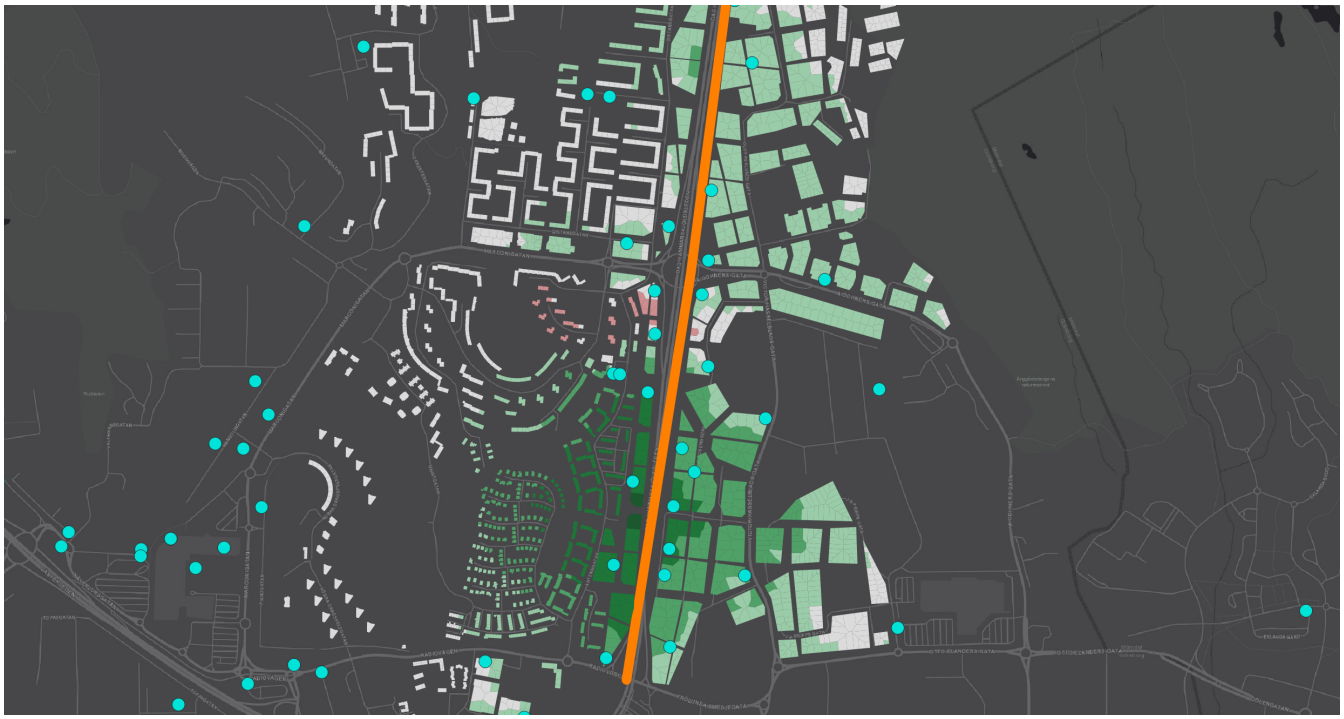
CHALMERS
UNIVERSITY OF TECHNOLOGY



Boulevardisation as a tool to reduce barrier effects from transport infrastructure

A case study of the planned Dag Hammarskjöld boulevard

Master's thesis in Infrastructure and Environmental Engineering

Henrik Lindblad
Arvid Nord

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
Urban Design and Planning

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2022
www.chalmers.se

Master's thesis ACEX30

Boulevardisation as a tool to reduce barrier effects from transport infrastructure

A case study of the planned Dag Hammarskjöld boulevard

HENRIK LINDBLAD & ARVID NORD



CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of Architecture and Civil Engineering
Division of Urban Design and Planning
Spatial Morphology Group
Chalmers University of Technology
Gothenburg, Sweden 2022

Boulevardisation as a tool to reduce barrier effects from transport infrastructure
A case study of the planned Dag Hammarskjöld boulevard

HENRIK LINDBLAD & ARVID NORD

© HENRIK LINDBLAD & ARVID NORD, 2022.

Examiner/Supervisor: Associate Professor Jorge Gil, Department of Architecture and Civil Engineering
Supervisor: Mathias Drefelt, Ramboll Sverige AB

Department of Architecture and Civil Engineering
Division of Urban Design and Planning
Spatial Morphology Group
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Figure 4.15. Change in choice of grocery stores for addresses after boulevardisation of Dag Hammarskjöldsleden with future urban development. Green indicates improvements. Orange is the planned boulevard and dots in cyan are grocery stores. Created in QGIS.

Typeset in LaTeX
Department of Architecture and Civil Engineering
Gothenburg, Sweden 2022

Boulevardisation as a tool to reduce barrier effects from transport infrastructure
A case study of the planned Dag Hammarskjöld boulevard
HENRIK LINDBLAD & ARVID NORD
Department of Architecture and Civil Engineering
Urban Design and Planning
Spatial Morphology Group
Chalmers University of Technology

Abstract

Dag Hammarskjöldsleden is a multi-lane freeway stretching from Linnéplatsen to the interchange Jänrbrottsmotet in Gothenburg, Sweden. The city of Gothenburg wants to rebuild it into a boulevard, with one of the purposes to reduce barrier effects, hence making it a more attractive area to live in. Reduced accessibility and increased travel times to services and workplaces are examples of direct barrier effects. Job van Eldijk has created a conceptual model describing these barrier effects.

In this thesis, the suitability of boulevardisation of transport infrastructure as a means to reduce barrier effects for pedestrians and cyclists is studied, using the Dag Hammarskjöld boulevard project as a case study. A geographic model of the area around Dag Hammarskjöldsleden was created with GIS and quantitative indicators were used to assess the extent of barrier effects under different scenarios. Four scenarios were created with different street networks, residential development and distribution of facilities: 0 - how the area looks today, A - how the area would look with a boulevard design only, B - how the area will look with the planned new urban development only, and C - how the area would look with both the future urban development and a boulevard design, which also represents the design the municipality proposes.

Five barrier effects indicators were calculated for each scenario: choice of a facility of given category, facilities' catchment area, proximity to a facility category, Betweenness, and Detour factor. By comparing the indicator analyses for scenarios 0 & A, it can be concluded that the boulevardisation of Dag Hammarskjöldsleden, without further urban development, would have limited effect on the barrier effects, due to the lack of demand for crossing the road today because of the absence of activities on the east side. The comparisons between scenario B & C, which included increased urban development, indicates that the boulevardisation would have a significant effect on the southern and middle sections of the studied area. It is especially addition of new crossing facilities that improves the accessibility in these areas, hence reducing the barrier effects.

Keywords: barrier effect, spatial analysis, boulevard, GIS, indicators, impact assessment, scenario evaluation.

Boulevardisering som ett verktyg för att minska på barriäreffekter från transportinfrastruktur
En fallstudie på den planerade Dag Hammarskjölds boulevarden
HENRIK LINDBLAD & ARVID NORD
Institutionen för arkitektur och samhällsbyggnadsteknik
Stadsbyggnad
Spatial Morphology Group
Chalmers tekniska högskola

Sammanfattning

Dag Hammarskjöldsleden är en flerfilig motortrafikled som sträcker sig från Linnéplatsen till Järnbrottsmotet i Göteborg, Sverige. Göteborgs stad vill bygga om Dag Hammarskjöldsleden till en boulevard för att bland annat minska dess barriäreffekter och därmed möjliggöra exploatering av nya bostäder och verksamheter längsmed den. Minskad tillgänlighet och ökade restider till service och arbete är exempel på direkta barriäreffekter. Job van Eldijk har framställt en konceptuell modell som beskriver dessa barriäreffekter.

I detta arbete undersöks lämpligheten av boulevardiseringen av transportinfrastruktur för att reducera barriäreffekter för gående och cyklister. Projektet Dag Hammarskjölds boulevard används som fallstudie. Genom att använda GIS har en geografisk modell av området kring Dag Hammarsskjöldsleden gjorts och kvantitativa indikatorer beräknats för att utvärdera barriäreffekterna i olika scenarion. Fyra scenarion har modellerats med skillnad i vägnät, bebyggelse och lokalisering av målpunkter: 0 – hur området ser ut idag, A – hur området skulle se ut med en endast en boulevarddesign, B - hur området skulle se ut med endast den framtida bebyggelsen och C - hur området skulle se ut med framtida bebyggelsen och en boulevarddesign, vilket också utgör det framtagna förslaget av kommunen.

Fem indikatorer på barriäreffekter är beräknande för vartdera scenario: valmöjlighet för en typ av målpunk, målpunkters upptagningsområde, närhet till en typ av målpunkt, stråkanalys och genhetsfaktor. Genom att jämföra indikatoranalyserna för scenariona 0 & A kan det konstateras att boulevardising av Dag Hammarskjöldsleden (utan ny bebygglese) enbart skulle ha begränsade effekter på dess barriäreffekter med nuvarande bebyggelse eftersom det inte finns något större behov av att korsa barriären idag på grund av liten aktivitet på den östra sidan. Jämförelserna mellan analyserna av scenariona B & C (med ny bebyggelse) indikerar på att boulevardiseringen skulle utgöra en signifikant förbättring av barriäreffekterna i de södra och mellersta delarna av området med den planerade bebyggelsen. Det är framför allt nya korsningspunkter som gör att tillgängligheten blir bättre i dessa områden och därmed minska på barriäreffekterna.

Nyckelord: barriäreffekt, rumsanalyser, boulevard, GIS, indikatorer, konsekvensanalys, scenario utvärdering.

Contents

Abstract v

Sammanfattning vi

Contents x

Preface xi

List of Figures xii

List of Tables xv

Acronyms xvi

1 Introduction 1
- 1.1 Dag Hammarskjöldsleden . . . 1
  - 1.1.1 Description of the current freeway . . . 1
  - 1.1.2 Future plans for Dag Hammarskjöldsleden . . . 3
- 1.2 Aim and research questions . . . 4
- 1.3 Scope . . . 4

2 Theoretical background 5
- 2.1 Barrier effects . . . 5
  - 2.1.1 People's needs . . . 6
  - 2.1.2 Land use . . . 7
  - 2.1.3 Transport features . . . 7
  - 2.1.4 People's abilities . . . 8
  - 2.1.5 Crossing facilities and routes . . . 10
  - 2.1.6 Effects and potential feedback loops . . . 13
- 2.2 Measures to reduce barrier effects . . . 13
- 2.3 Boulevards . . . 18
  - 2.3.1 The origin . . . 18
  - 2.3.2 Categories of boulevards . . . 19
  - 2.3.3 Values and benefits . . . 21
- 2.4 Indicators of barrier effects . . . 24

3 Methodology 26
- 3.1 Literature study . . . 27
- 3.2 Choice of facility categories . . . 27
- 3.3 Selection of study- and analysis area . . . 29
- 3.4 Choice of indicators . . . 30
- 3.5 Data sources . . . 31
- 3.6 Scenarios . . . 34
- 3.7 Creation of the GIS-model . . . 36
  - 3.7.1 Address-points . . . 36
  - 3.7.2 Street network . . . 37

3.7.3 Facilities . . . 39
3.8 Calculate and visualise the barrier effect indicators . . . 43
3.8.1 Scaling . . . 44
3.8.2 Change in ranking . . . 44
3.8.3 Difference calculations with regard to the scenarios . . . 44
3.8.4 Presentation of the Choice and Proximity indicators . . . 45

4 Results **47**
4.1 Models of the four scenarios . . . 47
4.2 Barrier effect indicators (scenario 0) . . . 51
4.3 Comparison of barrier effect scenarios . . . 56
4.3.1 Comparison of scenarios 0 and A . . . 57
4.3.2 Comparisons of scenarios B and C . . . 64

5 Discussion **81**
5.1 Reflections on the boulevardsiation . . . 81
5.1.1 Boulevardisation reduces the barrier effect in the southern part of the study area . . . 81
5.1.2 Improvements of the boulevard project . . . 81
5.1.3 The advantages with boulevards in comparison to other measures . . . 82
5.2 Learnings on boulevards and barrier effects . . . 83
5.2.1 The importance of travel demands . . . 83
5.2.2 The impact of land use . . . 83
5.2.3 Considerations regarding boulevard designs . . . 84
5.2.4 The complexity of the Dag Hammarskjölds boulevard project . . . 85
5.3 Practical applications for van Eldijk's conceptual model . . . 86
5.4 Limitations . . . 87
5.4.1 Representation of destinations with large areas . . . 87
5.4.2 Lack of development plans . . . 87
5.4.3 Lack of street network feature data . . . 88
5.4.4 No reference values of acceptable barrier effects . . . 88
5.5 Further work . . . 89
5.5.1 Psychological aspects . . . 89
5.5.2 Trips made by motor vehicles . . . 89

6 Conclusion **90**

References **96**

Appendices **i**

A Development plans **ii**
A.1 Comprehensive plan areas . . . iv
A.2 Detailed development plans (DP) . . . vi
A.2.1 Other used detailed development plans . . . vii

B Existing buildings **viii**

C Address-points x

D Street network xii
D.1 Model creation xiv

E Facility categories xvi
E.1 Model creation xx

F Statistical summaries of the GIS-analyses xxii
F.1 Statistical summaries of indicator calculations of the individual scenarios . xxii
F.2 Statistical summaries of the difference calculations xxv

Preface

This master's thesis was carried out at the Department of Architecture and Civil Engineering, Chalmers University of Technology, Sweden. The project has been in collaboration with Ramboll. Firstly, we would like to thank our supervisor and examiner Jorge Gil for the valuable feedback and Job van Eldijk who helped us understand the concept of barrier effects.

We would like to thank the rest of the people at Ramboll, including our supervisor Matthias Drefet who made it possible to do our thesis at Ramboll. Staffan Sandberg who was the former project leader of Dag Hammarskjöld boulevard project and was very helpful in informing us about the project. Thanks also to Elsa Thomasdotter and Sara Nilsson for the support with GIS. The input of ideas and thoughts from Aleksej Beilin was also appreciated.

Henrik Lindblad & Arvid Nord, Göteborg June 2022

List of Figures

1.1 The freeway Dag Hammarskjöldsleden in Gothenburg, Sweden is stretching from Linnéplatsen in the north to the interchange Järnbrottsmotet in the south. . . . 2
2.1 Theoretical framework regarding barrier effects in urban areas presented in van Eldijk, Gil, & Marcus (2022). . . . 6
2.2 View of Dag Hammarskjöldsleden facing northwards from Margretebergsgatan. 8
2.3 View of Dag Hammarskjöldsleden facing northwards from the footbridge located between Flatåsmotet and Marconimotet. . . . 9
2.4 The western bracket of the footbridge located between Flatåsmotet and Marconimotet. The bracket demonstrates a steep gradient, creating difficulties for people with reduced mobility. . . . 10
2.5 The stairs leading to the entrance of the underpass located close to Marklandsgatan. The usage of stairs can generate difficulties for people with reduced mobility, exemplified with elderly. This design is particularly problematic due to the steep gradient of the stairs and the lack of passeability for wheelchairs and strollers. . . . 11
2.6 Underpass below Dag Hammarskjöldsleden located just south of Marconimotet. The design and insufficient lighting of the underpass generates a feeling of insecurity for pedestrians, especially during the dark hours. . . . 12
2.7 Underpass below Dag Hammarskjöldsleden located close to Marklandsgatan. Insufficient lighting and the narrow design contributes to a feeling of insecurity, hence reducing the attractiveness of the crossing facility. . . . 12
2.8 Lamps in a park just outside the dog park in Högsbo that make the area and path more attractive when it is dark. . . . 14
2.9 Trafic signal controlled intersection at Marklandsgatan and Högsboleden with separate lanes and signals for motor vehicles, cyclists and pedestrians. 15
2.10 A green buffer with trees that separates the bike lanes from Dag Hammarskjöldsleden close to the Botanical garden tram station. The green median makes the cyclist feel safer. . . . 15
2.11 The Bonaventure Expressway in Montreal, Canada that previously generated barrier effects for the residents in the neighbourhood Griffintown (Grevet, 2015) (CC BY-NC-SA 2.0) . . . 17
2.12 Photo of Boston, USA when the Central Artery was dug down under the city and a green area with a boulevard were implemented (Hellogreenway, 2008) (CC BY-SA 3.0) . . . 18
2.13 Cross section sketch of centre median boulevard Vasagatan in Gothenburg, Sweden. . . . 19
2.14 Cross section sketch of the bouelavrd street Kungsladugårdsgatan in Gothenburg, Sweden. . . . 20
2.15 Cross section sketch of the multiway boulevard Avenue de la Grande Armée in Paris, France. . . . 20
2.16 The multiway boulevard Avenue de la Grande Armée in Paris, France that handle multiple transport modes (Salard, 2020) (CC BY-SA 2.0) . . . 21

2.17 The values of implementing boulevards in cities. The values are related to supporting social, ecological, and economic sustainability among others (Jacobs, Macdonald, & Rofé, 2003; Göteborgs stad, trafikkontoret, 2018; Boverket, 2019). 21
2.18 The boulevard La Rambla in Barcelona, Spain that is a lively place with pedestrians as the main road users (Mulder, 2015) (CC BY 3.0) 22
2.19 The boulevard Sønder in Copenhagen, Denmark that has a green and playful median (Webster, 2014) (CC BY 2.0) 23
3.1 Method of the thesis, where the coloured boxes represent the four major phases in the project. The dashed arrows represent revision, in contrast to the regular arrows represent the main flow of the method. 26
3.2 Proposed location of the Dag Hammarskjöld boulevard, the study- and analysis area in the thesis. 29
3.3 An overview of the development plans that been considered to create the GIS-model. 33
3.4 The four scenarios. 0 represents the existing infrastructure and urban development, and C the proposed infrastructure and development in the study area. 34
3.5 Non-buildable area in green to modulate scenario B. The study area in pink and existing and new buildings in black. Background: ESRI Gray (dark). . 35
3.6 The address-points are converted to Voronoi polygons to illustrate the Proximity and Choice analyses of the buildings. 46
4.1 GIS-model overview of scenario 0. Scenario 0 shows how the area looks like today with the freeway and current urban development. 48
4.2 The four scenarios around Marconimotet to visualise the differences in the geographic information system (GIS) model. Orange represents the future streets and buildings, while black what is existing existing. Background: CartoDB - Positron 49
4.3 GIS-model overview of the four scenarios. The coloured layers in scenarios A, B and C illustrate differences in comparisons to from scenario 0. See section 3.6 for an explanation of the scenarios. 50
4.4 Choice of grocery stores [-], scenario 0 51
4.5 Catchment of daycares [residents], scenario 0 52
4.6 Network distance to the closest park [m], scenario 0 53
4.7 Betweenness [ranking], scenario 0. Colour intervals with natural breaks (Jenks). 54
4.8 Detour factor [-], scenario 0 55
4.9 The changes between scenario 0 and scenario A in regard of grocery stores for indicator Choice. 57
4.10 The changes between scenario 0 and scenario A in regard of grocery stores for indicator Proximity. 58
4.11 The results for indicator Proximity for scenarios 0 and A in regard to facility category parks. 60
4.12 Presents the Detour factor for scenarios 0 and A. 61
4.13 Presents the Detour factor for scenarios 0 and A in comparison with the guidelines presented in Trafikverket, Boverket, & SKL (2015). 62

4.14 Presents the comparison between scenarios 0 and A for indicator Betweenness. 63
4.15 The changes between scenario B and scenario C in regard to choice of grocery stores for indicator Choice. 65
4.16 The changes between scenario B and scenario C in regard to choice of sport facilities for indicator Choice. 66
4.17 The changes between scenario B and scenario C in regard of gyms for indicator Choice. 67
4.18 The changes between scenario B and scenario C in regard of bars, restaurants, and cafes for indicator Choice. 68
4.19 The changes between scenario B and scenario C in regard of daycare for indicator Catchment. 69
4.20 The changes between scenario B and scenario C in regard of parks for indicator Catchment. 70
4.21 The changes between scenario B and scenario C in regard of schools for indicator Catchment. 71
4.22 The results for the comparison between scenario B and scenario C in regard of grocery stores for indicator Proximity. 73
4.23 The results for the comparison between scenario B and scenario C in regard of gyms for indicator Proximity. 74
4.24 The results for the comparison between scenario B and scenario C in regard of gyms for indicator Proximity. The are expressed in absolute values. . . . 75
4.25 The results for indicator Proximity for scenarios B and C in regard to facility category parks. 76
4.26 Presents the Detour factor for scenarios B and C. 77
4.27 Presents the Detour factor for scenarios B and C in comparison with the guidelines presented in Trafikverket et al. (2015). 78
4.28 Presents the comparison between scenarios B and C for indicator Betweenness. 79
A.1 comprehensive plan (CP)-areas, based on Göteborgs stad, stadsbyggnadskontoret (n.d.) iv

List of Tables

2.1 Quality of pedestrian network regarding detour (Trafikverket et al., 2015) . 25
3.1 The selected facility categories and their corresponding determination of attraction. 28
3.2 Indicators of direct barrier effects that will be analysed 30
3.3 Datasets used to create the GIS models to represent the current situation. 32
3.4 Plans of future urban development in the study area of to create scenario A, B and C. 33
3.5 gross floor area (GFA) [m^2] per person and form of housing, based on Statistics Sweden (2020d). 36
3.6 Residential density of new buildings. 37
3.7 The selected facility categories and the types of facilities included in each category. 40
3.8 Total number of current and future facilities within the CP of Högsbo-Flatås 41
3.9 Performed spatial analyses 43
3.10 Colour intervals of change in ranking to make analyses with normalised values comparable. Green indicates improvements and red vice versa. 45
A.1 Current and future population in the CP and current and predicted new population in the model. The data is based on Göteborgs stad, stadsbyggnadskontoret (n.d.). v
A.2 People per household in Gothenburg (Statistics Sweden, 2020a) vi
A.3 Population is calculated with values in table A.2 vi
F.1 Statistical summary of the Proximity analyses xxii
F.2 Statistical summary of the Choice analyses xxiii
F.3 Statistical summary of the Catchment analyses xxiv
F.4 Statistical summary of the Proximity difference analyses xxv
F.5 Statistical summary of the Choice difference analyses xxv
F.6 Statistical summary of the Catchment difference analyses xxvi

Acronyms

CP comprehensive plan. iv, v, xi, xiv, xv, xx, xxi, 31, 33, 34, 36–41

DF Detour factor. 24, 30, 43, 55, 61, 62, 77, 78, 81, 86, 88, 90

DP detailed development plan. xi, xx, 31, 33, 34, 36–38, 40–42, 87

GFA gross floor area. x, xv, 32, 36

GIS geographic information system. xiii, 30, 31, 36, 41, 43, 49, 87, 89

OSM Open Street Map. 31, 37

PST Place Syntax Tool. 30, 38, 43, 44

SMoG Spatial Morphology Group, Chalmers University of Technology. x, 30, 31, 36

1 Introduction

With increasing population and growing cities, transport infrastructures such as highways and railways are crucial features in many cities. To meet the travel demand, these infrastructures are often centrally located. An efficient highway or railway requires a high-capacity design with level separated crossings to reduce the conflicts. However, they can become barriers in a city, divide areas and segregate people. The effects a transport infrastructure can have on the local movement of people, especially by active modes such as walking and cycling, and their interactions are called barrier effects. In contrast to highways, a boulevard is less dedicated to motor vehicles but used to create attractive urban areas and serve multiple traffic modes, including walking and cycling. Boulevardisation of transport infrastructures is an established concept to expand cities and build vibrant areas.

