material on the bicycle paths was documented for each section. Furthermore, a visual inspection was carried out to classify the quality of the surface. Drop-down lists were created in the MDC application to classify both the type of surface material and its quality. The quality was classified as below:

- Poor quality – requires a lot of improvement including reconstruction of roadbed and coating.
- OK quality – only requires recoating.
- Good quality – the surface does not need improvements.

Safety and security: The sense of security is important to make the bicycle express-route attractive and was therefore visually evaluated in field. Aspects of safety and security are partly assessed within other parameters such as lighting and crossing. The factors that are considered important and not evaluated in earlier paragraphs were listed as a check-box selection sheet in the MDC application.

Appendix II: Travel time

Amount of stops and estimated time per stop both before and after the proposed upgrades:

Stops	passages	signalized	no infrastructure	priority crossing	overpass/underpass
Current situation	20	3	2		
upgrade		4		19	2
Time (sec)	10	20	10	0	0

Estimated stopping time before and after upgrades:

Delay (sec)	passages	signalized	no infrastructure	priority crossing	overpass/underpass	total (sec)	Minutes
Current situation	200	60	20	0	0	**280**	**4.7**
upgrade		80		0	0	**80**	**1.3**
					Gained time due to fewer stops:		**3.3**

Travel time before upgrading the route according to google:

Got - Lerum	Length (km)	Time (min)	Speed (km/h)
Google	18	65	16.6

Estimated travel time for actual speeds of 15 km/h, 20 km/h and evaluated speeds for each stretch after upgrading the route:

Stretch	Length (km)	Actual speed (km/h)	Time (min)	Actual speed (km/h)	Time (min)	Actual speed (km/h)	Time (min)
1	1.5	15	6	20	4.5	15	6
2	1.5	15	6	20	4.5	20	4.5
3	1.5	15	6	20	4.5	25	3.6
4	1	15	4	20	3	25	2.4
5	0.5	15	2	20	1.5	15	2
6	0.8	15	3.2	20	2.4	20	2.4
7	0.3	15	1.2	20	0.9	15	1.2
8	2.1	15	8.4	20	6.3	25	5.0
9	0.8	15	3.2	20	2.4	20	2.4
10	1.8	15	7.2	20	5.4	25	4.3
11	3.5	15	14	20	10.5	25	8.4
12	2.7	15	10.8	20	8.1	20	8.1
Sum:	**18**		**72**		**54**		**50**

Appendix III: Cost analysis I – Description of measures and cost references

Measures required for cost analysis along with their description:

Measure	Description
Roadbed + asphalt concrete coating	Amount of new construction needed, roadbed and asphalt concrete coating. The price is 1.391 SEK/m^2 which is the average price from Trafikverket and Lerum municipality. For some section of the route, only roadbed was needed when coating should be coloured asphalt concrete. The price for roadbed is 1.091 SEK/m^2. Prices include materials and construction.
Asphalt concrete recoating	Amount of asphalt concrete needed for surface coating, approximately 4 cm. This only applies when recoating is required and not reconstruction (see roadbed+asphalt concrete coating). The price is 300 SEK/m^2. Price includes material and construction.
Coloured asphalt concrete coating	Amount of coloured asphalt concrete needed for surface coating. The price is 450 SEK/m^2. Price includes material and construction.
Surface painting	The amount of surface markings painted on the path´s surface, including edge lines, midlines, markings at crossings and pictograms. The price is 13 SEK/m. Price includes material and painting.
Sign posts	Number of signs needed for the route. More than one sign can be placed on a single post, therefore there are two different categories; 1. Sign and post. The price for the unit is 3.000 SEK/unit 2. Single sign. The price for the sign is 600 SEK/unit Prices include material and set up construction.
Speed bump	Number of speed bumps needed to be installed at crossings and as speed reduction measures. The price is 50.000 SEK/unit
Light posts	Number of additional light posts required for the route. Number of units was determined by the length of the section that requires lighting and placed at 30 m intervals. The price is 17.100 SEK/unit. Price includes material and construction.
Tunnel	The length of new construction required. The standard width of the tunnel is 8.5 m, whereof 4.5 m is asphalt concrete coated. The price per meter of tunnel is 73.100 SEK/m. Price includes material, design and construction.
Bicycle bridge over road/railway	Amount of bicycle bridge required over a carriageway. Several variations of design exist for bicycle bridges resulting in a wide price range. The chosen price is 13.680 SEK/m^2. Price included material, design and construction.
Bicycle bridge at water level	Amount of bicycle bridge needed at water level. Several variations of design exist for bicycle bridges resulting in a wide price range. The chosen price is 10.100 SEK/m^2. Price included material, design and construction.