Due to the large number of factors influencing barrier effects, the subject forms a complex problem difficult to address. To better understand the concept of barrier effects, van Eldijk et al. (2022) performed a literature study summarising the current knowledge of the subject. The study proposes a conceptual model and a summary of barrier effect indicators that will be used in this thesis to assess and describe the barrier effects in the case of the boulevardisation of Dag Hammarsköldsleden.

1.1 Dag Hammarskjöldsleden

The city of Gothenburg was subject to large growth in the early 1960-s due to the incorporation of surrounding urban areas like Säve, Angered, Tuve, and Torslanda (Göteborgs stad, trafikkontoret, 2013). Beyond this incorporation was a massive development of dwellings in progress, primarily in the suburban areas of Bergsjön, Tynnered, and Västra Frölunda. Besides the overall expansion of Gothenburg had the access to cars among the average citizens increased rapidly, generating a need to adapt the transportation system to the new conditions. To address these demands, the City of Gothenburg adopted a new traffic plan in 1959, advocating the construction of a network of freeways to ensure good connectivity throughout the city (Göteborgs stad, trafikkontoret, 2013). The design suggested a separation between the traffic and surrounding residential buildings, creating a street network segregated based on function. The freeways were dimensioned to ensure sufficient capacity also for the expected increase in traffic during the following decades, hence guaranteeing the functionality of the freeways in the longer time perspective. Examples of freeways and highways build during the 1960-s area are Lundbyleden, Västerleden, Söderleden and Dag Hammarskjöldsleden, which all still constitutes important routes for the motorised traffic within Gothenburg.

1.1.1 Description of the current freeway

Dag Hammarskjöldsleden is located southwest of the city center in Gothenburg in connection to the park Slottsskogen and Änggårdsbergen, see figure 1.1. The freeway covers a distance of 5 km from Linnéplatsen in the north to the interchange Järnbrottsmotet in the south (Göteborgs stad, trafikkontoret, 2022). The traffic volumes on Dag Hammarskjöldsleden have generally reduced during the last decades, to various extents along the route. However, Dag Hammarskjöldsleden remains heavily trafficked with approximately 24 000

vehicles/day north of the street Marklandsgatan and between 31 000 - 37 000 vehicles/day south of Marklandsgatan, meaning that the freeway still constitutes an important part of the general road network.

The area surrounding Dag Hammarskjöldsleden can be divided into three main parts, dependent on the characteristics of the urban development (Göteborgs stad, trafikkontoret, 2022). The northern part of the freeway is surrounded by Slottsskogen on the western side and of a minor residential area and Änggårdsbergen on the eastern side. One of Gothenburg's main facilities, Sahlgrenska University Hospital, is located approximately 500 meters from the freeway along its eastern side. The urban development of the middle area is formed by residential areas with apartment buildings and corresponding services along the western side, and industrial areas and smaller businesses on the eastern side. The southern part shares many similarities with the middle part, with the exception that the residential areas are formed by detached houses and terrace houses. A few crossing facilities constituted by bridges and underpasses for pedestrians and cyclists can be identified along the freeway, especially in the middle part of the route. Additionally, several interchanges are located along Dag Hammarskjöldsleden: Annedalsmotet in the northern part, Margretebergsmotet, Flatåsmotet, and Marconimotet in the middle part, and Radiomotet in the southern part.

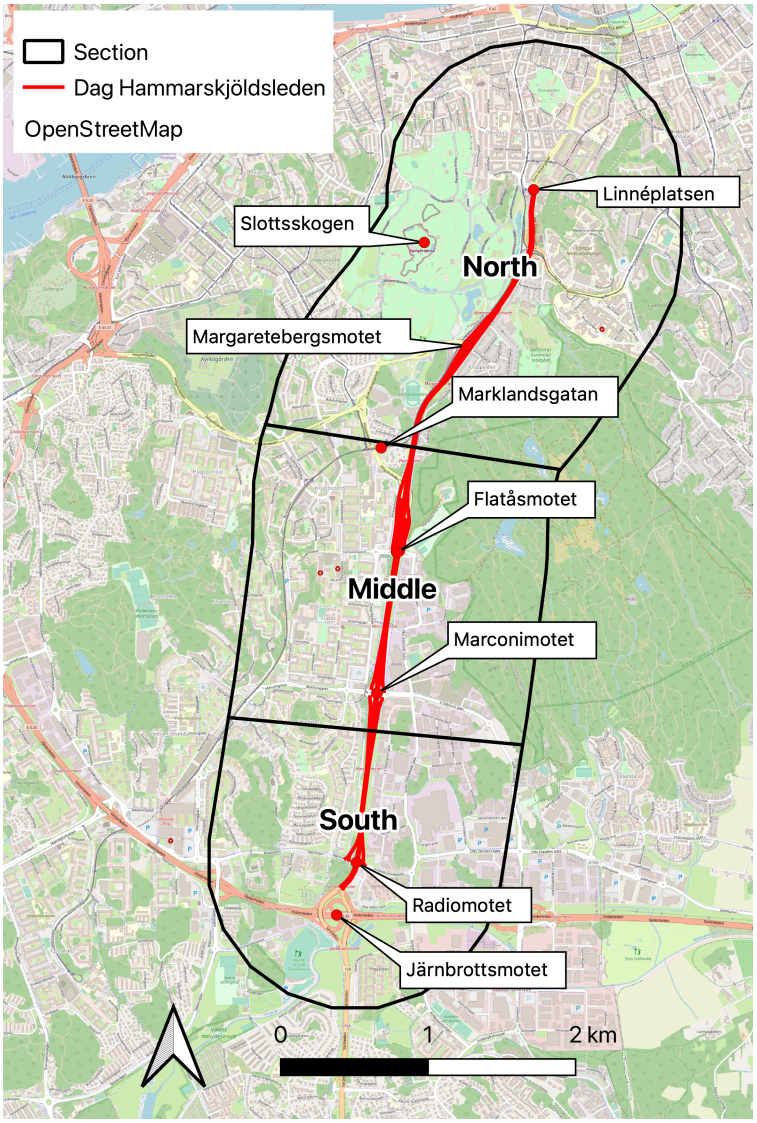


Figure 1.1: *The freeway Dag Hammarskjöldsleden in Gothenburg, Sweden is stretching from Linnéplatsen in the north to the interchange Järnbrottsmotet in the south.*

1.1.2 Future plans for Dag Hammarskjöldsleden

Dag Hammarskjöldsleden and the surrounding areas are part of the new immersed comprehensive plan for Högsbo-Frölunda, presenting the strategy for the planned densification of southwestern Gothenburg (Göteborgs stad, trafikkontoret, 2022). The plan is to increase the current population by approximately 53 000 in the year 2020 to around 100 000 in the year 2050, through the densification of current residential areas and the transformation of current industrial areas towards residential areas. An area of special interest is the middle and southern parts of Dag Hammarskjöldsleden and surrounding areas, where a substantial share of the new dwellings are planned. To achieve these goals, the City of Gothenburg suggests a transformation of the current freeway Dag Hammarskjöldsleden into an urban boulevard. The current freeway has overcapacity in comparison to current needs and covers large amounts of land that the city desires to use for residential buildings.

The City of Gothenburg has created a set of goals for the potential boulevardisation of Dag Hammarskjöldsleden, affecting both the urban development and the travel patterns of the city's inhabitants. One of the major goals presented in Göteborgs stad, trafikkontoret (2022) is to ensure cohesive neighborhoods accommodating both dwellings and services, connecting the western and eastern sides of the current freeway through a reduction of its associated barrier effects. One important aspect of the connected city around Dag Hammarskjöldsleden is to ensure access to services and businesses for the residents, exemplified by schools and grocery stores. Attractive and lively city environments are another of the main goals related to the project and presented in the city of Gothenburg's traffic strategy document (Göteborg stad, trafikkontoret, 2014), which constitutes the governing document for traffic-related decisions within the city. Göteborg stad, trafikkontoret (2014) presents orientability and the absence of bigger barriers in the street network as an important factor to consider to ensure an attractive city, and emphasises the need for a fine mesh network that links the city together. Finally, Göteborgs stad, trafikkontoret (2022) presents the importance to promote sustainable transportation within the area. This is planned to be achieved through the construction of a new tramline in the middle of the planned boulevard as well as improvements of the network for pedestrians and cyclists through the constriction of new bike lanes and pavements.

One major feature of the transformation is the proposed tramway in the middle of the planned boulevard. Göteborgs stad, trafikkontoret (2022) emphasises the importance of public transport with high capacity to enable the planned urban development in connection to the current freeway. Additionally, investigations of a potential railway below the planned boulevard have been introduced. The railway is intended to improve the connections between the southern part of the city and the central areas, as an extension of the Västlänken project.

To address both the current conditions and challenges as well as the future goals of the planned boulevardisation, a preliminary design of the future boulevard is presented in Ramboll & Göteborgs Stad (2021). Noteworthy features of the preliminary design are the high density of the suggested urban development in the middle part, especially in connection to the current interchange Marconimotet, and the addition of several crossing facilities for pedestrians and cyclists, predominantly in the middle and southern parts of the study area.

1.2 Aim and research questions

This thesis aims to investigate the suitability of boulevards as a method to reduce the problems related to barrier effects caused by transport infrastructure in cities. It also aims to determine how to design boulevards to reduce barrier effects using the Dag Hammarskjöld boulevard project as a case study. Finally, the thesis aims to determine how the model from van Eldijk can be used for the determination of barrier effects of boulevards and which of the included indicators is most beneficial for these cases.

The following questions will be addressed:

1. Does the suggested boulevardisation of Dag Hammarskjöldsleden contribute to the fulfilment of the project's objectives in regard to barrier effects?
2. What is the impact of boulevardisation on barrier effects?
    2.1 What is the contribution of the boulevard design?
    2.2 What are the effects of the urban development and land use change?
3. How can the barrier effects conceptual model be applied in practise to the case of boulevards?
    3.1 What quantitative indicators seem to be most relevant for the determination of barrier effects?
    3.2 At what stages of a project regarding barrier effects is the conceptual model best applied?

1.3 Scope

Though benefits of boulevardisation from a barrier effect perspective are examined, barrier effects of the boulevardisation of Dag Hammarskjöldsleden is only studied with the current and future planned urban development.

Direct static barrier effects for local trips regarding pedestrians and cyclists are analysed. Therefore, how barrier effects affect motorised vehicles and wildlife are not taken into consideration. The variants of the local trips are dependent on the chosen facility categories.

2 Theoretical background

This section presents an overview of the theory and has acted as a framework when choices, assumptions and interpretations have been made in the project. Firstly, van Eldijk's conceptual model of barrier effects is presented, describing the five determinants and how they are related. The following subsection presents examples of design measures that can be implemented to reduce barrier effects and other street transition projects addressing barrier effects. Next, the concept of boulevards is introduced and finally indicators of barrier effects.

2.1 Barrier effects

Railways and freeways are commonly found features of transport infrastructure that are present in many urban environments. These types of transport infrastructure are intended to improve inter-urban and regional accessibility for the motorised road- and rail traffic. However, transport infrastructure does often generate a negative impact on the local accessibility for pedestrians and cyclists through the creation of barrier effects (van Eldijk, Gil, & Marcus, 2022). Typical impacts caused by barrier effects are reduced access to services and workplaces, increased travel time and effort for pedestrians and cyclists through detours, and a decrease in social contacts and street life. The barrier effects and their amplitude are the product of the inter-communion of multiple factors, making the determination of the effects difficult in many cases. Anciães, Jones, & Mindell (2016) demonstrates that even though multiple ways to determine barrier effects exist as of today, they are seldom used in practice due to their deficient, complicated input data and difficulties to provide quantitative results possible to use as a decision basis for possible improvements.

In the review by van Eldijk et al. (2022) the authors created a conceptual model that describes the origin of barrier effects using five determinants. The five determinants identified by van Eldijk et al. (2022) are: (1) people's needs, (2) land use, (3) transport features, (4) people's abilities, and (5) crossing facilities and routes. In accordance with Guo & Black (2004) and Korner (1979), van Eldijk et al. (2022) divides the resulting barrier effects into three levels: (1) direct effects, (2) indirect effects, and (3) wider effects. The direct effects can be described as effects that occur instantly and can be exemplified with an increase in travel time, crossing and trip effort, and decreased accessibility. The indirect effects are impacts that emerge as an effect of the limited accessibility. These effects can be exemplified through changes in travel behaviour and modal choice on a personal level. The third and final level is the wider effects concern the changes in travel behaviour on a societal level, hence influencing factors like urban development as well as the health and well-being of the citizens. Figure 2.1 displays a visual design of the interface between these five identified determinants and the three levels of resulting barrier effects.

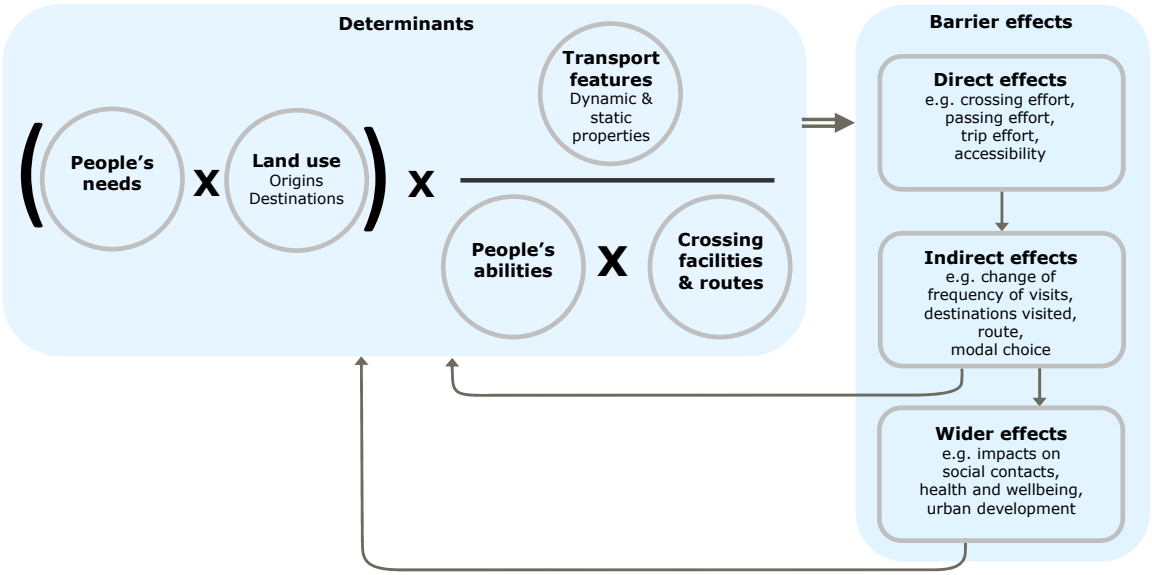


Figure 2.1: *Theoretical framework regarding barrier effects in urban areas presented in van Eldijk et al. (2022).*

2.1.1 People's needs

People's needs are according to van Eldijk et al. (2022) a necessity if barrier effects should arise. The determinant can be described as the access that the citizens require to a certain facility or service, where grocery stores, schools, and green areas are examples. If the access to any required service or facility is limited or hindered by transport infrastructure acting as a barrier, the actual barrier effect is created (Shergold & Pankhurst, 2009). Hence, the need to pass a barrier to access the needed service acts as a basis for this phenomenon. The needs of the local population can vary on an individual level, dependent on the demography of the area (van Eldijk et al., 2022). However, since the impacts cannot be assessed on an individual level in practice, it is necessary to group people with similar needs. Boon, van Wee, & Geurs (2003) states three general groups of needs: consumption, self-fulfilment, and social interaction. Göteborgs stad, trafikkontor (2018) provides a few common destinations for travel within Gothenburg, which demonstrates similarities to or is included in the previously mentioned groups.

2.1.2 Land use

According to van Eldijk et al. (2022) can land use both have a passive and active role in the occurrence and effects of barrier effects. The passive role is noticed through the density and spatial distribution of multiple types of the built environment exemplified through facilities and residential addresses. Land use plays an active role through changes in the spatial distribution, affecting the barrier effects through an increased or decreased need to cross an existing barrier (Héran, 2011). Changes in land use can also contribute to changes where the need to pass a barrier occurs, which also contributes to either increases or decreases of the barrier effects dependent on the conditions. According to Héran (2011) are typical changes to the land use affecting the barrier effects the re-localisation of services such as schools, hence affecting the destinations for the local trips, and the creation of new and expansion of existing residential areas, influencing the origin of the trips. Korner (1979) states that land use through separation of the land in zones with different use, exemplified through industry, residential, retail and service, also has a contribution to barrier effects. The division of land into different zones can increase the distances between different facilities and the need to cross the barrier certain locations, hence generating barrier effects.

2.1.3 Transport features

The determinant transport features describe the characteristics of the certain barrier and constitute a major factor when considering the barrier effects caused by the infrastructure. According to van Eldijk et al. (2022) was the attention towards barrier effects first caused by problems related to road traffic, such as freeways. However, barrier effects are not restricted to road traffic but can also include other types of transport infrastructure found in cities for example railways, or even natural barriers lite waterways. Many researchers distinguish between static and dynamic effects ((Korner, 1979),(Guo & Black, 2000), (Anciães et al., 2016)).

The static effects are related to the design and dimensions of the barrier itself. Examples of factors regarding the transport features that can be assessed as static are according to Korner (1979) road width, height differences through ditches and embankments, visual conditions at crossing points, and traffic isles. Additional static factors are the presence of noise barriers, fences, and railings (van Eldijk et al., 2022). Figure 2.2 and figure 2.3 exhibits two different locations along Dag Hammarskjöldsleden where multiple of the features determining the static properties of the transport features can be detected.

The dynamic factors of the barrier effects are not related to the physical properties of the barrier, but rather to the traffic itself. Korner (1979) states that typical dynamic factors are travel flow, the proportion of heavy traffic, speed, the vehicle distribution in different lanes, and finally the vehicle's headway. Guo & Black (2000) further investigates the impact on barrier effects caused by traffic flow and notes the importance of the headways. If the headways are too small will the gap acceptance not be fulfilled, hence increasing the barrier effects. The presence of parked cars along the barrier can also have an impact on the barrier effects (Anciães et al., 2016). Even though the physical characteristics of a potential barrier makes it fairly easy to cross can it still cause barrier effects through psychological barriers. Barrier effects can be divided into objective barriers, which are the factors related to the characteristics of the barrier itself and independent of the people aiming to cross the

barrier, and the subjective barriers that are the physical reactions that are caused by the built environment. The subjective barriers are heavily influenced by personal perceptions and can therefore vary from person to person, making them more complicated to address beforehand. Examples of effects causing subjective barriers are noise, dust, pollution, vibrations perceived risk for accidents and nuisances caused by traffic (van Eldijk et al., 2022).



Figure 2.2: *View of Dag Hammarskjöldsleden facing northwards from Margretebergsgatan.*

2.1.4 People's abilities

Besides the physical characteristics of the barrier itself and the related crossing facilities, people's abilities are a major determinant of the magnitude and impacts of the barrier effects (van Eldijk et al., 2022). People's abilities affect all types of movement for both pedestrians and cyclists, not only the movement along the barrier or at the crossing facilities. Age is stated to be a dominant factor by both Héran (2011) and Hine & Mitchell (2003), where elderly people and children constitute two vulnerable groups. Children have decreased mobility regarding the physical aspects in comparison with adults. However, the largest difference between children and adults as road users are their ability to understand the traffic, act carefully, and perceive risks (Héran, 2011). Hine & Mitchell (2003) refers to a study that concluded that independent travelling by children to schools had declined between 1971 and 1990, instead of being escorted to school by their parents. Héran (2011) refers to the same study and points out that the single largest reason behind parents escorting their children instead of letting them walk by themselves is the dangers in traffic.



Figure 2.3: *View of Dag Hammarskjöldsleden facing northwards from the footbridge located between Flatåsmotet and Marconimotet.*

Walking is the predominant mode of transportation among elderly people, especially for the younger portion of this group (Hine & Mitchell, 2003). Elderly people's physical abilities are in general lower than younger people. Studies has concluded that elderlies suffer from difficulties when walking related to steps, hills, road and traffic crossings, ramps, uneven pavements, and when carrying bags (Hine & Mitchell, 2003). Mazzonna & Peracchi (2012) describes the proven connection between aging and the loss of cognitive abilities, which naturally varies on an individual level. The cognitive abilities are of importance for understanding and assessments when interacting with others in traffic, hence influencing safety and mobility. According to Hine & Mitchell (2003), the probability for pedestrians to suffer from a traffic accident is three times higher for people older than 70 in comparison with people aged between 30 and 50.