References

Measure	Company	Interviewed person	Date
Asphalt concrete	Lerum kommun	Rebecca Greek	2017-03-31
Roadbed + asphalt concrete	Lerum kommun and Trafikverket	Rebecca Greek Inger Ranheim	2017-03-01 and 2016-02-08
Coloured asphalt concrete	DuoAsphalt	Stefan Mattson	2017-03-31
Speed bump	Lerum kommun	Rebecca Greek	2017-03-31
Lightpost	Trafiksystem	Martin Jansson	2017-04-03
Sign and poles	Blinkfyrar	Leif Lirvall	2017-03-31
Surface painting	Svevia	Mattias Nätterqvist	2017-04-07

Measure	Author	Title	Year
Bridge (missing link)	Ipv Delft (English summary of the CROW design guide)	Brief Dutch Design Manual for Bicycle and Pedestrian Bridges	2015
Tunnel	Tyréns på uppdrag av Kristianstads kommun	Gång- och cykeltunnel under Hammarleden	2013
Bridge over road	Paths for all – for a happier healthier Scotland	Estimating price guide for path projects	2014

Appendix IV: Cost analysis II - Calculations

Total							
Measure	**Length [m]**	**Width[m]**	**Area [m2]**	**Quantity**	**[kr/unit]**	**Unit**	**Cost [kr]**
Asphalt	1650		5515	0	300 kr	m^2	1 654 500.00 kr
Roadbed + asphalt	2030		30304	0	1 391 kr	m^2	42 152 864.00 kr
Roadbed	1020		6636	0	1 091	m^2	7 239 876.00 kr
Coloured asphalt	1400		21985	0	450 kr	m^2	9 893 250.00 kr
Speed bump	0		0	8	50 000 kr	per unit	400 000.00 kr
Lightpost	2630		0	260	17 100 kr	per unit	4 440 300.00 kr
Bridge (missing link)	90		2895	0	10 105 kr	m^2	29 253 975.00 kr
Only sign	0		0	148	600 kr	per unit	88 800.00 kr
Sign + pole	0		0	75	3 000 kr	per unit	225 000.00 kr
Tunnel	60		0	0	73 100 kr	m	4 386 000.00 kr
Bridge over road	0		420	0	13 680 kr	m^2	5 745 600.00 kr
Surface painting	46335		0	0	13 kr	m	602 355.00 kr
							106 082 520.00 kr

Gothenburg							
Measure	**Length [m]**	**Width[m]**	**Area [m2]**	**Quantity**	**[kr/unit]**	**Unit**	**Cost [kr]**
Asphalt	0		0	0	300 kr	m^2	- kr
Roadbed + asphalt			7500	0	1 391 kr	m^2	10 432 500.00 kr
Roadbed			5310	0	1 091	m^2	5 793 210.00 kr
Coloured asphalt			12000	0	450 kr	m^2	5 400 000.00 kr
Speed bump			0	4	50 000 kr	per unit	200 000.00 kr
Lightpost			0	50	17 100 kr	per unit	855 000.00 kr
Bridge (missing link)			0	0	10 105 kr	m^2	- kr
Only sign			0	46	600 kr	per unit	27 600.00 kr
Sign + pole			0	36	3 000 kr	per unit	108 000.00 kr
Tunnel			0	0	73 100 kr	m	- kr
Bridge over road			0	0	13 680 kr	m^2	- kr
Surface painting	13500		0	0	13 kr	m	175 500.00 kr
							22 991 810.00 kr

Partille							
Measure	**Length [m]**	**Width[m]**	**Area [m2]**	**Quantity**	**[kr/unit]**	**Unit**	**Cost [kr]**
Asphalt	1650		4850	0	300 kr	m^2	1 455 000.00 kr
Roadbed + asphalt	2030		13619	0	1 391 kr	m^2	18 944 029.00 kr
Roadbed	1020		1326	0	1 091	m^2	1 446 666.00 kr
Coloured asphalt	1400		8130	0	450 kr	m^2	3 658 500.00 kr
Speed bump	0		0	2	50 000 kr	per unit	100 000.00 kr
Lightpost	2630		0	118	17 100 kr	per unit	2 017 800.00 kr
Bridge (missing link)	90		270	0	10 105 kr	m^2	2 728 350.00 kr
Only sign	0		0	44	600 kr	per unit	26 400.00 kr
Sign + pole	0		0	17	3 000 kr	per unit	51 000.00 kr
Tunnel	0		0	0	73 100 kr	m	- kr
Bridge over road	0		210	0	13 680 kr	m^2	2 872 800.00 kr
Surface painting	18600		0	0	13 kr	m	241 800.00 kr
							33 542 345.00 kr

Lerum							
Measure	**Length [m]**	**Width[m]**	**Area [m2]**	**Quantity**	**[kr/unit]**	**Unit**	**Cost [kr]**
Asphalt			665	0	300 kr	m^2	199 500.00 kr
Roadbed + asphalt			9185	0	1 391 kr	m^2	12 776 335.00 kr
Roadbed			0	0	1 091	m^2	- kr
Coloured asphalt			1855	0	450 kr	m^2	834 750.00 kr
Speed bump			0	2	50 000 kr	per unit	100 000.00 kr
Lightpost			0	91.66666667	17 100 kr	per unit	1 567 500.00 kr
Bridge (missing link)			2625	0	10 105 kr	m^2	26 525 625.00 kr
Only sign			0	58	600 kr	per unit	34 800.00 kr
Sign + pole			0	22	3 000 kr	per unit	66 000.00 kr
Tunnel	60		0	0	73 100 kr	m	4 386 000.00 kr
Bridge over road			210	0	13 680 kr	m^2	2 872 800.00 kr
Surface painting	14235		0	0	13 kr	m	185 055.00 kr
							49 548 365.00 kr

Cost per km without bridge	4 349 292 kr
Cost per km with bridge	5 893 473 kr