Another factor regarding people's abilities is mobility restrictions, often related to some sort of disability. These disabilities vary a lot among different individuals and create difficulties of diverse nature. Examples of disabilities affecting mobility are disabilities related to physical aspects like the usage of wheelchairs and crutches, blindness or partial sighting, deafness, and mental disabilities (Héran, 2011). Due to these difficulties, people affected by disabilities often travel less, hence lowering their access to activities and services. Several of the existing crossing facilities are designed in a unsuitable way for people with reduced mobility, such as elderly people and people with disabilities. Figure 2.4 displays a bridge bracket suffering with a sharp slope and figure 2.5 the stairs leading to the entrance for one

of the underpasses, both . A third factor is gender, where women, in general, have lower access to cars than men and tend to travel to other parts of the day, often trying to avoid dark hours for safety reasons (Hine & Mitchell, 2003).



Figure 2.4: *The western bracket of the footbridge located between Flatåsmotet and Marconimotet. The bracket demonstrates a steep gradient, creating difficulties for people with reduced mobility.*

2.1.5 Crossing facilities and routes

The fifth determinant included in the conceptual model presented in van Eldijk et al. (2022) is the crossing facilities and routes, hence the places where pedestrians and cyclists can cross and overcome the barriers. Regarding the crossing facilities are their design, frequency, and location important factors that determine their reduction of barrier effects. For slower modes of transportation, which include both cycling and walking, is distance a very important factor, since both these modes are associated with muscular power and physical effort (van Eldijk et al., 2022). To account for the distance aspect for cyclists and pedestrians, these transport modes require a higher frequency of crossing facilities along the barrier in comparison with motorised modes of transportation, for which the travel time is the main factor (Héran, 2011). The location of crossing facilities is also of high importance as a method to decrease the detours, by placing them close to important facilities or along passages where many people travel. High connectivity between the surrounding street network and the crossing facilities is a key factor to utilise the effects on the decrease of barrier effects from crossing facilities (Héran, 2011). Korner (1979) states the importance of the visual conditions and the overview of crossing points to create an understanding



Figure 2.5: *The stairs leading to the entrance of the underpass located close to Marklandsgatan. The usage of stairs can generate difficulties for people with reduced mobility, exemplified with elderly. This design is particularly problematic due to the steep gradient of the stairs and the lack of passeability for wheelchairs and strollers.*

of the facility and a feeling of safety. Grade-separated crossing facilities, like bridges and underpasses, are commonly used in connection to freeways, railways, etc. Since they remove the interaction of different modes of transportation do they have a positive impact on the safety of pedestrians and cyclists but are still generally disliked (Anciaes & Jones, 2018). Grade-separated crossing facilities are often regarded as both time- and effort-consuming, since they are associated with detours and height differences. Underpasses are often perceived as unsafe by elderly people and women, especially during nighttime (Anciaes & Jones, 2018). Figure 2.6 and figure 2.7 displays two of the existing underpasses along Dag Hammarskjöldsleden which both exemplifies underpasses with poor lighting.



Figure 2.6: *Underpass below Dag Hammarskjöldsleden located just south of Marconimotet. The design and insufficient lighting of the underpass generates a feeling of insecurity for pedestrians, especially during the dark hours.*



Figure 2.7: *Underpass below Dag Hammarskjöldsleden located close to Marklandsgatan. Insufficient lighting and the narrow design contributes to a feeling of insecurity, hence reducing the attractiveness of the crossing facility.*

2.1.6 Effects and potential feedback loops

As earlier described can according to van Eldijk et al. (2022) the barrier effects be divided into three categories: : (1) direct effects, (2) indirect effects, and (3) wider effects. The effects follow a hierarchical structure where (2) and (3) are caused by (1) and (2) respectively. Besides the hierarchical structure, the conceptual model contains several feedback loops from (2) and (3) towards the determinants, see figure 2.1. This feedback represents changes to the determinants caused by differences in people's behavior, and even urban development and land use. A potential feedback loop associated with the barrier effects related to Dag Hammarskjöldsleden can be the perceived safety when using the current underpasses. Several of current crossing facilities constitutes of underpasses. As previously described are the lightning conditions within these underpasses substandard, creating a feeling of insecurity. The feeling of insecurity will most probably lead to a decrease in the usage of these underpasses, especially during dark hours. Social surveillance is regarded as a factor that has a positive impact on the fear of crime, increasing the perceived feeling of security. The reduced usage of underpasses will probably decrease social surveillance, hence hurting the overall perceived safety and increasing the barrier effects. A second potential feedback loop is described by van Eldijk et al. (2022), stating that barrier effects can cause a modal shift towards increased car usage. The increase in car usage will lead to larger traffic volumes along with the barriers, hence increasing the barrier effects even further. The diversity between the determinants as well as the effects and their feedback loop makes barrier effects a complex problem to both address and anticipate. It often requires a great understanding of the entire system and awareness of the problem to avoid barrier effects.

2.2 Measures to reduce barrier effects

Due to the complexity of barrier effects, multiple approaches and measures used for the reduction and mitigation of barrier effects exist today. These measures demonstrate a great variation regarding both type and scale, ranging from smaller impacts related to lighting and design of streets to city development and the planning of entire infrastructure projects.

As mentioned in the introduction, the traffic strategy document by Göteborg stad, trafikkontoret (2014) emphasises the benefits of aiming for a fine and united mesh street network in city development for all traffic modes to reduce barrier effects. A fine mesh network makes an area accessible and reachable for all road users because it benefits the directness of the trips. In addition, the increased number of route Choices and crossings increase the traffic volume capacity by spreading the traffic out over the city's street network. It can also create new public spaces that make the city more dynamic and safe because of the lively streets. Implementing street lamps and having aesthetically pleasing buildings are also measures to improve the attractiveness in an area (Trafikverket et al., 2015), see figure 2.8. From a pedestrian point of view, it is beneficial if the sidewalks are wide with a high capacity volume and the capability of activities along the streets such as outdoor seating (Göteborgs stad, trafikkontoret, 2018).



Figure 2.8: *Lamps in a park just outside the dog park in Högsbo that make the area and path more attractive when it is dark.*

The conflict between pedestrians, cyclists and motor vehicles should be avoided by having separated spaces for the different traffic modes (Göteborgs stad, trafikkontoret, 2018; WSP & Parsons Brinckerhoff, 2017). It can be achieved with for example separate bicycle lanes, signals and buffers between the traffic modes on streets with high traffic volume, see figures 2.9 and 2.10. A specific lane for cyclists makes the cyclists also more visible in the traffic as accident prevention (WSP & Parsons Brinckerhoff, 2017). A buffer can for example consist of a tree line as in a boulevard, exemplified in figure 2.10. Additionally, tree lines adds green features in the city (Göteborgs stad, trafikkontoret, 2018).

Vehicle speeds and volume are also parameters that affect the conflict and should therefore be low and restricted (Göteborgs stad, trafikkontoret, 2018). Streets wider than 6 m and with a volume of more than 600 vehicles per daily hour are perceived as a barrier because pedestrians and cyclists have to wait for more than 60 s to cross (Trafikverket et al., 2015). The speed and volume are also extra crucial from a barrier effective perspective if the trip destination is a large playground, a primary school or a small store/kiosk. The speed can be reduced except from regulation with for example adjusting street features such as narrowing the street and implementing parking spaces (Jacobs et al., 2003). Parking along a street results in slower vehicle speeds because of the friction between cars that go in and out of the parking spaces as in multi-way boulevards. It also makes it more accessible to visit the buildings in an area. If possible, level crossings are an option to reduce the conflict between traffic modes (Trafikverket et al., 2015).



Figure 2.9: *Trafic signal controlled intersection at Marklandsgatan and Högsboleden with separate lanes and signals for motor vehicles, cyclists and pedestrians.*



Figure 2.10: *A green buffer with trees that separates the bike lanes from Dag Hammarskjöldsleden close to the Botanical garden tram station. The green median makes the cyclist feel safer.*

City development projects are often based on the idea of transforming an old area into a modern and dense urban space (Göteborgs stad, trafikkontoret, 2018). It could be that a heavily trafficked road is transformed to a lively passage to expand and meet the demand of new homes and businesses. Below are three examples of street infrastructure that will or has been transformed presented.

Helsinki, Finland has a strategic city development plan that involves to gradually redeveloping several of the freeways in the city into boulevards in the next coming decades (Helsingfors stad, stadsplaneringskontoret, 2015). The main reason is the need of growing the city due to the expected increment in the population. By 2050 will more than half a million more people live in the Helsinki region. The increased population requires an expansion of the city and where the highways will not fulfil the purpose of providing fast connections towards the city centre. Boulevards are useful according to the city of Helsinki because they provide the opportunity to exploit along these. However, the Finish transport administration warn for traffic congestion that will affect logistics and timetables for long-distance busses and goods vehicles because of increased travel time due to increased congestion because of the boulevards (Dahlström, 2016). Several surrounding municipalities of Helsinki are also sceptical because of the increased travel time according to Dahlström (2016). They predict that the boulevards are a great investment that benefits Helsinki more than they do to the rest of the region. For that reason, to prevent traffic congestion and promote sustainable transportation are new high-speed trams and cycling lanes are included in the plan (Helsingfors stad, stadsplaneringskontoret, 2015). The travel times are expected to only increase a couple of minutes due to slower speeds and traffic lights according to Helsingfors stad, stadsplaneringskontoret (2015).

An 11-lane Bonaventure Expressway was built in Montreal, Canada for the 1967 World's Fair to ensure a smooth traffic to the downtown (CNU, n.d.). The expo was a success, although it created a barrier to the neighbourhood of Griffintown and made less attractive for development along the waterfront while was very lightly used, see figure 2.11. Before the expressway had inhabitants in Griffintown problems such as chronic unemployment (Lindeman, 2018). Houses become abandoned because people moved out from which increased after the expressway. In September 2017, 50 years later, was the expressway replaced with two boulevards with a multi-purpose with green spaces, exercise equipment, a playground and public art (CNU, n.d.; Lindeman, 2018). With several urban development initiative in the area before and after the boulevard is Griffintown today an exclusive area with high-rise buildings in glass and rooftop swimming pools (Lindeman, 2018).

Another change of infrastructure was "the Big Dig" in Boston, USA. In the 1990s was the Central Artery in Boston, USA one of the busiest highways in the states (Mass.gov, n.d.). The number of vehicles more than doubled since the opening 1959 which led to traffic jam more than 10 hours per day. The highway also cut of neighbourhoods in North end to the rest of the city. The solution to the problem become to dig down the highway under the ground along with building a new tunnel under the water to the airport that leads the traffic around the city centre. In the 1970s was the idea conceived and by 2005, the project was practically finished (Gelinas, 2007). The biggest challenge was to have the city open for business and people while constructing the infrastructure (Mass.gov, n.d.). Efforts to mitigate the project's consequences on the city was a fourth of the total budget. For exam-



Figure 2.11: *The Bonaventure Expressway in Montreal, Canada that previously generated barrier effects for the residents in the neighbourhood Griffintown (Grevet, 2015) (CC BY-NC-SA 2.0)*

ples was temporary roads built to a post distribution centre and industries was promised to not lack electricity for more than a few hours (Gelinas, 2007). The improvements resulted in a 62% lower total vehicle hour from 1995 to 2003, and the air quality got much better (Mass.gov, n.d.). The quality of life and the travel become better for the inhabitants in the northern part of the city. Areas earlier occupied by elevated highways were transited to more than 45 parks, plazas and a tree-lined boulevard along it, see figure 2.12.

When examining the three examples of street infrastructure transformation above can a common denominator in the usage of boulevards be ascertained. A detailed introduction to the origins, categories as well as values, and benefits of boulevards is presented in 2.3.



Figure 2.12: *Photo of Boston, USA when the Central Artery was dug down under the city and a green area with a boulevard were implemented (Hellogreenway, 2008) (CC BY-SA 3.0)*

2.3 Boulevards

There is no universal definition of what a boulevard is, although Jacobs, Macdonald, & Rofé (2003) define boulevards in their most simple form as "a wide street with generous, tree-lined sidewalks". Streets like boulevards are urban spaces that can have multiple purposes such as mobility, economic, recreational, and social activities (Global Designing Cities Initiative & NACTO, 2016; Göteborgs stad, trafikkontoret, 2018). It is in other words a place where people experience a city.

2.3.1 The origin

Boulevards were originally built on obsolete ramparts (Jacobs et al., 2003). Ramparts were parts of medieval city defensive systems as staging areas for weapons within the city wall. These urban spaces were transformed into allée promenades at the end of the 16th century in several European cities, especially in Paris, France. The promenades soon become the centre of recreational purposes due to the lack of social places in Paris and other cities and thereafter become called boulevards. The word boulevard is referred to fortified parts of a city wall. The concept of a boulevard evolved slowly from being a pleasant green path to a lively wide city street with lined trees. The areas around the boulevards in Paris become successively fashionable and popular where restaurants, theatres opened there as the city

grew. With time, different traffic modes become permitted on the boulevards there. Similar rampart boulevards were frequently built around Europe during the 18th century.

Although, the majority of the Paris boulevards were built in the middle of the 19th century (Jacobs et al., 2003). At that time, street fighting and riots were the main cause then to rebuild the medieval Paris roads into boulevards (Moughtin, 2003). This helped the police to move troops fast and efficient between different areas of the city. Baron Georges Eugéne Hussmann was the project leader of this city transformation that occurred between 1853 and 1869 under the commands of Napoleon lll. Hussmann redesigned big parts of Paris and updated the rampart design by for example adding paved roadway and raised curbs (Jacobs et al., 2003). Other benefits that developed the French capital with boulevards were the improved accessibility to public buildings, improved esthetics and better ability to transport goods and people. Sanitation infrastructure was also implemented under the new city streets which improved public health (Jacobs et al., 2003; Moughtin, 2003). However, to be able to build the wide boulevards across the city were historic buildings demolished where often poor people lived which caused major protests. Although, the overall result became that the French economy was stimulated due to the places for social interactions that attracted and enhanced business (Jacobs et al., 2003; Göteborgs stad, trafikkontoret, 2018).

2.3.2 Categories of boulevards

Jacobs et al. (2003) categorise boulevards into three types: centre median boulevard, boulevard street, and multiway boulevard. A centre median boulevard has a median where for example tram rails, pedestrian paths, or a green area are located. Vasagatan in Gothenburg is an example of this type, see figure 2.13. Boulevard street has a vehicle lane located in the middle in each direction, with sidewalks on the sides with a tree line that separate the pedestrians from the vehicle traffic (Jacobs et al., 2003). Parts of Kungladugårdsgatan in Gothenburg is a boulevard street, see figure 2.14.

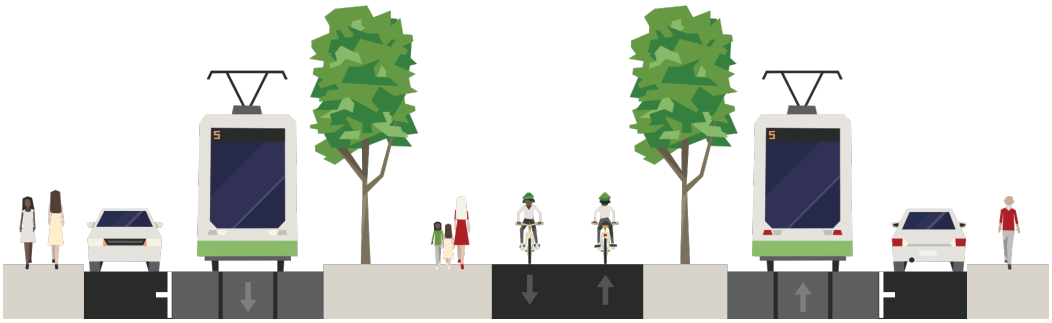


Figure 2.13: *Cross section sketch of centre median boulevard Vasagatan in Gothenburg, Sweden.*

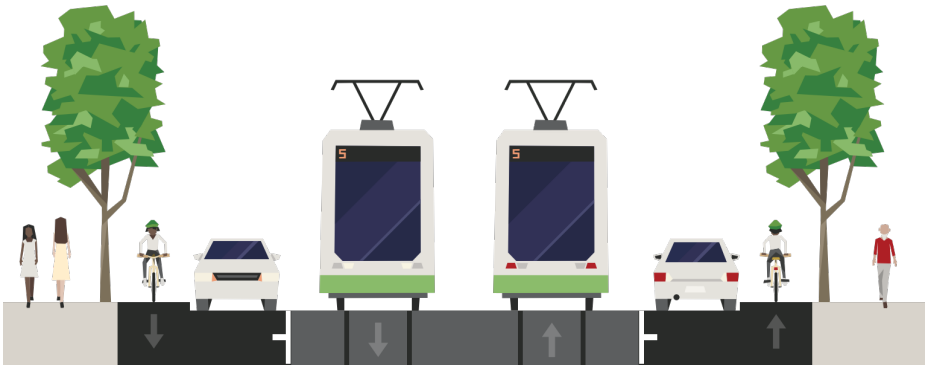


Figure 2.14: *Cross section sketch of the bouelavrd street Kungsladugårdsgatan in Gothenburg, Sweden.*

The last one, the multiway boulevard, is a wide street that separates the local and slower traffic from the through traffic with tree medians (Jacobs et al., 2003). This results in a pedestrian realm and a through-going realm. According to Jacobs et al. should at least four lanes be dedicated for the through traffic. Avenue de la Grande Armée in Paris, France is a characteristic multiway boulevard (Jacobs et al., 2003), see figure 2.15 and 2.16. These are not frequently used in Sweden, although, Ringvägen in Stockholm is a great example of a multiway boulevard. It separates the local traffic from the through traffic and has double lines of linden trees between the two realms (Stockholm stad, Södermalms stadsdelsförvaltning, 2019). A multiway boulevard serves different purposes such as recreation, communication, and parking (Jacobs et al., 2003). The disadvantages of these multifunctional streets are the complex and dangerous intersections and the complicated implementation in an already dense established city environment.

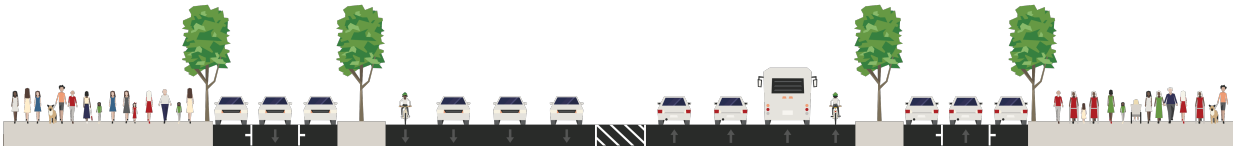


Figure 2.15: *Cross section sketch of the multiway boulevard Avenue de la Grande Armée in Paris, France.*



Figure 2.16: *The multiway boulevard Avenue de la Grande Armée in Paris, France that handle multiple transport modes (Salard, 2020) (CC BY-SA 2.0)*

2.3.3 Values and benefits

Boulevards are used as a tool in city developments because of their multi-functional usages such as technical, social, economic and ecological functions (Göteborgs stad, trafikkontoret, 2018; Boverket, 2019). See figure 2.17 for examples of values and benefits that boulevards can contribute to an urban area.

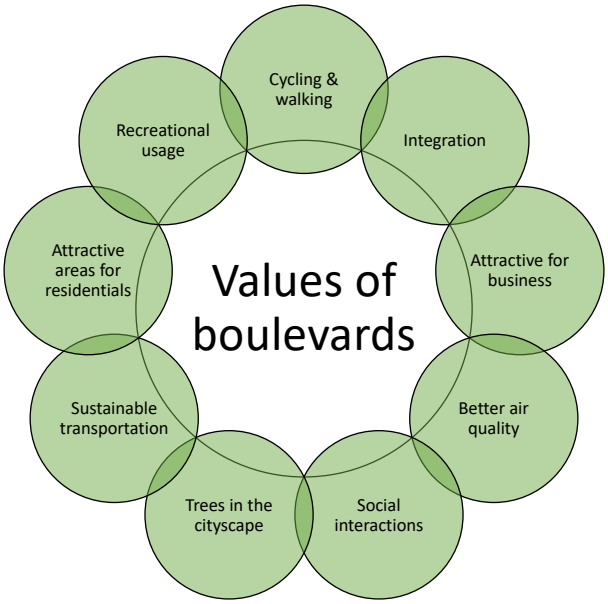


Figure 2.17: *The values of implementing boulevards in cities. The values are related to supporting social, ecological, and economic sustainability among others (Jacobs et al., 2003; Göteborgs stad, trafikkontoret, 2018; Boverket, 2019).*

Implementing boulevards can have socio-economic effects due to their ability to form lively and attractive urban spaces with social interactions (Göteborgs stad, trafikkontoret, 2018). It boosts business and the well-being of the people in the nearby areas. Therefore, boulevards have become landmarks in many cities with trendy neighbourhoods often around and along these. In addition, the common urban space a boulevard can create can benefit the integration between generations and suburban areas in the city. Ramblas Boulevard is a street in central Barcelona, Spain where pedestrians are the main road users and vehicles used for services are restricted to the sides of the street (Moughtin, 2003), see figure 2.18. There are market stalls and cafes along the street for people to meet and interact with each other. It is one of the most famous streets in Spain.



Figure 2.18: *The boulevard La Rambla in Barcelona, Spain that is a lively place with pedestrians as the main road users (Mulder, 2015) (CC BY 3.0)*

Boulevards can also be designed to improve the access of recreational activities in an urban area. Sønder Boulevard in Copenhagen, Denmark was transformed from a traditional wide boulevard aimed for vehicles to a boulevard with a playground and pause areas in the median space (National Association of City Transportation Officials, 2020), see figure 2.19. Before the redesign were trees dying along the road because of the traffic emissions which made the area unattractive.

Wide boulevards are often designed with a mobility purpose to handle a large amount of traffic in densely populated urban areas (Göteborgs stad, trafikkontoret, 2018). They connect locations that many people have as trip destinations, such as universities, office areas and hospitals. Boulevards often serve multiple modes of transportation, such as walking, cycling, public transport and motor vehicles. Although, the many modes on the same street make the intersections as mentioned before complicated and insecure because of the high level of conflict.



Figure 2.19: *The boulevard Sønder in Copenhagen, Denmark that has a green and playful median (Webster, 2014) (CC BY 2.0)*

Investment in public transport is often necessary to avoid traffic congestion and increased travel time. Boulevards can also be unattractive for pedestrians if there are high traffic volumes with high speeds. A Transit Boulevard has a transit system in the middle of the road, such as light rail or tram (Calthorpe, 2002). The usage of public transport and the green areas in a city can improve the air quality and lower the emissions of carbon dioxide (Göteborgs stad, trafikkontoret, 2018).

Bicycle Boulevards are streets that have a high level of safety for cyclists with pavement markings and signs designed for them (WSP & Parsons Brinckerhoff, 2017). They are in comparison to other mobility-boulevards usually with low traffic volumes and speed limits to improve the safety of the cyclists. Lower noise and traffic volumes can also be beneficial for pedestrians and other street users.

2.4 Indicators of barrier effects

As mentioned in section 2.2, barrier effects can be reduced or mitigated through several measures and design solutions. These measures vary in type and scale, exemplified by boulevards. To better understand the potential impact on the reduction of barrier effects caused by these measures, several tools have been developed to assess barrier effects. These tools can be used to measure these impacts by comparing the conditions before and after their implementation. van Eldijk et al. (2022) describes these tools as indicators and divides them into three groups that correspond to the three types of effects. Most of the indicators are created to handle the direct barrier effects and consist of indicators based on geospatial analyses, site visits, and observations as well as surveys and interviews. Table 8 found in van Eldijk et al. (2022) lists all these indicators related to the direct barrier effects, categorised according to their related effects.

The crossing effort constitutes the first category of indicators of direct barrier effects and includes both the static and dynamic characteristics. Indicators of the static characteristics are generally retrieved from geospatial analyses or site visits and can according to Korner (1979) be exemplified by the localisation of barriers, number of lanes, road width, and height differences. The dynamic characterise is related to the speed, volume, and composition of the traffic itself, and is obtained primarily from observations and site visits. One example of an associated indicator is the distribution of acceptable gaps described in Guo & Black (2000). A third and final dimension of the crossing effort is the facilities, where an example presented in Korner (1979) is the effort required for the usage of the crossing feature concerning bridges and overpasses. Indicators related to the passing effort are predominantly the same as for the dynamic characterises but focus on the efforts of transport along the barrier. Another minor category is related to the fear of crime. These indicators are determined through the site audits and examples of associated indicators can be visual conditions and possible escape routes in case of need.

Another major category of indicators related to the direct barrier effects is the trip effort, which is determined through the usage of geospatial analyses. Trip effort can be described as the effort required to conduct a trip regarding distances and angels. The importance of the distance is further emphasized in Trafikverket et al. (2015), even asserting distance as the most affecting factor that governs pedestrians' and cyclists' accessibility to services and other trip destinations. The design of the network and the Choice of destinations are the predominant factors in the determination of the trip effort, both heavily influencing the distances of the trips. Examples of indicators for the trip effort presented by Héran (2011) are the distance between crossing facilities and the number of barriers along routes, which both increases the distances between the origin and the destination of the trip.

Another very useful indicator described by Héran (2011) is the Detour factor (DF) which can be described as the ratio between the real distance between two locations following the network and the linear distance between the same locations. The DF is calculated using equation 2.1 and can be seen as a measurement of the quality of a trip regarding the detour. According to Trafikverket et al. (2015) should the DF preferably not exceed 1.25, see table 2.1. Dhanani & Vaughan (2016) presents the indicator betweenness, which corresponds to the design of the network through the density of segments and the angles between them. The betweenness can be described as the centrality of a street segment on all routes between

any two street segments within a specific distance. In other words, the betweenness of a street segment will be high if it is traversed many times on the shortest angular route between a set of origins and destinations (Dhanani & Vaughan, 2016). An additional indicator of the trip effort is the Proximity of destinations, describing the distance between each address point and the nearest facility within a given facility category (van Eldijk et al., 2022).

The final category of indicators for the direct barrier effects is the accessibility, presenting the influence of barrier effects on the access to services, facilities, and meeting points. The indicators associated with accessibility are determined using geospatial analyses. Examples of indicators included in this category are Choice of destinations, describing the number of destinations of a specific category accessible from each address point within a given distance, and Catchment area, which describes the number of address points within a specific catchment area of each facility within a given facility category (van Eldijk, Gil, Kuska, & Sisinty Patro, 2020).

$$\text{Detour factor} = \frac{\text{Network distance}}{\text{Straight distance}} \text{ (Héran, 2011)} \tag{2.1}$$

Table 2.1: *Quality of pedestrian network regarding detour (Trafikverket et al., 2015)*

Network type	Detour factor		
Local pedestrian network	> 1.5	1.25 - 1.5	< 1.25

Several indicators for the determination of indirect barrier effects are listed in table 9 in van Eldijk et al. (2022). These indicators have in common that they measure changes in the travel behaviour of the people exposed to the barrier effects, hence making them based on surveys and interviews. However, since some of these behaviours are possible to detect through observations Anciaes & Jones (2018) empathises the importance of combining quantitative and qualitative methods for the determination of indirect barrier effects. Tirachini (2015) presents a complementary approach for the calculation of changes in transport behaviour by estimating trips-not-made through the usage of general data for pedestrian travel. Examples of indicators for indirect barrier effects listed by van Eldijk et al. (2022) are modal share, the ratio of changed routes, and the ratio of changes in the number of visits. Regarding the wider effects of barriers, very few explicit indicators exist as of today. The reason behind this is according to van Eldijk et al. (2022) the multiple involved factors, complexity, and development over time associated with the wider barrier effects. The literature discussing the wider barrier effects does instead include the wider barrier effects as one dimension alongside for example pollution and noise in social impact assessments of transport systems. Forkenbrock, Benshoff, & Weisbrod (2001) illuminate the difficulties to translate the social theory regarding barrier effects towards tools used in practice, hence meaning that research for the identification of indicators associated with wider barrier effects needs further attention.

3 Methodology

The methodology of this project is divided into several steps, see figure 3.1. These steps can be grouped into four major phases: literature study (2), initial project setup (3, 4), GIS modelling (5, 6, 7) and assessment and interpretation (8, 9). Step 5 to 9 can be seen in general as an iteration with the goal in step 10 to draw conclusions connected to the research questions. The creation of the GIS-model is simultaneously done and connected with the data gathering along with the calculation and illustration of the spatial analyses. In the assessment & interpretation phase were revision made.

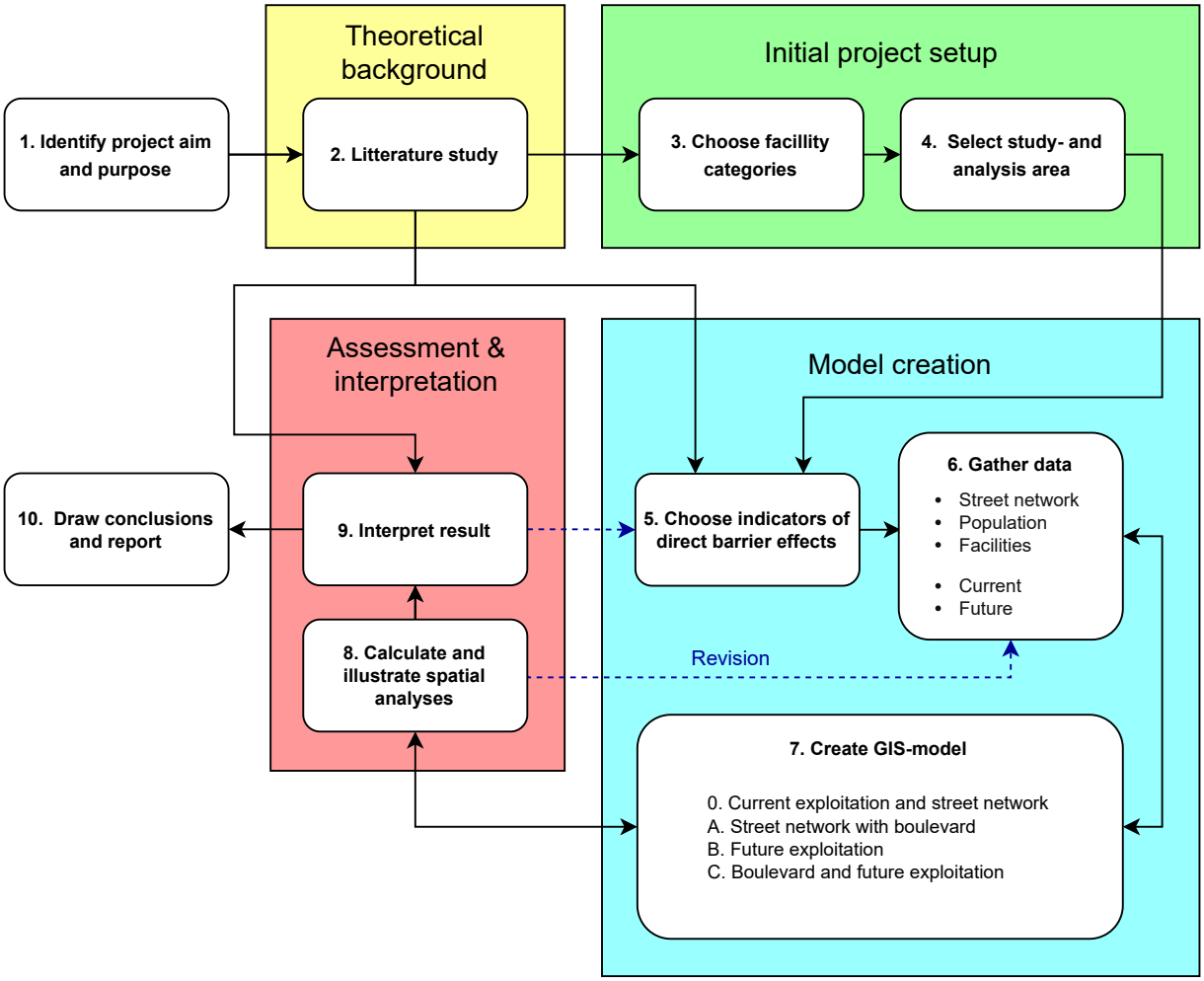


Figure 3.1: *Method of the thesis, where the coloured boxes represent the four major phases in the project. The dashed arrows represent revision, in contrast to the regular arrows represent the main flow of the method.*

3.1 Literature study

A literature study (2) has been conducted to state the causes of barrier effects, the definition and purposes of boulevards and what urban street design can be made to reduce the barrier effects. It supports the work of choosing indicators and facility categories and interpreting the analyses.

For the barrier effect section has the literature van Eldijk, Gil, & Marcus (2022) been central since it describes the conceptual model of barrier effects and contains useful references to investigate the subject. In the boulevard subsection 2.3 the Boulevard Book by Jacobs, Macdonald, & Rofé (2003) and the city of Gothenburg's knowledge compilation of boulevards (Göteborgs stad, trafikkontoret, 2018) have been frequently used. The Boulevard book is almost an encyclopedia for multiway boulevards, with sketches, design suggestions and more. The knowledge compilation is a theoretical background for the Dag Hammarskjöld boulevard project regarding how boulevards are use full and what role do they have in urban environments. The documentation for the handbook of traffic for an attractive city, TRAST, financed and published by the Swedish transport administration (Trafikverket et al., 2015) has mainly been used in the section about design measures to reduce barrier effects. TRAST is a guideline for road planners and decision makers in traffic related topics and projects.

Reports and papers published by the city of Gothenburg at the Dag Hammarskjöld project webpage[1] on the city of Gothenburg has been used to obtain information about the case study place and about boulevards in general. Figures 2.13, 2.14 and 2.15 in the boulevard theory subsection have been created in the web-based program Streetmix[2]. The content is governed under Creative Common CC-BY-SA license.

3.2 Choice of facility categories

According to the conceptual model presented in the theory section 2.1 is land use combined with people's needs the factors that create the need to pass barriers, hence generating barrier effects. Several facility categories that constitute target points for local travel within the research area were selected to represent these driving factors (3), see table 3.1. The choice of facility categories was based on statistics in Göteborgs stad, trafikkontor (2018) of local trips in the region of Västra Götaland, where the five most common local travel categories were selected, see table 3.1. One of the categories presented in Göteborgs stad, trafikkontor (2018), shopping, has been simplified to grocery stores, due to the lack of shopping centres in the study area. Trafikverket (2011) describes that a majority of the shopping except groceries is conducted in shopping malls with a large variety of stores and products.

[1] https://goteborg.se/wps/portal/start/byggande--lantmateri-och-planarbete/kommunens-planarbete/plan--och-byggprojekt?uri=gbglnk%3Agbg.page.bb7386fd-1152-47cb-9da4-d06bd7780a77&projektid=3757-16

[2] http://streetmix.net

The selected facility categories can be divided into three main groups: education, food business and leisure. The access to education as schools and daycare constitutes important services, hence making them important target points within the planning of urban development. Many food businesses constitute important target points for the local trips within the city and are hence of interest when examining the barrier effects caused by transport infrastructure. Another important type of target point is activities related to leisure, exemplified by parks, gyms, and sports facilities. Access to different types of leisure is of high importance to ensure an attractive city for the inhabitants. Within the selected facility categories were attraction values assigned to each of the included facilities. Due to the variation within each of the selected facility categories were the attraction determined by different factors, see table 3.1.

Table 3.1: *The selected facility categories and their corresponding determination of attraction.*

Facility category		Determination of attraction
Education	Daycare	Equal attraction
	Schools	Equal attraction
Food business	Grocery stores	Equal attraction
	Bars, cafes and restaurants	Equal attraction
Leisure	Gyms	Equal attraction
	Parks	Area
	Sport facilities	Equal attraction

3.3 Selection of study- and analysis area

Since this project focus on local trips is only trips made by foot and bicycle focused on (Göteborgs stad, trafikkontor, 2018). According to Göteborgs stad, trafikkontor (2018) table 15, the median distance of a cycling trip is 3km. Hence, data are collected in a buffer of 3000 m around the Dag Hammarskjöld boulevard from the design proposal (Ramboll & Göteborgs Stad, 2021), see figure 3.2. This area is refereed in this thesis as the analysis area (4). A buffer of 1000 m was also calculated which is refereed as the study area where the spatial analyses will be analysed. The median distance of trip by foot is 1000m (Göteborgs stad, trafikkontor, 2018).

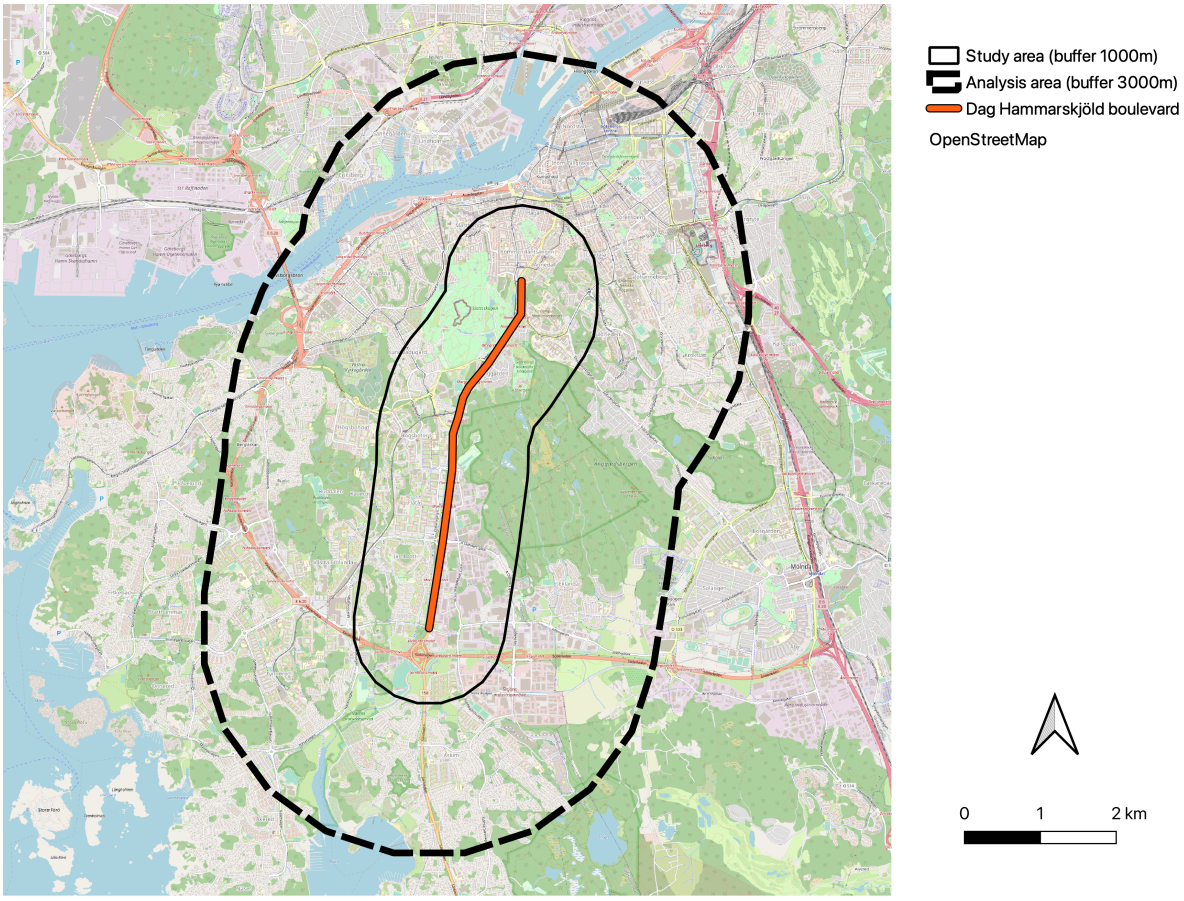


Figure 3.2: *Proposed location of the Dag Hammarskjöld boulevard, the study- and analysis area in the thesis.*

3.4 Choice of indicators

Based on the knowledge from the theoretical background and the goals and ambitions set by the city of Gothenburg have five indicators been selected among those that can be used to investigate the direct barrier effects of the proposed Dag Hammarskjöld boulevard (5), see table 3.2. To examine the barrier effects related to the accessibility to services; Catchment areas, Choice/substitutability of destinations and Proximity were chosen. DF and Betweenness are indicators that focus on examining the walkability and the attractiveness of the street network itself. Place Syntax Tool (PST)[3] is an open-source GIS plug-in developed by KTH of Architecture, Spatial Morphology Group, Chalmers University of Technology (SMoG) and Spacescape AB. It is used to perform most of the spatial analyses. For calculating the DF, a script provided by Ramboll used that calculates the mean DF within a given radius.

Table 3.2: *Indicators of direct barrier effects that will be analysed*

Indicator	Description	Tool
Proximity of destinations	Network distance/travel time from a address to the nearest specific category facility	PST, Attraction Distance
Choice/substitutability of destinations	Number of destinations that are accessible from each address point within a given radius	PST, Attraction Reach
Catchment areas for facilities	Number of residents in a facility category's Catchment area within a given radius	PST, Attraction Reach
Detour factor	Network distance dived by the distance of a straight line	DF script
Betweenness	How often a segment is part of the route with lowest impedance within a radius	PST, Angular choice

[3] https://www.smog.chalmers.se/pst

3.5 Data sources

To be able to create suitable models to perform the spatial analyses, data gathering (6) of the current and planned street network, population and facilities are required. In other words, network, origins and destinations. See table 3.3 for the datasets that have been used to create the GIS models.

Three sources have been used to obtain data for the facility categories. The City of Gothenburg has data of all the business and services that handles food in the city (Göteborgs stad, miljöförvaltningen, n.d.). This is because the municipality is responsible to control these for food handling according to food regulations (Swedish Food Agency, 2022). The services and business that are included and relevant based on the chosen facility categories in the dataset are daycares, schools, grocery stores, bars, cafes and restaurants. Schools and daycares are included in this dataset because they have to handle and serve school lunch to their pupills (SkolmatSverige, n.d.). To complement the dataset is Open Street Map (OSM) used to obtain the same data of restaurants and grocery stores within the border of Mölndal municipality. Since the boulevard is within the border of the city of Gothenburg, schools and daycare facilities are neglected since trips to these are made within the City of Gothenburg municipality. The quality and quantity of the data in OSM are dependent on work from volunteers. Although, it has been considered to be enough accurate to build a reliable model of the area and perform the spatial analyses in this project. The OSM datasets are downloaded through Over Pass Turbo[4] and the tool Query Wizard there. OSM has also been used to obtain GIS-data of leisure facility categories gyms, parks, and sport facilities together with data of locations of the address-points in the area. For the street network, a non-motorised street network created by SMoG been used to module the current street infrastructure network (Stavroulaki, Pont, Marcus, & Sun, 2020). The dataset is based on vector-data from OSM that been adjusted.

Different types of plans in the analysis area have been used to create the model for the future street network and urban development, see table 3.4, figure 3.3 and appendix A. When the plans were not compatible with each other were primarily the detailed development plans (DPs) modulated followed by the design proposal of the boulevard and lastly the CP of the suburban areas Frölunda-Högsbo. DPs are used primary since they are legally binding documents and therefore also the most accurate to future urban development.

[4] https://overpass-turbo.eu

Table 3.3: *Datasets used to create the GIS models to represent the current situation.*

Dataset	Description	Source (Licence)
Street network	Vector lines of the non-motorised street network	Stavroulaki et al. (2020) (CC BY-NC-SA 4.0) via Swedish National Data Service
Buildings	Vector polygons with the buildings' purposes (apartment building, detached house, industry etc.)	© Lantmäteriet (2021)(FUK)
Buildings	Vector polygons with the number of floors and gross floor area (GFA) $[m^2]$	Spatial Morphology Group (n.d.)
Addresses	Vector points with the location of the addresses	Open Street Map (n.d.-a)(ODbL 1.0) via Overpass turbo
Population	Vector polygons representing DEsO-areas with the number of residents	Statistics Sweden (2020b,c) (CC0 1.0)
Facility categories - food businesses, education	CSV-file with coordinates and purposes of the food business and education facilities in the city of Gothenburg	Göteborgs stad, miljöförvaltningen (n.d.)(CC0 1.0)
Facility categories - food business	Vector points with the location and purposes of facility categories restaurants and convince stores in the municipality of Mölndal	Open Street Map (n.d.-c)(CC0 1.0)
Facility categories - leisure	Vector points and polygons to define the locations and purposes of the leisure facilities in the analysis area	Open Street Map (n.d.-b)(ODbL 1.0) via Overpass turbo

Table 3.4: *Plans of future urban development in the study area of to create scenario A, B and C.*

Plan	Type	Purpose	Source
Detailed development plans (DPs)	Street network, land usage	Defining the future non-motorised street network, new urban development (including schools, daycare and leisure) and parks	Göteborgs stad, stadsbyggnadskontoret (2019b,a, 2018, 2017). See also appendix A.2.1
Design proposal of the Dag Hammarskjöld boulevard project	Street network (streets, tram rail, pedestrian/cycling paths, crossings), density of new urban development, green areas	Defining the future non-motorised street network, new urban development	Ramboll & Göteborgs Stad (2021)
Comprehensive plan (CP) of sub-area Högsbo-Frölunda	Planed future number of residents, current number of residents, area status	Define how many new residents will move into the area	Göteborgs stad, stadsbyggnadskontoret (n.d.)

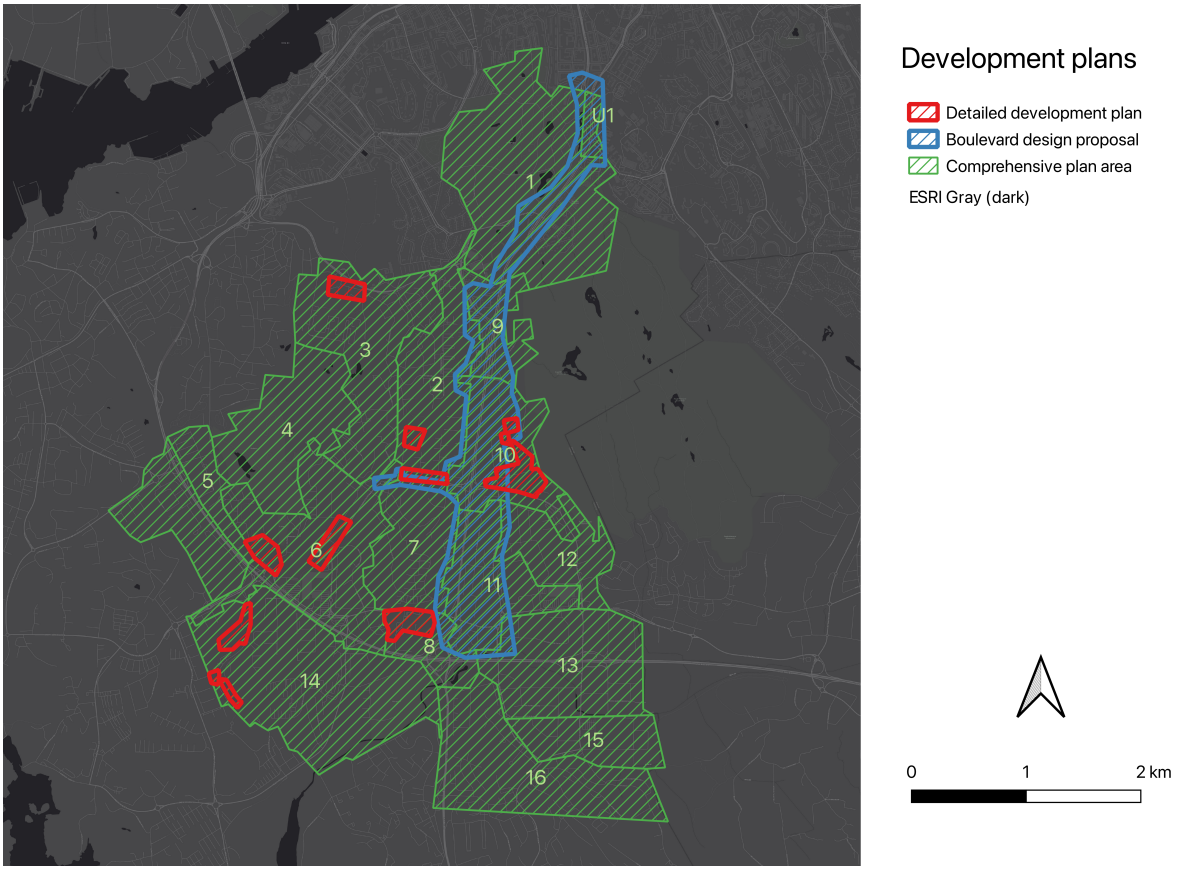


Figure 3.3: *An overview of the development plans that been considered to create the GIS-model.*

3.6 Scenarios

Four scenarios have been created, see table 3.4. The different scenarios are supposed to represent different stages and alternatives related to the project to examine the impact of the barrier effects related to the street network.

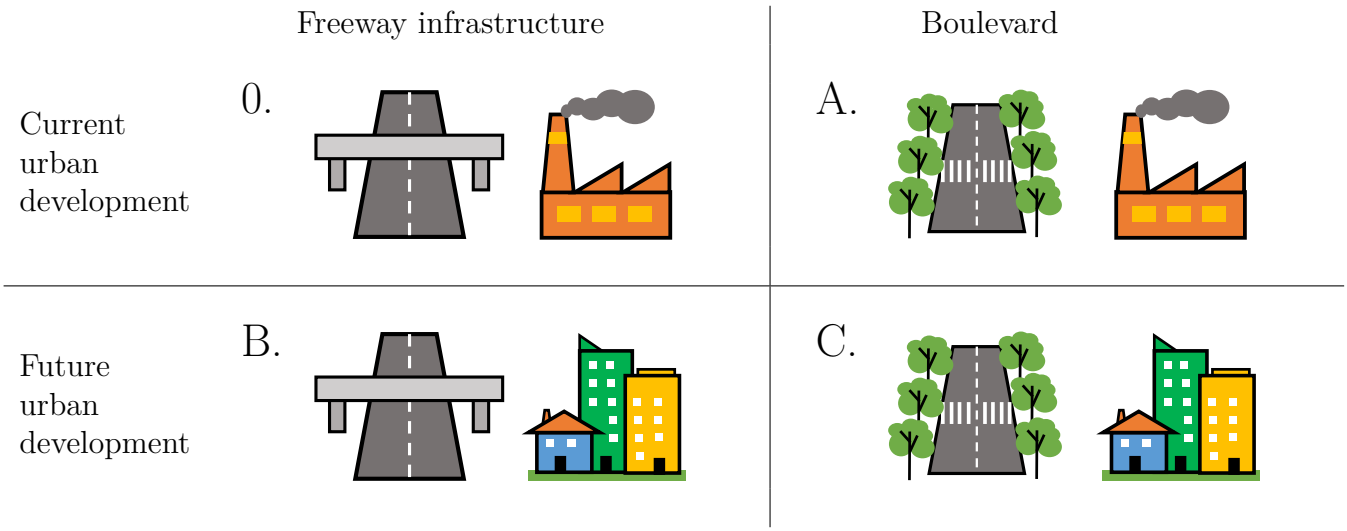


Figure 3.4: *The four scenarios. 0 represents the existing infrastructure and urban development, and C the proposed infrastructure and development in the study area.*

Scenario 0 is meant to describe the current situation in the research area, with the current urban development and Dag Hammerskjöldsleden being kept as a freeway. The first step in the creation of this scenario was to implement the network for motor, cycle and pedestrian traffic. This network will act as the possible paths that pedestrians and cyclists can choose between different destinations within the research area. The source of this network can be seen in table 3.3. Secondly, were the facilities located in the area assigned. The facilities are locations that attract local trips, hence creating barrier effects within the area. The chosen facility categories and their corresponding attraction as well as the data sources for the facilities can be found in table 3.1 and table 3.3 respectively.

Scenario A describes the case when the urban development remains unchanged, but the current freeway is replaced with the planned boulevard. The scenario is a transformed version of scenario 0, in which the network along and in direct connection to the boulevard are altered. The alteration of the network is based on the suggested design proposal presented in Ramboll & Göteborgs Stad (2021).

Scenario B represents the case when the urban development is changed according to the design proposal, the CP for Högsbo-Frölunda and DPs in the area, see table 3.4. The changes in urban development will generate a massive increase in inhabitants and facilities in the research area, hence affecting both the people's needs and the land use in van Eldijk's conceptual model. There have also been adjustments to the street network in these new areas of new urban development. The adjusted street network is a necessity to simulate realistic trips to and from the new buildings. However, the network will remain the same as today in the parts of the area not affected by the suggested changes, such as most of Flatås and Högsbo on the western side of the current freeway. In scenario B will the existing Dag

Hammarskjöldsleden be kept as it is today, which in reality is almost impossible that some of the additional urban development is planned on the same location as the freeway. A non-buildable area has been drawn along the existing Dag Hammarskjöldsleden as support in the modulation process where new urban development and streets are not possible, see figure 3.5.

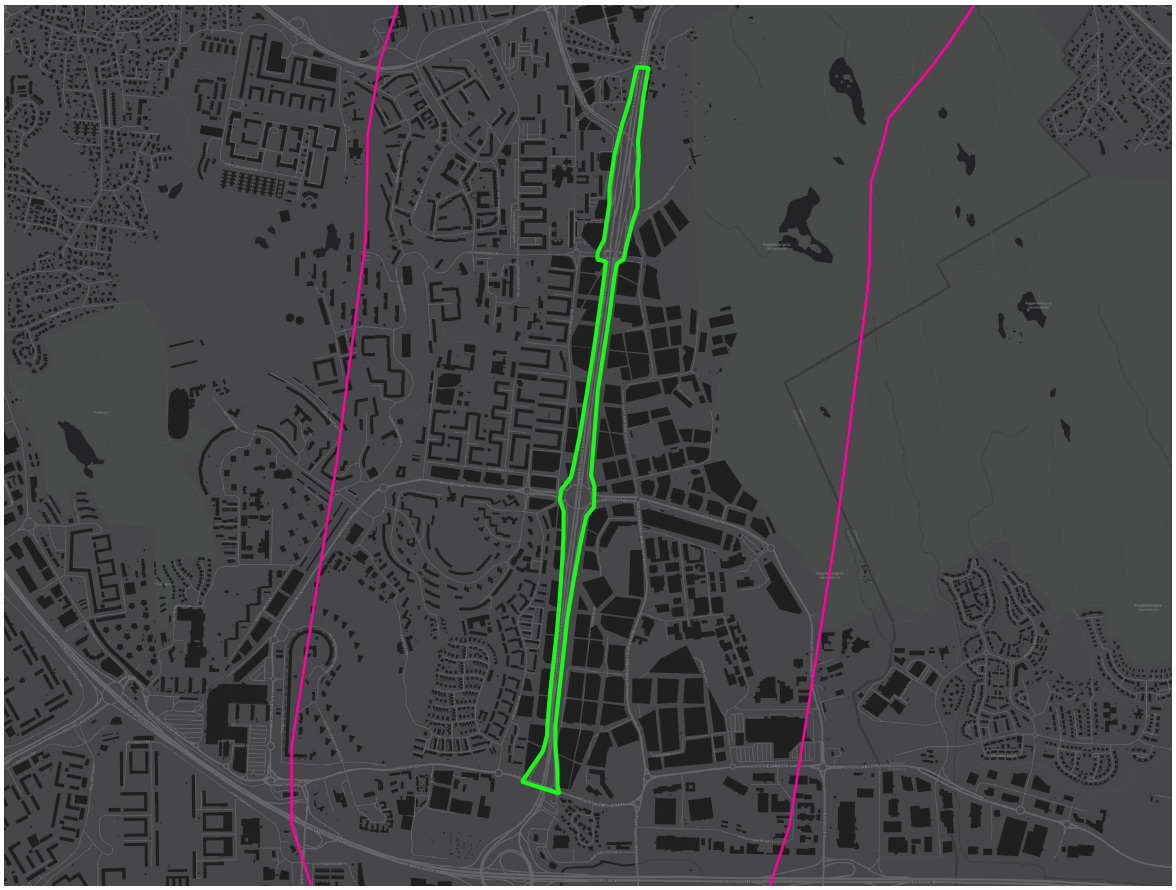


Figure 3.5: *Non-buildable area in green to modulate scenario B. The study area in pink and existing and new buildings in black. Background: ESRI Gray (dark).*

The fourth and final scenario, C, represents when the entire proposal for the area is accomplished: the additional and altered urban development and the planned boulevard. Hence, C is the final design of the boulevard project that the municipality proposes. Thus, scenarios A and B can be described as a mix between 0 and C in terms of either the boulevard or the future urban development.

3.7 Creation of the GIS-model

The GIS-model was created (7) in the open-source and cross-platform software QGIS[5] version 3.16.14-Hannover. Development plans listed in table 3.4 have been used to model scenario A, B and C. Because DPs of Olof asklundsgata, Järnbrottsmotet, Distansgatan/Marconigatan and Nymilsgatan (Göteborgs stad, stadsbyggnadskontoret, 2019b,a, 2018, 2017) are within the study area, see section 3.3, these have been extra considered when drawing new buildings and the street network. Other DPs outside the study area that have been considered in the model are listed in appendix A.2.1. Although, these have been roughly drawn. The areas in the CP have been slightly adjusted to the design proposal, resulting in all-new urban development in the design proposal being within areas 9, 10 and 11, see figure A.1 in the appendix.

Due to the differences in both the address-points, street network, and facilities between the four different scenarios all the features included in the models were assigned a scenario-attribute. The scenario-attribute identifies in which of the four scenarios the specific feature is used. Most of the features located within the analysis area are used in all four scenarios. However, variations in the scenario-attribute exist for the features located in areas subject to the changes in infrastructure and urban development. To ensure that only features present in the current scenario were used in the analyses was the filter tool used. The filter tool was also used to change between the different scenarios.

3.7.1 Address-points

For calculating the number of residents per address in scenario 0, four data sources were used: the national land survey (Lantmäteriet, 2021) (I) to obtain the information of which buildings are aimed for housing (apartment buildings and detached houses), SMoG (Stavroulaki et al., 2020) (II) to obtain GFA of the buildings, Open Street Map (n.d.-a) (III) to obtain location of address-points and Statistics Sweden (2020c) (IV) for population data. See table 3.3 for the sources in more detail. To estimate how many residents there are per address are factors calculated based on values from Statistics Sweden (2020d) used presented in table 3.5. See appendix C of the steps conducted in QGIS.

Table 3.5: *gross floor area (GFA) [m^2] per person and form of housing, based on Statistics Sweden (2020d).*

Form of housing	GFA [m^2]	Factor
Detached house (småhus)	38	1
Apartment building (flerbostadshus)	35	38/35 = 1.0857

To model the location of the future buildings DPs and the design proposal (Ramboll & Göteborgs Stad, 2021) have been used, see table 3.4. The design proposal has three levels of density for the urban development: low, medium-high and high. The CP states that area 15 will transits to a residential area with low density urban development, see table A.1 in appendix A.1. However, there are no data on how the urban development there will appear in the future. Similar situations are with the outer parts of the design proposal

[5] https://qgis.org/en/site/

where the low-density urban development is not proposed on a detailed level. Polygons are drawn in these areas with regard to the existing street network.

To be able to distribute the population to the buildings weighted areas are calculated based on numbers from Nelson, Malmqvist, & Stålner (2016) which is transformed into factors, presented in table 3.6. The modulated future population are based on primary the DPs and secondary the CP, see appendix A.

Table 3.6: *Residential density of new buildings.*

Density (residents/ha)(Nelson et al., 2016)	Factor
Low (20-40)	1
Medium (80-100)	3
High (110-130)	4

Since the DPs do not cover all of the estimated future population in the CP have the current population (scenario 0) been adjusted except for areas 8 and 10. Area 8 has a very low population (81 people) and based on the DP of Järnbrottsmotet and the CP would the population increase by 140 people or by 170% which is not realistic. In addition, without adjusting the current population is it still within the range of the future population. In area 10 has the DP of Olof Asklunds gata a higher density of people than what the design proposal and CP indicate. That has been solved by first calculating the population in area 10 the same way as areas 9, 11 and 15; and then having the population of the buildings affected by the DP been adjusted to the DP. The population in areas U1, 1, 4, 5, 7, 12, 13 and 16 have not adjusted due to the population in the model being within the ranges of future population or do not have a future population estimation in the CP.

3.7.2 Street network

The street network used for the distribution of trips between the origins and destinations in the model is primarily based on data provided by Stavroulaki et al. (2020), which presents the non-motorised street network for Gothenburg and its surroundings created in 2016. To ensure a workable model was all of the network outside the analysis area removed. See appendix D of the conducted steps to create the used street network. Several parts of the research area have been subject to changes in the built area since 2016 due to remodelling and construction of new neighbourhoods, meaning that the provided network was corrected to represent the existing network. A smaller number of areas where the network was insufficient were detected, hence resulting in a development of the street network in these areas. In addition to the corrections conducted due to changes in the built area was the network within the study area from the location of the planned boulevard further developed to better represent the network within the area. The part of the network closest to the existing freeway and planned boulevard has the largest influence on the final results, meaning that this area is the most sensitive to differences between the networks used in the model and reality to ensure valid results. For both these corrections were Google Maps[6] and OSM used as references.

[6] https://www.google.se/maps

After the creation of the street network for scenario 0, representing the current situation where Dag Hammarskjödsleden remains a freeway and the urban development remains unchanged, the street network for scenario C was created, see appendix D. The network used in scenario C is predominantly the same as in scenario 0, with changes due to differences in the urban development within the research area and the transformation of Dag Hammarskjöldsleden from a freeway to a boulevard. The plans of future urban development presented in table 3.4, following the same hierarchy as presented earlier, constitutes the basis for the creation of the street network for scenario C. Firstly were the network used in scenario 0 compared with the plans in table 3.4. If differences were discovered was the assigned scenario for the affected segments changed and replaced with segments representing the conditions of scenario C. A large number of segments representing the changes in urban development and transformation of Dag Hammarskjöldsleden were also added to obtain street network representative to the conditions in scenario C. For the areas without DPs but with an expected increase in population based on the CP were the street network adjusted to encircle the suggested buildings, following the same pattern as in the surrounding areas.

The street network used in scenario A is predominately the same as in scenario 0, except for the area in direct connection to the suggested design of the boulevard. The assigned scenario for the segments representing the boulevard and its corresponding crossing facilities, found in the network used in scenario C, were changed to also be used in scenario A. Finally, were the segments taken from scenarios 0 and C respectively connected by adding segments in suitable locations to create a realistic network if scenario A would be realised.

The street network for the fourth and final scenario B is a modified version of the network used in scenario C, see appendix D. Scenario B differs from scenario C regarding Dag Hammerskjöldsleden, which is kept as a freeway similar to scenario 0. A non-buildable area was created, representing the shape of the current freeway, and the assigned scenario for all segments interfering with this area was changed and hence removed for scenario B. However, the crossing facilities corresponding to the freeway were kept according to scenario 0. Since the non-buildable area covers areas with changed urban development in scenario C were changes to the street network in these also necessary to reflect the built area found in scenario B.

In addition, the original street network that constitutes the basis upon which the networks used in the four scenarios are created did Stavroulaki et al. (2020) provide data regarding unlinks. Unlinks can be described as locations where the segments cross each other, but at different levels making it impossible for pedestrians and cyclists to change between the segments at these specific locations. All of the initial points with the unlinks were assigned a scenario in the same way as for the segments in the street networks, see appendix D. When creating each of the four street networks were also changes in the unlinks corresponding to this conducted by performing changes in the assigned scenarios. When creating scenarios B and C were two points added to the unlinks due to changes in the built area close to Marklandsgatan.

The PST-plugin tool "Create segment map" was used on the street network once the four scenarios was created. This tool corrects minor inaccuracies and ensures that all segments are connected to their nearby points as intended.

3.7.3 Facilities

The facilities, which act as both origins and destinations for the indicators, can be divided as mentioned before into three groups: education, food businesses, and leisure. However, since the data for education and food businesses were received from the same sources have this data been reworked similarly. On the other hand, the data related to leisure has been retrieved and reworked differently, resulting in the two different approaches described below.

Education and food businesses

The data regarding education and food businesses were primarily obtained from Göteborgs stad, miljöförvaltningen (n.d.). Due to the extent and diversity of the dataset, multiple reductions of the data were performed, see appendix E of the conducted steps i QGIS. Firstly, all facilities located outside the analysis area were removed. Thereafter were all activities not included in any of the facility categories presented in table 3.1 removed. The sorting of the second reduction was based on the type found in the attribute table for Göteborgs stad, miljöförvaltningen (n.d.). Table 3.7 presents which of the types found in Göteborgs stad, miljöförvaltningen (n.d.) that belongs to each of the facility categories found in table 3.1. Further information about the facility categories and how they were selected can be found in subsection 3.2. After the sorting of data was the corresponding attribute table adjusted by the removal of fields containing unuseful information.

Similar to both the address-points and the street network does facilities related to education and food businesses vary between the different scenarios. All existing facilities related to education and food businesses were assigned an initial scenario-attribute, which later could be changed to address the alterations between the different scenarios. A majority of these facilities were located in areas not directly affected by the changes in urban development, meaning that they remained unchanged between the different scenarios. The following step was to introduce the plans for future urban development presented in table 3.4. Some of the facilities related to education and food businesses were located where the built area is planned to be altered, hence meaning that they will be removed in the future. To address this were the scenario-attribute changed for the affected facilities.

To represent the changes in urban development presented in the CP for scenarios B and C were the addition of facilities related to education and food business required. These alterations were conducted both regarding the numbers and positions of facilities. To determine a reasonable number of facilities to add where the distribution of current facilities and the current population used. The CP research area's current population was divided by the existing number of each facility category existing in the area to determine the density of each facility category per population. Table 3.8 presents the results of these calculations.

Table 3.7: *The selected facility categories and the types of facilities included in each category.*

Facility category	Type
Daycare	Förskola - mottagning (Daycare - reception)
	Förskola - tillagning (Daycare - cooking)
Schools	Skola - mottagning (School - reception)
	Skola - tillagning (School - cooking)
Bars, restaurants and cafes	Bageri (Bakery)
	Frukostservice (Breakfast service)
	Glasskiosk (Ice cream kiosk)
	Kafé (Café)
	Kiosk
	Restaurang (Restaurant)
Grocery	Fiskbutik (Fishmongers)
	Köttbutik (Butchers)
	Livsmedelsbutik (Grocery store)
Gyms	Fitness centre
	Fitness station
Parks	Park
	Dog park
	Recreation ground
	Playground
Sports	Sports centre
	Dance
	Pitch
	Sports and arts for kids and adults
	Golf course
	Track
	Miniature golf
	Bowling alley

The distribution of the added facilities along the research area was decided using the CP. The CP presents the predicted population in each of the 16 areas included, see table A.1. When combining the information in table A.1 and table 3.8 could the amount of added facilities per category be calculated. For CP-areas where DPs existed were DPs used as the primary determinant of the location of specific facilities.

Table 3.8: *Total number of current and future facilities within the CP of Högsbo-Flatås*

Facility category	Current number	Current people per facility	Future number
School	14	3918	11.4
Daycare	36	1524	29.3
Grocery store	61	899	49.7
Bar, cafe or restaurant	120	457	97.7
Gym	16	3428	13.0

To complement the DPs and for areas missing DPs were the location of facilities related to education and food businesses decided in an attempt to imitate the conditions of the existing built area. This can be exemplified by schools, whose location aimed to cover areas where schools do not exist today, and bars, restaurants, and cafes, which primarily were placed in locations with high potential for lively street life. All the added facilities related to education and food businesses were given another scenario-attribute. Similarly, as for the street network was this done to distinguish them from the initial ones and to change between the different scenarios. Since some of the facilities used for the creation of scenario C were located in the non-buildable area used in scenario B were these given different scenario-attributes as well. To account for this difference were some additional facilities related to education and food businesses added outside the non-buildable area to compensate.

Leisure

Data for the facilities related to leisure were retrieved from Open Street Map (n.d.-b), generating the requested data for both the City of Gothenburg and the City of Mölndal. Similar to the facilities related to education and food businesses were the given data very extensive and diverse, generating a need for reductions. Firstly, all the leisure facilities located outside of the analysis area were removed, see appendix E of the conducted steps in the GIS model. Secondly, all facilities not included in any of the facility categories listed in 3.2 were removed. 3.7 presents the types of leisure facilities associated with each chosen facility category.

The data provided in Open Street Map (n.d.-b) constitutes multiple layers where the facilities are presented either as polygons or points. Facilities included in the category "parks" were in general given as polygons, corresponding to their spatial distribution. Facilities belonging to the categories "gyms" and "Sports" were given as points, which correspond to a single location and not a distribution. In addition to the facilities in "gyms" and "Sports" were several playgrounds also given as points, meaning that data regarding their spatial distribution were lacking. Since the area constitutes the attraction for facilities in "parks" were their area calculated using the formula $\$area$ in the field calculator. However, since several playgrounds were given as points was the calculation of their respective area impossible. The usage of the formula $\$area$ requires information regarding the spatial distribution, which points do not provide. However, after an examination of these playgrounds using the satellite view in Google Maps, it could be stated that their area was

rather similar. An area of 50 m^2 was assigned to all these playgrounds. To be able to include the facilities given as polygons they were transformed into points by generating a centroid for each polygon. The layers containing the centroids and the points respectively were then merged into one layer. The attribute table associated with the leisure facilities was altered by the removal of columns containing information unuseful for the project.

Similar to the facilities related to education and food businesses, all the points associated with the leisure facilities were assigned an initial scenario-attribute. A vast majority of the leisure facilities were used in all four scenarios, hence remaining unchanged. However, the scenario-attribute was adjusted for the facilities affected by the changes in the built area. For scenarios B and C, new gyms were added in a similar way as for the facilities related to education and food businesses. For the determination of the numbers and locations of the added gyms were the same approach used as for previous facilities. Table 3.8 presents both the current and added number of gyms within the research area.

The addition of facilities in the category "parks" was based on Göteborgs stad, park- och naturförvaltningen (2014), which describes the City of Gothenburg's urban green space development strategy. Göteborgs stad, park- och naturförvaltningen (2014) states the importance of access to urban green spaces and how this access shall be considered in urban planning. To ensure good access to urban green spaces in connection to the planned areas were several new parks added. In some of the DPs were locations of new parks suggested, which were added. As a complement, some additional parks were added as polygons in locations suitable according to the design proposal of the Dag Hammarskjöld boulevard project. Two types of parks were added: Residential parks and District parks. Residential parks are according to Göteborgs stad, park- och naturförvaltningen (2014) smaller urban green spaces primarily used by local residents. They should have a minimum area of 0.2 hectors and should be accessible within 300 meters from residences, without crossing any major barriers like larger streets, freeways, waterways, etc. District parks are defined as urban green spaces with a minimum area of 2 hectors, primarily used by district residents (Göteborgs stad, park- och naturförvaltningen, 2014). They should be accessible within 1 km from the residence without the need to cross any major barriers. To determine the attraction of the new parks were their area calculated following the procedure previously described. Centroids were created for the new parks and the created layer was merged with the existing layer of leisure facilities.

When considering category Sports were a smaller number of facilities added. The number and location of the facilities included in this category vary noticeably across the research area, making it difficult to detect and follow any existing pattern. The added facilities were placed in locations deemed suitable where no current or planned buildings existed or in areas with low density. During this process, an even distribution of the added sports facilities was sought. In addition, the DP Göteborgs stad, stadsbyggnadskontoret (2019a) presents a planned sport facility.

3.8 Calculate and visualise the barrier effect indicators

See table 3.9 for the chosen spatial analyses. As mentioned in section 3.4 are the analyses calculated with the GIS plugin PST except for the DF which is calculated with a separate script (8).

Table 3.9: *Performed spatial analyses*

Indicator	Origins	Destinations	Radius [m]
Choice [-]	Street network	Bars, cafes, restaurants	1000
		Daycares	1000
		Grocery stores	1000
		Gyms	1000
		Parks[a]	1000
		Schools	1000
		Sport facilities	2000
Catchment areas [residents]	Bars, restaurants and cafes	Address-points	1000
	Daycares		1000
	Grocery stores		1000
	Gyms		1000
	Parks		1000
	Schools		1000
	Sport facilities		2000
Proximity [m]	Street network	Bars, cafes, restaurants	1000
		Daycares	1000
		Grocery stores	1000
		Gyms	1000
		Parks	1000
		Schools	1000
Detour factor [-]			1000
Betweenness [-]			1000

[a] calculated in m^2

3.8.1 Scaling

To be able to compare the results between the facilities, scenarios and indicators, the data from the calculated indicators were min-max normalised with equation 3.1. x is the original value and x' is the normalised value. $\min(x)$ is the lowest value in the dataset, and $\max(x)$ the opposite. This gives a ranking [0, 1] where the highest value in a dataset, $\max(x)$, becomes 1 and the lowest becomes 0, $\min(x)$. Values between the highest and lowest values become normalised to values between 0 and 1 in relation to the highest and lowest values. As an example: the values 5, 8, 10, 15 become 0, 0.3, 0.5, 1.

$$\text{min-max normalisation: } x' = \frac{x - \min(x)}{\max(x) - \min(x)} \tag{3.1}$$

3.8.2 Change in ranking

These normalised values have then been used to calculate change in ranking [-1, 1], which can be seen in the comparisons between the scenarios. Differences in the original output values are also calculated to get an understanding of the changes with more common units. The change in ranking is not a percentage difference but a difference that is dependent on the distribution of the values and is a scale that is comparable with the different analyses. The change in ranking results are presented in nine intervals, which is the same in all comparison analyses, see table 3.10. The colours that represent the intervals in the results can either be green-red or red-green dependent if the changes are illustrating improvements regarding barrier effects or if it gets worse. For example, regarding Proximity is it beneficial if the distance to a facility of a specific facility category is getting smaller, but for change in Choice is it the opposite. Still, the intervals are the same although the colours are different for Proximity. To neglect the very small differences that otherwise may exaggerate the magnitude of the barrier effect differences in the maps, an interval from -0.01 - 0.01 is necessary.

3.8.3 Difference calculations with regard to the scenarios

For the Choice and Proximity comparisons between scenarios B and C, only address-points included in both scenarios B and C are presented. This is because a difference cannot be calculated if address-points are only in one of the scenarios. However, this is only a presentation technicality and does not affect the PST calculations.

Regarding the Catchment indicator, the values for facilities in scenario B have been copied over to their corresponding facilities in scenario C. This could easily be done because there are only nine facilities affected by this, see appendix E.

The same problem is for the Betweenness comparisons. The difference between the scenarios for a segment is calculated if the segment is included in both the scenarios. This means that new crossings or crossings that will be removed that cross the freeway/boulevard are not visualised. Although, the calculations in PST are performed per scenario and therefore with the whole network.

Table 3.10: *Colour intervals of change in ranking to make analyses with normalised values comparable. Green indicates improvements and red vice versa.*

Change in ranking	Choice Catchment Bettweenness	Proximity
< -0.2		
-0.2 - -0.1		
-0.1 - -0.05		
-0.05 - -0.01		
-0.01 - 0.01		
0.01 - 0.05		
0.05 - 0.1		
0.1 - 0.2		
> 0.2		

3.8.4 Presentation of the Choice and Proximity indicators

For Proximity and Choice are Voronoi polygons created from the address points to better visualise how the residents in the buildings are affected. The Voronoi polygons are clipped to match the buildings, see 3.6. The comparisons between scenarios B and C are the Voronoi polygons clip regarding the buildings in scenario B.

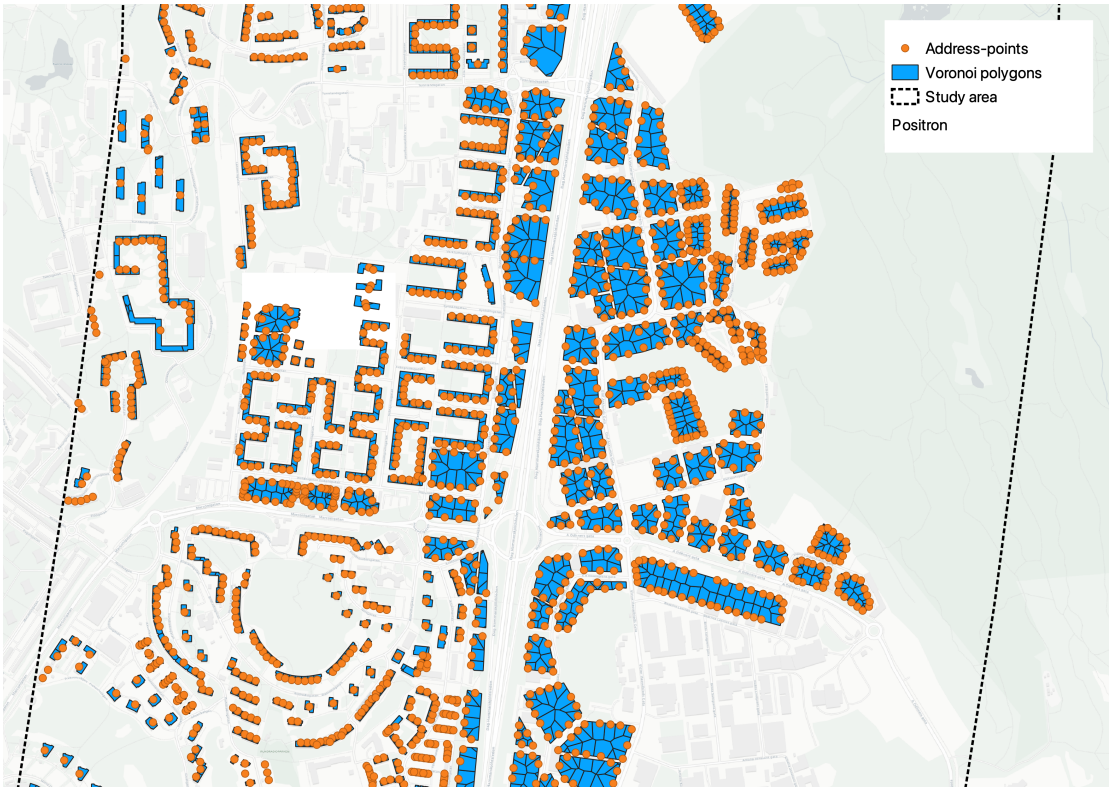


Figure 3.6: *The address-points are converted to Voronoi polygons to illustrate the Proximity and Choice analyses of the buildings.*

4 Results

The result section is divided into three subsections: presentation of the GIS-model for the four scenarios; an overview of the indicators for scenario 0; and comparisons of the indicators before and after the implementation of the boulevard (scenarios 0 & A and scenarios B & C). Based on the analyses presented in table 3.9, the most meaningful and interesting results are presented. Analyses of the same indicator often correlate with each other, and the differences are the illustrative qualities. For example, some indicator analyses show very small changes in terms of barrier effects. Statistical summarises of the Proximity, Choice and Catchment indicator analyses with the average, median, maximum and minimum absolute values can be found in appendix F for all facility categories. This is to get an overview of the ranges which can differ because of the indicator and facility category.

4.1 Models of the four scenarios

Figure 4.1 shows scenario 0 and represents how the area looks today. The three other scenarios introduced in the methodology subsection 3.6 are presented in figures 4.2 and 4.3 with their differences compared to scenario 0. These presented scenarios are the input data to calculate the indicators and the essential parts are the street network, the address-points and the facilities. As mentioned in the methodology, the biggest difference between scenarios 0 and A in comparison to B and C is the urban development along the road (see appendix A of planned urban development). In addition, the difference between the scenarios 0 and B in comparisons to A and C is the change in the street network, with the current freeway in 0 and B while the boulevard street network design in A and C. Hence, the buildings located within the non-buildable area are moved in scenario B to fit the freeway with its features. See appendix D of the proposed street network. See also appendix E for detailed maps of the facility categories that have been added.

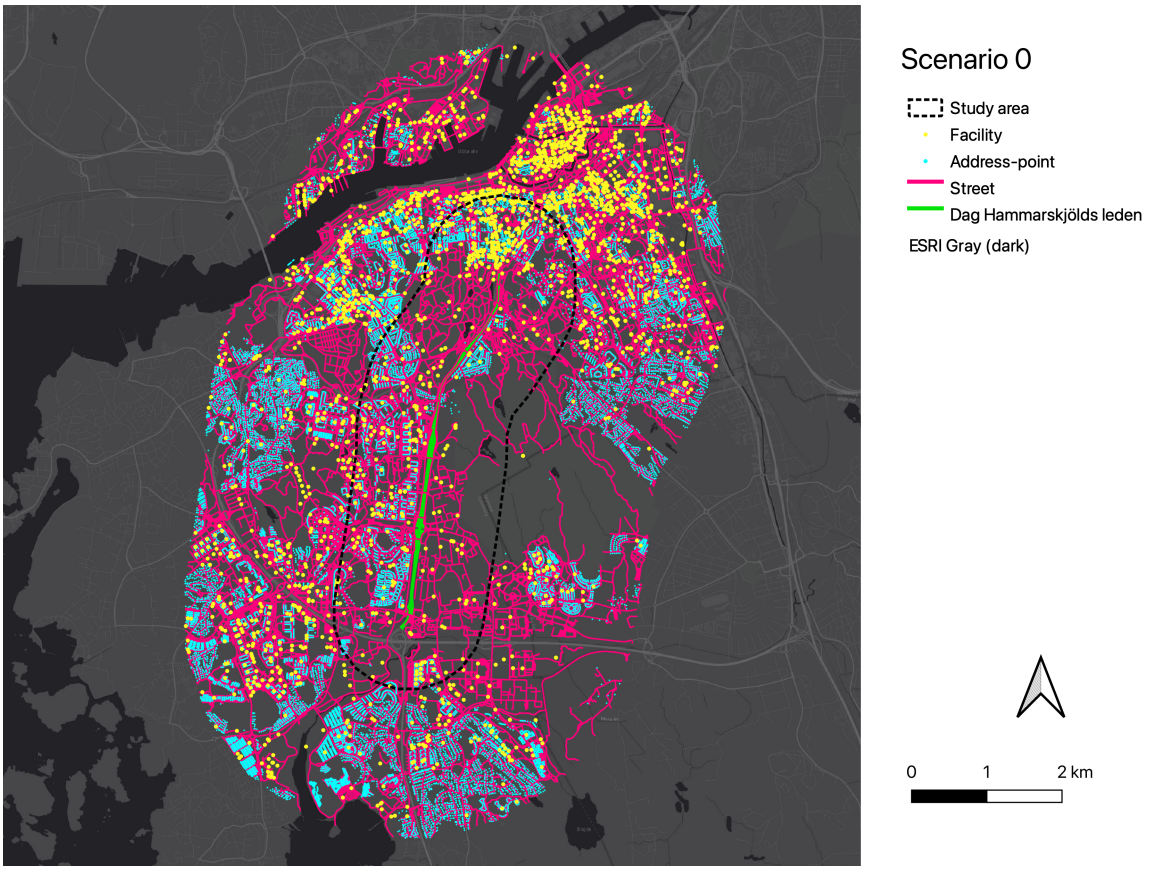


Figure 4.1: *GIS-model overview of scenario 0. Scenario 0 shows how the area looks like today with the freeway and current urban development.*

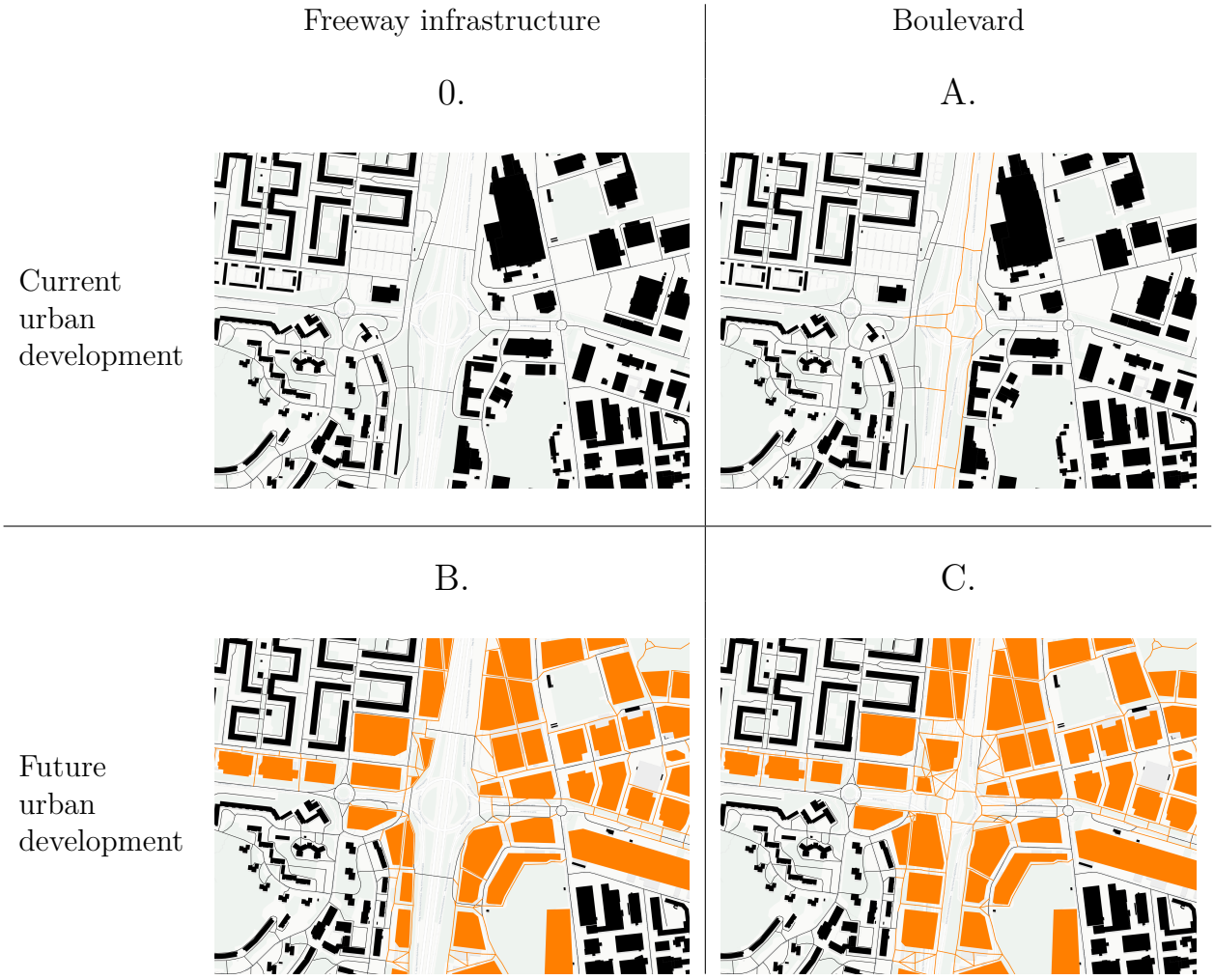


Figure 4.2: *The four scenarios around Marconimotet to visualise the differences in the GIS model. Orange represents the future streets and buildings, while black what is existing existing. Background: CartoDB - Positron*

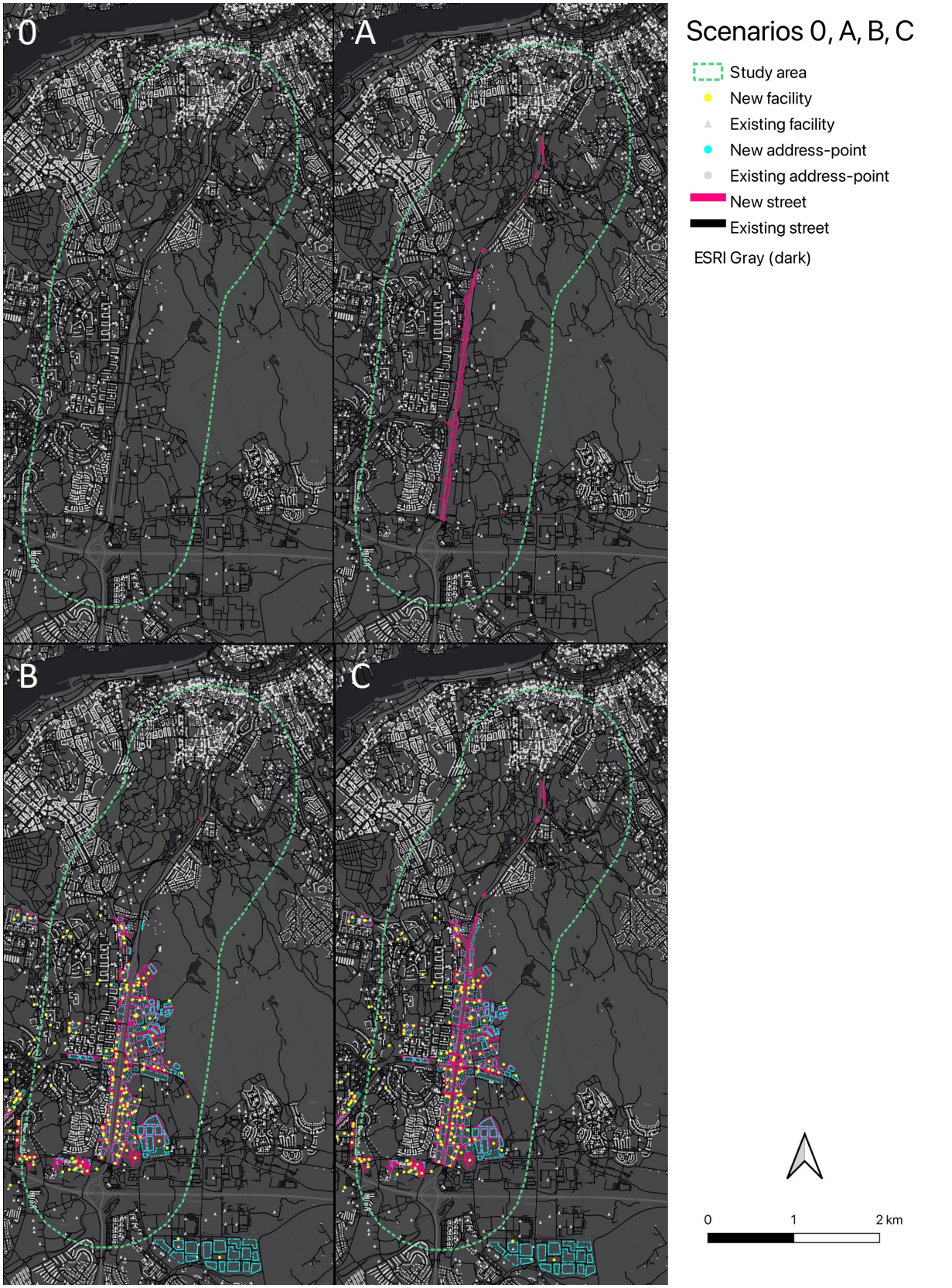


Figure 4.3: *GIS-model overview of the four scenarios. The coloured layers in scenarios A, B and C illustrate differences in comparisons to from scenario 0. See section 3.6 for an explanation of the scenarios.*

4.2 Barrier effect indicators (scenario 0)

To present an overview of the indicator calculations and what the outcome from these are, figures 4.4 - 4.8 are illustrating examples of each indicator in scenario 0.

The Choice indicator illustrates the number of facilities of a specific type is within a given distance from an origin. In figure 4.4, grocery stores are destinations and the address-points the origins. It can be seen that the option of grocery stores is highest in Linnéstaden in the north. This is mainly due to the frequency of facilities are high in this area. From a barrier effect perspective, aiming to increase the Choice values is valuable.

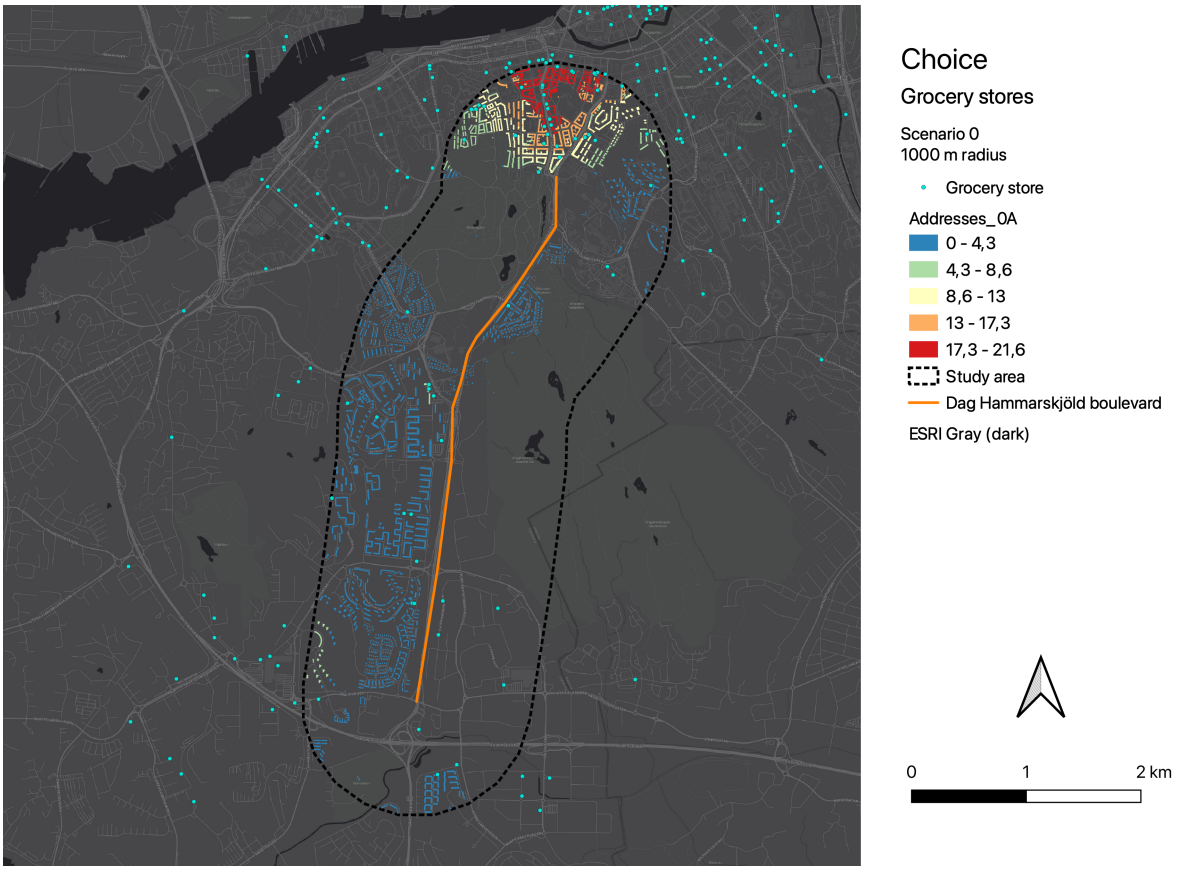


Figure 4.4: *Choice of grocery stores [-], scenario 0*

Catchment presents how many residents or households there are for a facility within a certain distance, also called catchment area. Figure 4.5 is an example where the daycare-facilities are origins and the address-points the destinations. The facilities that have the highest Catchments are facilities in central Gothenburg in the north part of the study area in Linnéstaden, the same area that has the highest values in the Choice analyse. As Choice, it is desirable for high Catchment values. For the facilities, a high catchment value means a high potential customer group.

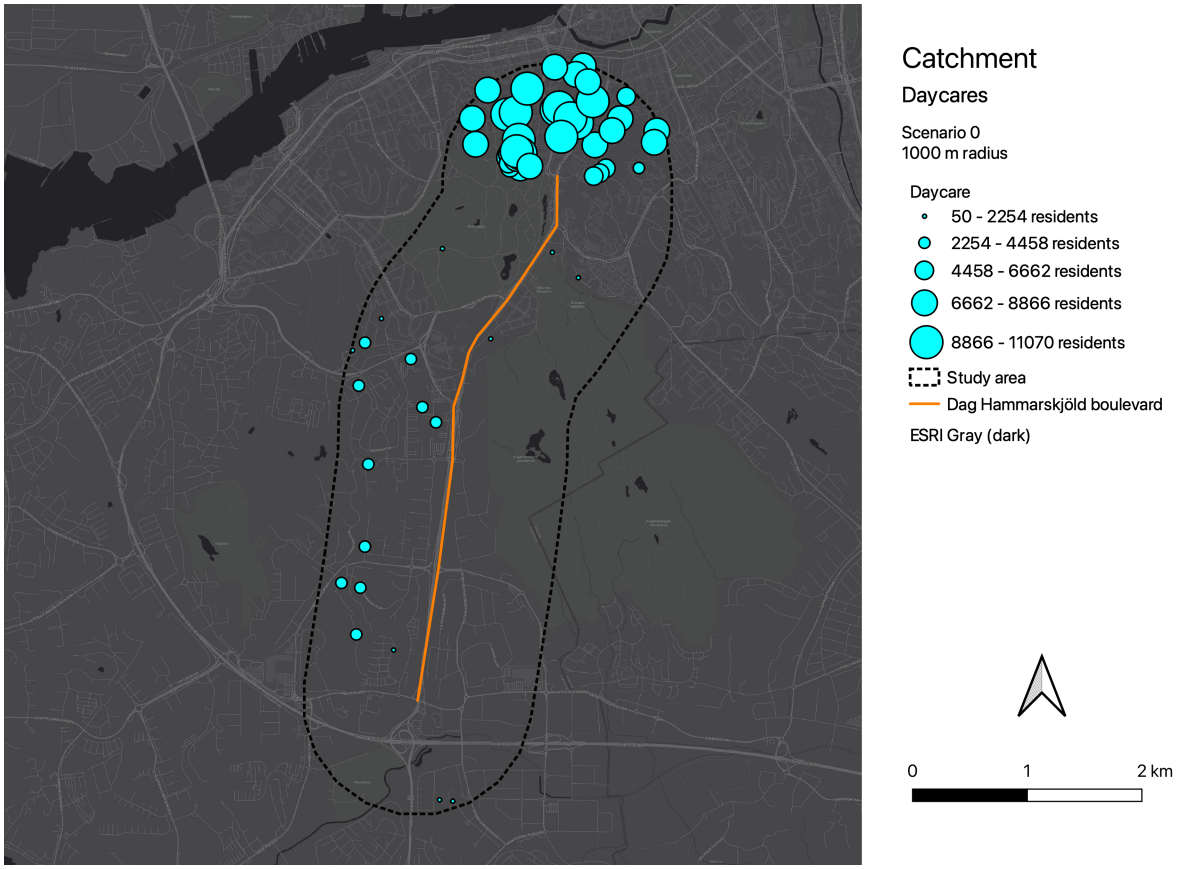


Figure 4.5: *Catchment of daycares [residents], scenario 0*

Proximity to the closest facility from an origin can be measured in many ways, such as the network distance. In figure 4.6, the address-points are the origins and parks the destinations in scenario 0. It can be seen that the distance is generally low from the address-points to a park in the whole study area, see more profound evaluation of the proximity of the parks in the next section 4.3. In contrast to Choice and Catchment, a short distance is desirable to reduce the barrier effects.

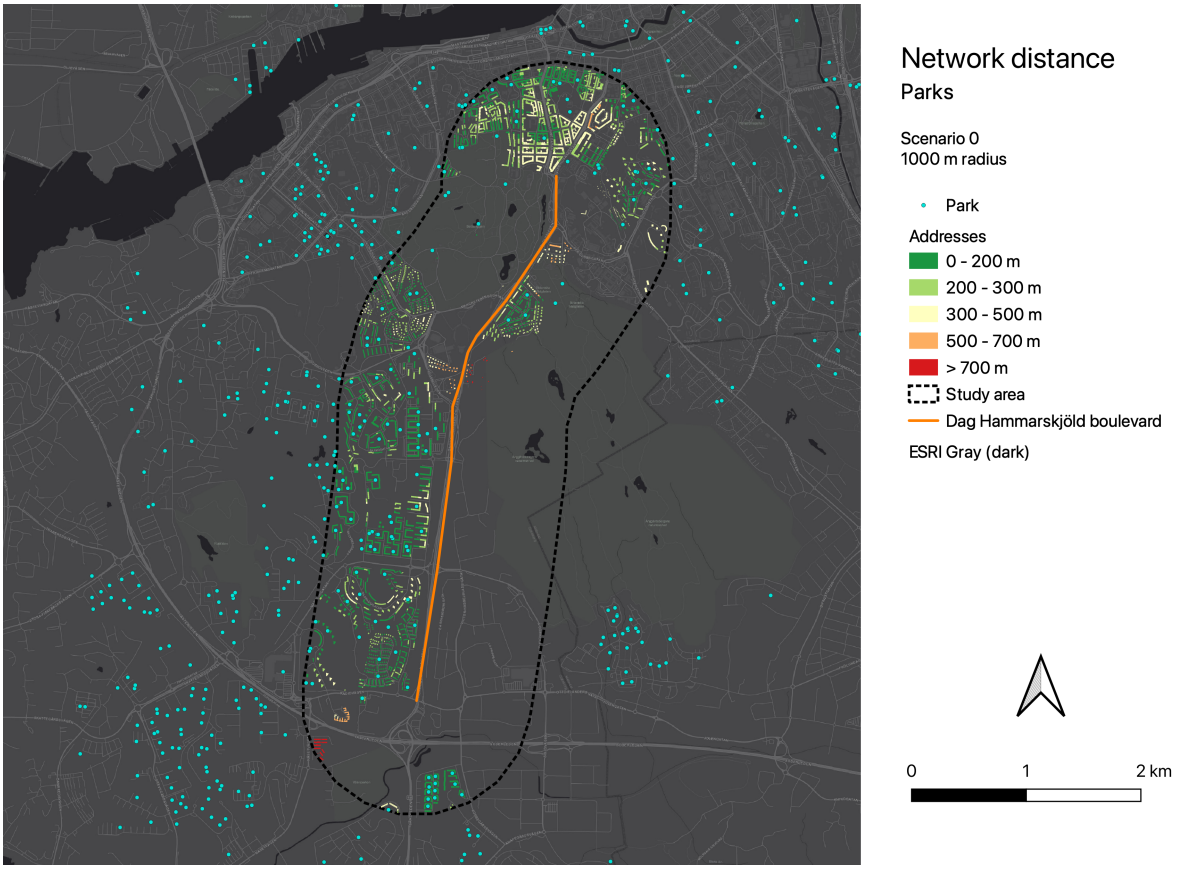


Figure 4.6: *Network distance to the closest park [m], scenario 0*

Betweenness shows how often a segment is included in the shortest path from one segment to another within a given distance. Figure 4.7 illustrates the Betweenness for the segments in scenario 0 with a radius of 1000 m. It shows that segments, especially on the west side of the freeway, have the highest potential of travel. From a barrier effect perspective, it can be seen that the crossings are frequently included in the shortest paths when crossing the barrier.

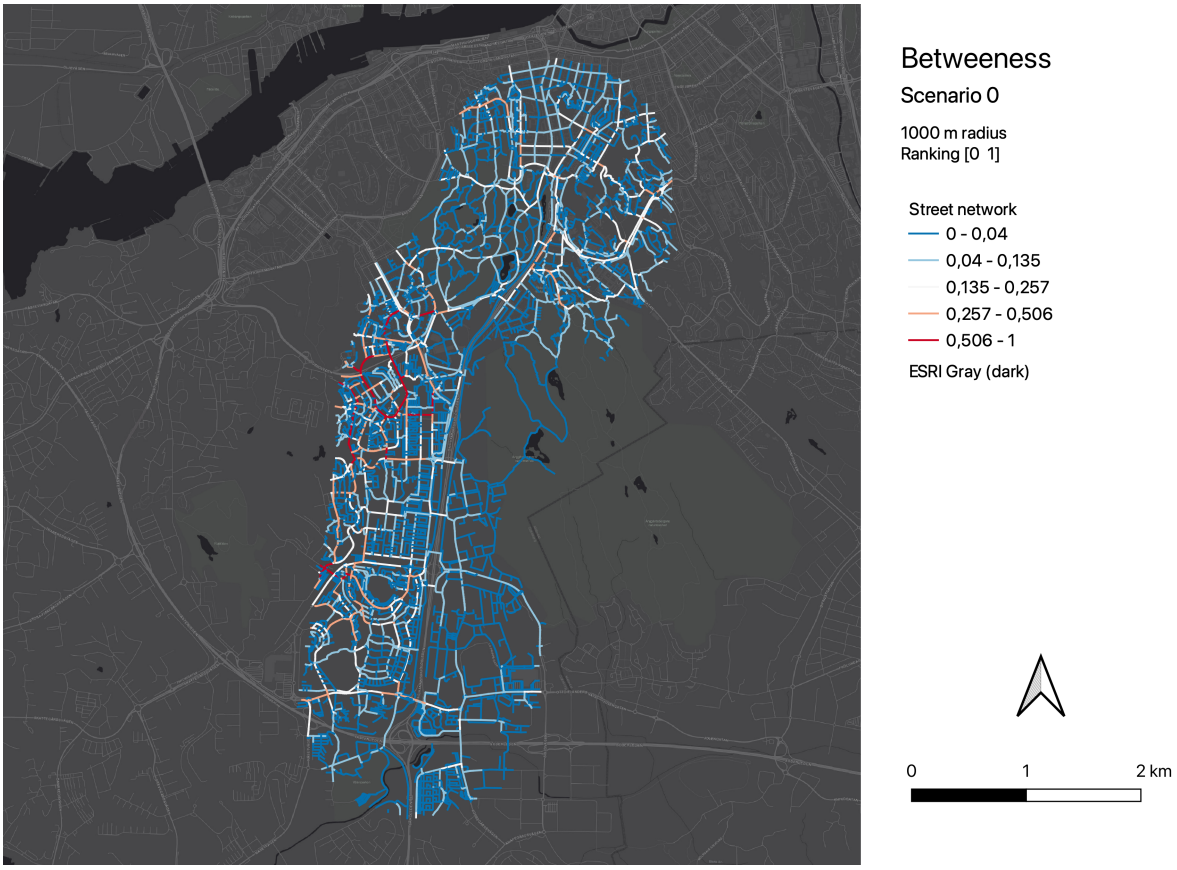


Figure 4.7: *Betweenness [ranking], scenario 0. Colour intervals with natural breaks (Jenks).*

The Detour factor (DF) indicates the detour of a trip from one segment to another, see equation 2.1. In this project, the DF is an average value of all the trips in a 1000 m radius. Low DF means that the detour is averagely low and is desirable from a barrier effect perspective. The areas with a fine mesh network have the lowest DFs illustrated in figure 4.8.

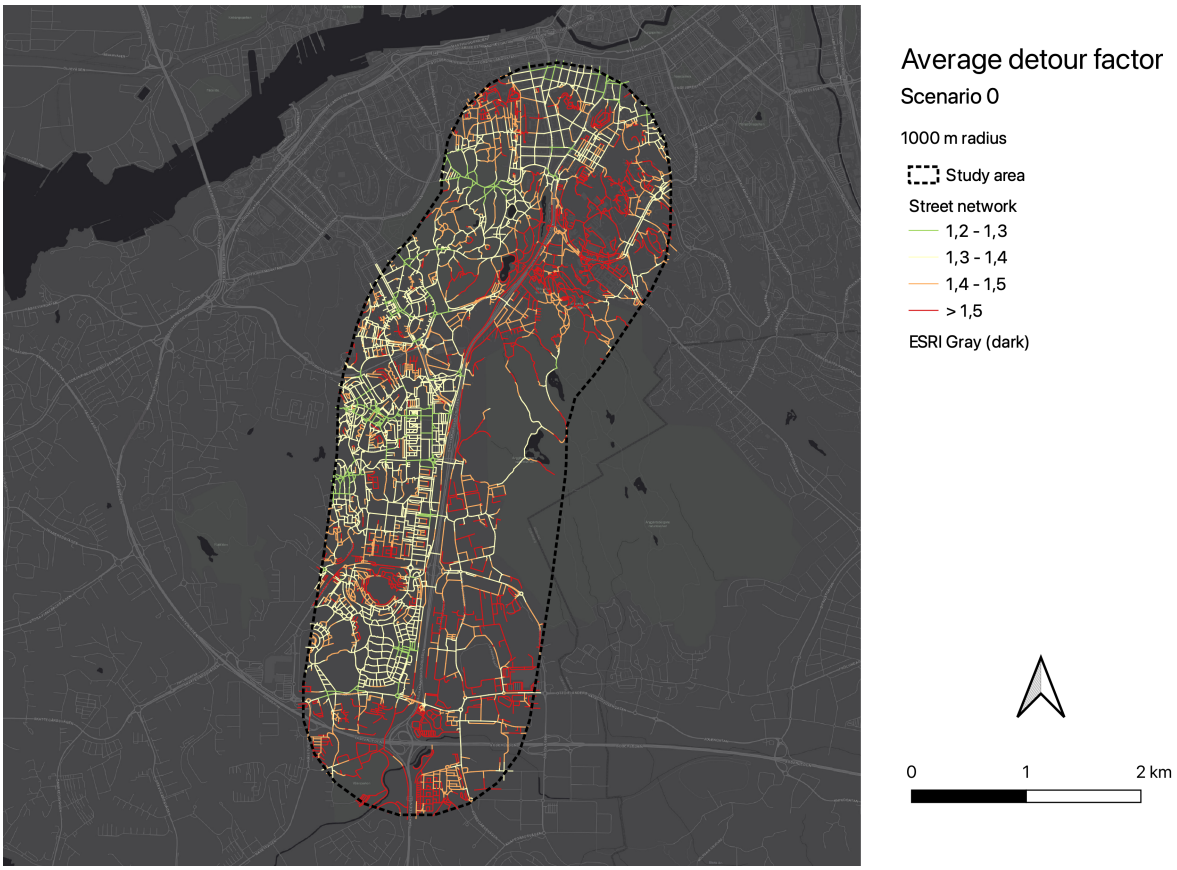


Figure 4.8: *Detour factor [-], scenario 0*

4.3 Comparison of barrier effect scenarios

To better understand the boulevardisation's influence on the barrier effects, the following subsections presents comparisons between scenarios 0 & A and scenarios B & C described in the section 3.6 and section 4.1. Results from these comparisons highlight the impact caused by different decisions, hence supporting the decision-making process. Comparison between scenarios 0 & A represents the results of a potential boulevardisation of the current freeway without any further changes to the surrounding urban development. The results from the comparison between scenario 0 & A highlights the effects of exclusive changes in the transport infrastructure. The comparison of scenarios B & C demonstrates the differences caused by a potential boulevardisation when there are also changes in the surrounding urban development. Comparing the results from the difference between scenarios 0 & A against the difference between scenarios B & C, gives us an indication of the impact of changes in land use on the barrier effects in the area.

4.3.1 Comparison of scenarios 0 and A

The following sub-section presents the results for the comparisons between scenarios 0 & A.

Accessibility

When examining the results for the comparison between scenarios 0 & A regarding the indicators related to accessibility, patterns can be discovered. The most explicit result is the lack of difference between scenarios 0 & A. When indicator Choice is compared using all the different facility categories described in section 3.2, the resulting differences are very limited, a pattern seen for all the selected facility categories. Figure 4.9 displays the results for Choice regarding grocery stores, which acts as a good representation of the results for the other facility categories as well. The extent of the calculated differences is noteworthy since the largest registered differences are lower than 0.05 in ranking, meaning that few differences that can be found only have a marginal impact on the barrier effects. Additionally, one can notice that the distribution of these changes is limited to the area in connection to the route of the planned boulevard. Similar patterns are found when analysing the results from indicator Catchment.

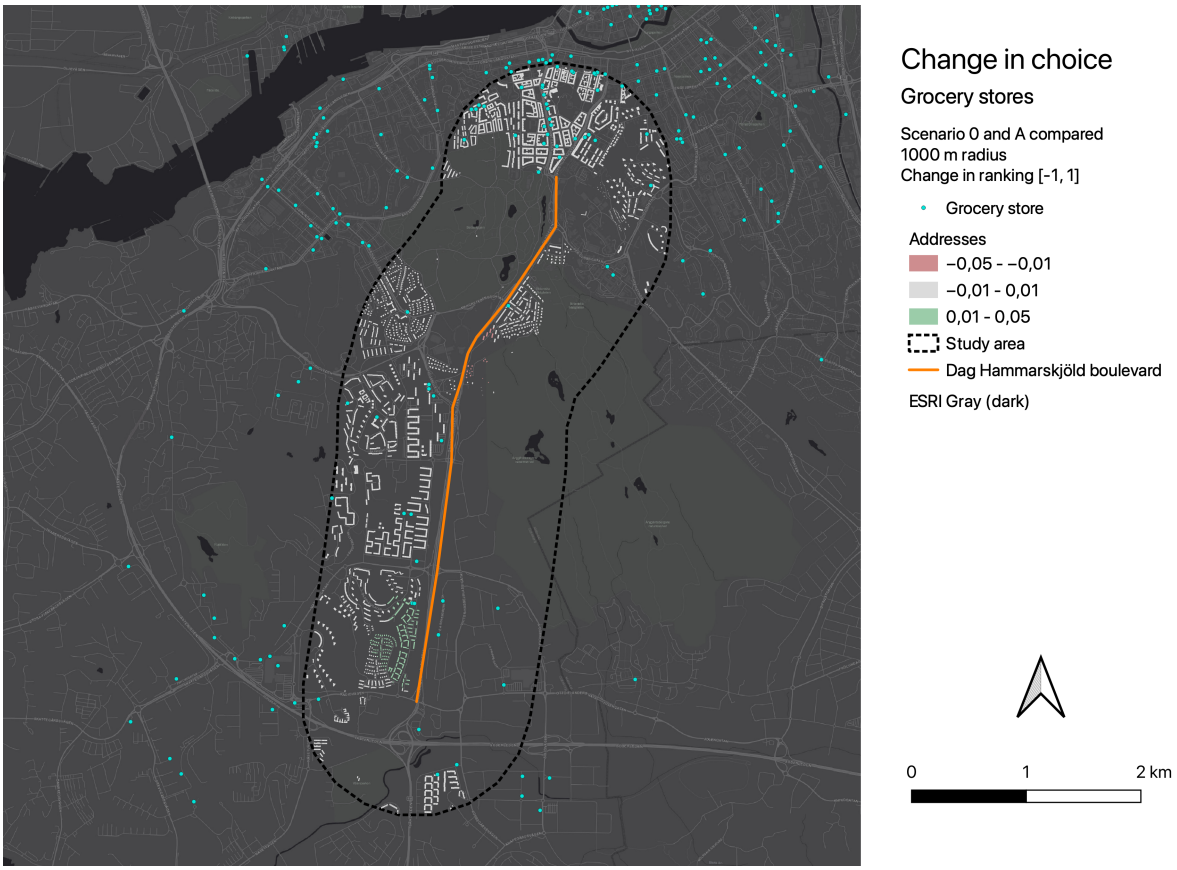


Figure 4.9: *The changes between scenario 0 and scenario A in regard of grocery stores for indicator Choice.*

Proximity

When analysing the results related to Proximity, the pattern found in the results for previous indicators is repeated for most of the facility categories. The detected differences are small and fragmented, hence having a very limited effect on the barrier effects. One exception was however found when analysing Proximity for grocery stores presented in figure 4.10. The results demonstrate considerable decreases in network distance for an area located on the western side of the southern area. Since the number of grocery stores located on the western side of Dag Hammarskjöldsleden in the southern area is limited,the improved access to the eastern side in scenario A had a big impact on the decrease in network distance.

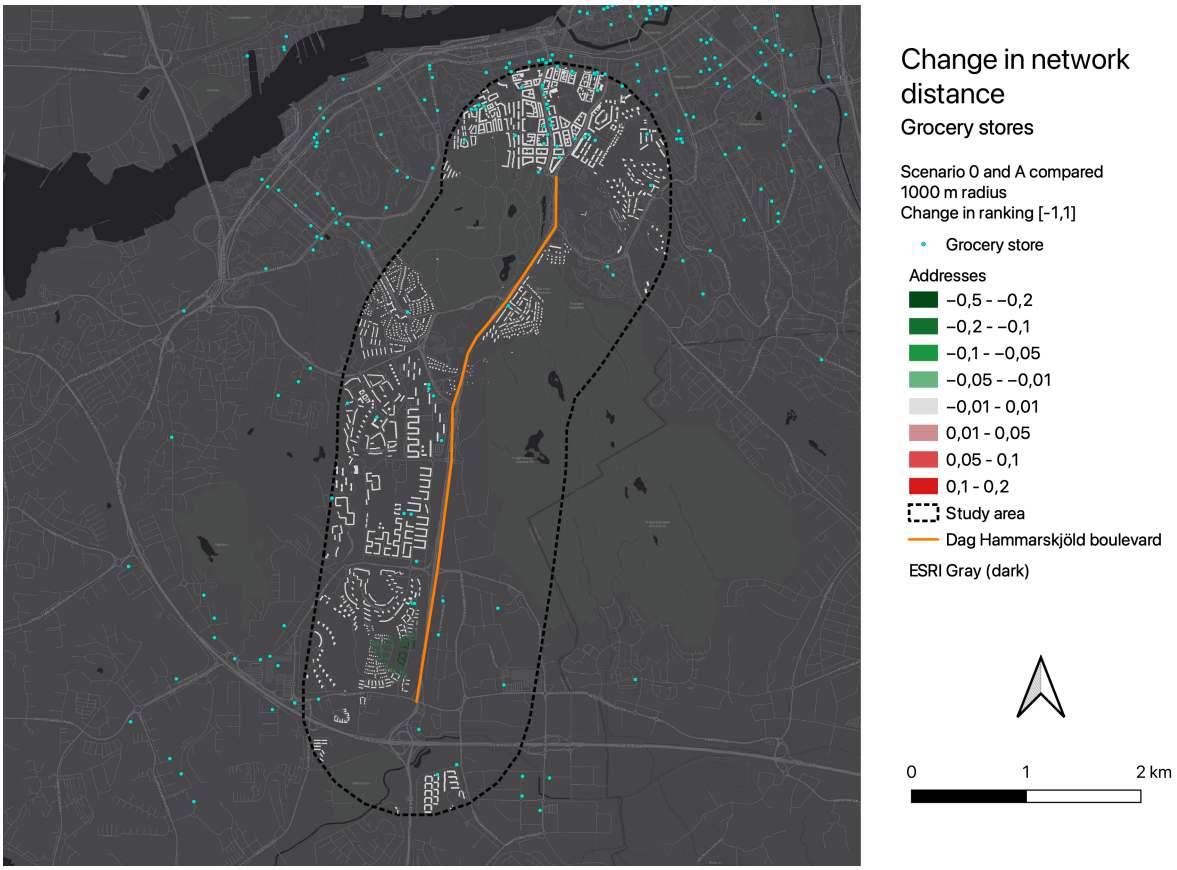


Figure 4.10: *The changes between scenario 0 and scenario A in regard of grocery stores for indicator Proximity.*

Comparisons of indicators Choice, Catchment and Proximity

The results associated with indicators Choice, Catchment, and Proximity suggest that the changes in infrastructure related to the proposed boulevardisation have a limited impact on the reduction of barrier effects. These results are likely the effects of the current land use on the eastern side of Dag Hammarskjöldsleden, which is composed of an industrial area with elements of service facilities. Only a handful of the facilities located on the eastern side are included in the chosen categories, hence reducing the need to cross the barrier to access these facilities for the residents living on the western side of the freeway. The importance of land use for the possible reduction of barrier effects from a boulevardisation is further strengthened by the results of grocery stores concerning Proximity, see figure 4.10.

Proximity of parks

When comparing the results for indicator Proximity most of the facility categories comply with the pattern described earlier. However, the facility category parks constitutes an interesting exception. The results for Proximity regarding parks for scenarios 0 & A can be seen in figure 4.11. The placement and frequency of parks are regulated by the recommendations decided by The city of Gothenburg and presented in Göteborgs stad, park- och naturförvaltningen (2014). These recommendations are presented more in detail in section 3.7.3. Provided that the recommendations presented in Göteborgs stad, park- och naturförvaltningen (2014) are complied with, the boulevardisation should only has a limited contribution to the reduction of network distance since all residents should have access to parks within 300 meters without crossing any major barrier. The results presented in figure 4.11 demonstrate that the recommendations are fulfilled for most of the study area with only minor exceptions.

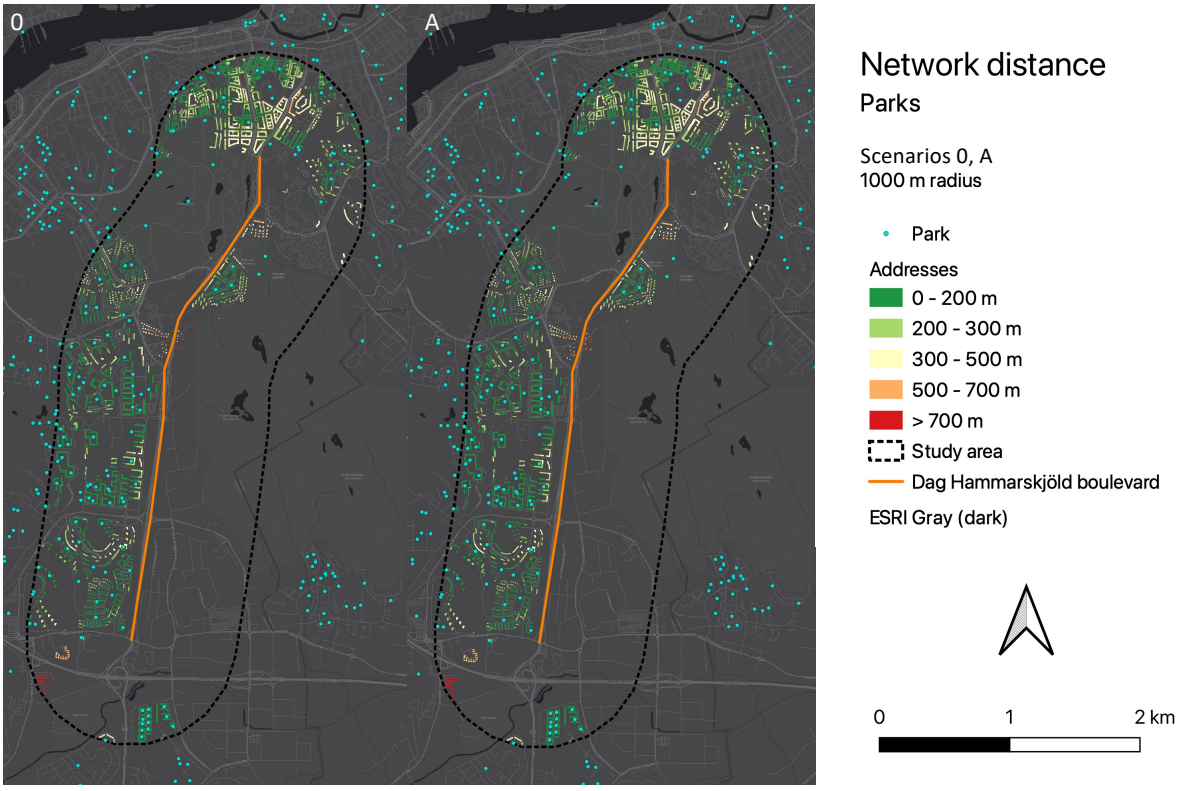


Figure 4.11: *The results for indicator Proximity for scenarios 0 and A in regard to facility category parks.*

Detour factor

Besides the analysis of accessibility and Proximity, where the results are highly affected by the location of origins and destinations for the trips, the network can be individually analysed. DF and Betweennes are both examples of indicators presented in section 3.4 and section 4.2 used for the analysis of the network. When the results for DF regarding scenarios 0 & A presented in figure 4.12 are analysed, it can be stated that high DF is observed for both scenarios. Areas suffering from a DF over 1.5 are detected at several locations within the study area, predominantly on the eastern side of Dag Hammarskjöldsleden in both the northern and southern areas as well as west of the interchange Marconimotet. The boulevardisation represented by scenario A has a positive impact on the DF, especially in connection to the route of the planned boulevard. However, when the impact on the DF from the boulevardisation on the study area as a whole is evaluated, the effect is rather limited and concentrated in a few smaller areas.

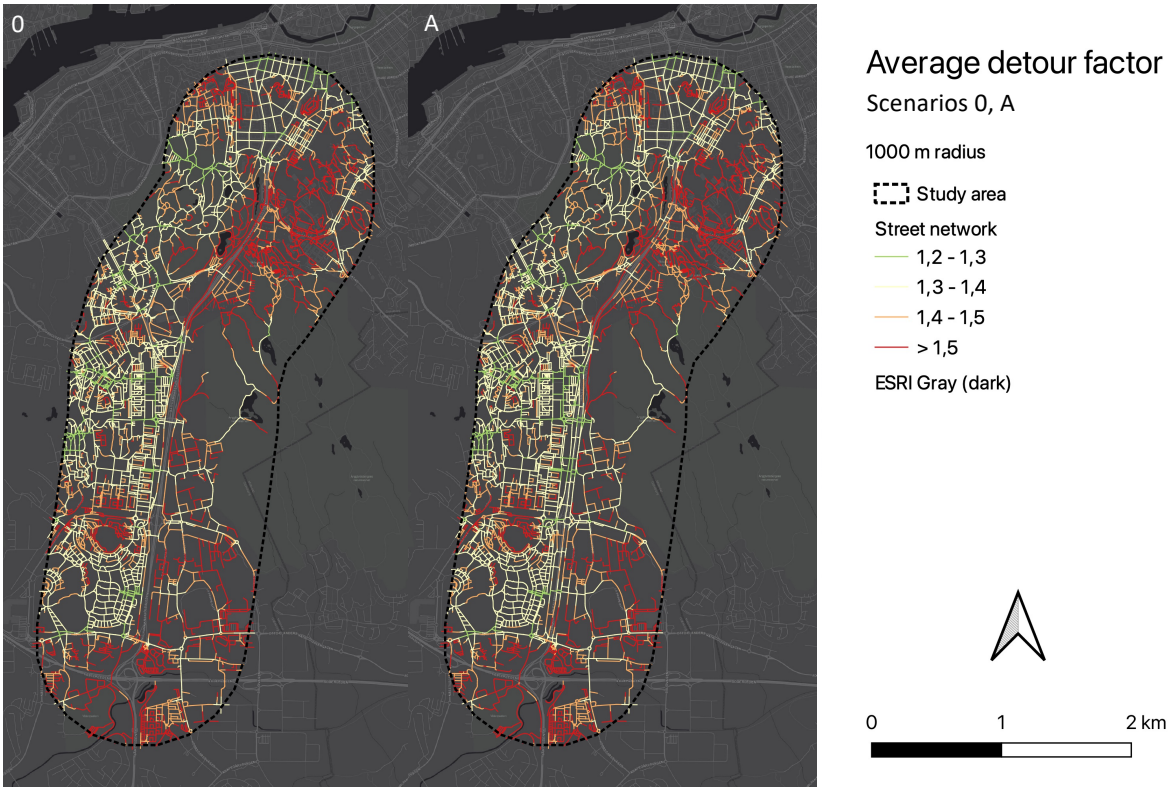


Figure 4.12: *Presents the Detour factor for scenarios 0 and A.*

As described in section 2.4 has Trafikverket et al. (2015) created guidelines for DF to determine the quality of the pedestrian network. Figure 4.13 displays the DF in comparison to the guidelines from Trafikverket et al. (2015) for all four scenarios. The results presented in figure 4.13 demonstrate that a majority of the network fulfils the requirements for average DF. Larger areas with high DF can be seen in both the northern and southern parts of the study area, while low DF is fulfilled only for isolated segments. When comparing the results for scenarios 0 & A, only occasional improvements in connection to the route of the boulevard can be seen. To summarise the findings presented in figure 4.12 and figure 4.13 respectively, a boulevardisation seems to have a minor impact on the DF in general, and the improvements that can be detected are amassed along the route of the planned boulevard.

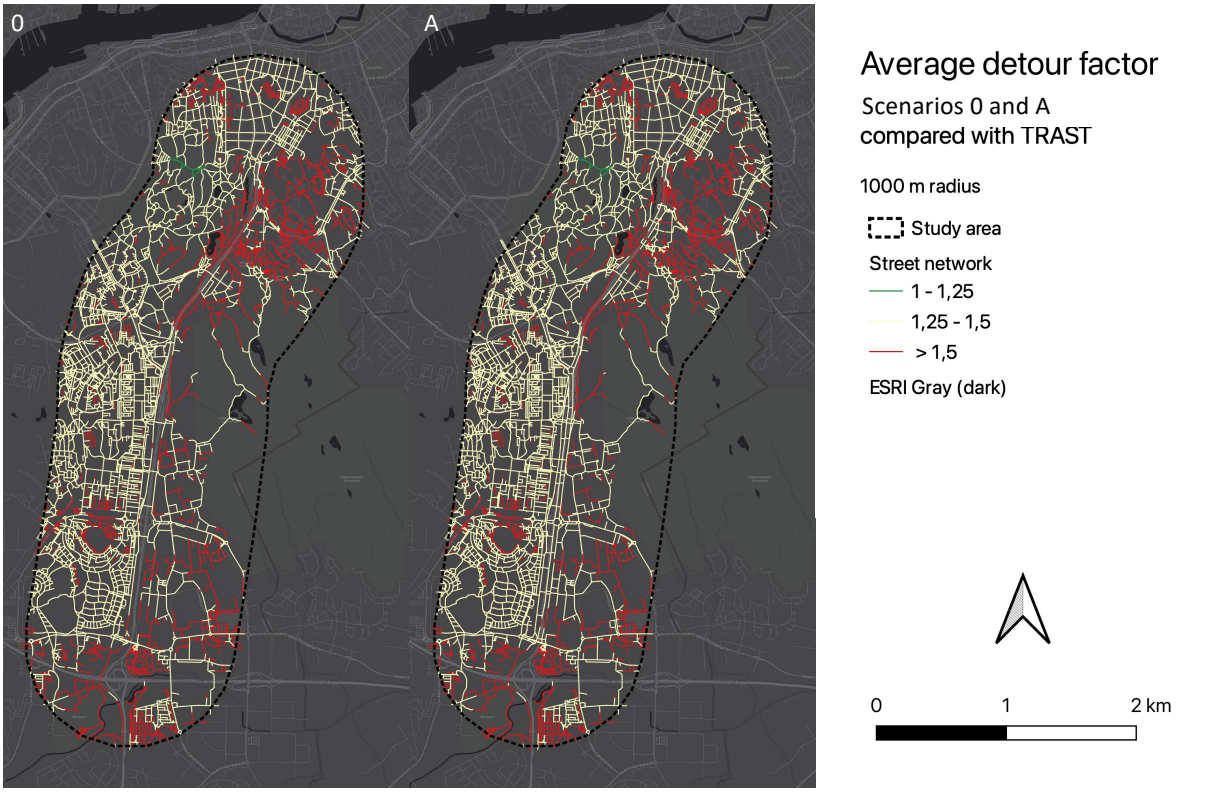


Figure 4.13: *Presents the Detour factor for scenarios 0 and A in comparison with the guidelines presented in Trafikverket et al. (2015).*

Betweenness

The second of the indicators used to analyse the network is Betweenness. When examining the results presented in figure 4.14, both improvements and reductions can be discovered along the route of the planned boulevard. These variations are associated with the alteration between the crossing facilities in scenarios 0 & A respectively. Generally, the reductions are located in connection to the current crossing facilities and the improvements in connection to the new crossing facilities generated through the boulevardisation. Since the Betweenness can be interpreted as a measure of the potential of traffic flows, the results indicate that parts of the flows using the current crossing facilities are transferred to the new crossing facilities if a boulevardisation occurs. The flow of pedestrians and cyclists crossing the barrier is more evenly distributed along the route of Dag Hammarskjöldsleden in scenario A in comparison to scenario 0, hence proving that the added crossing facilities have the potential to improve the ability to cross the barrier.

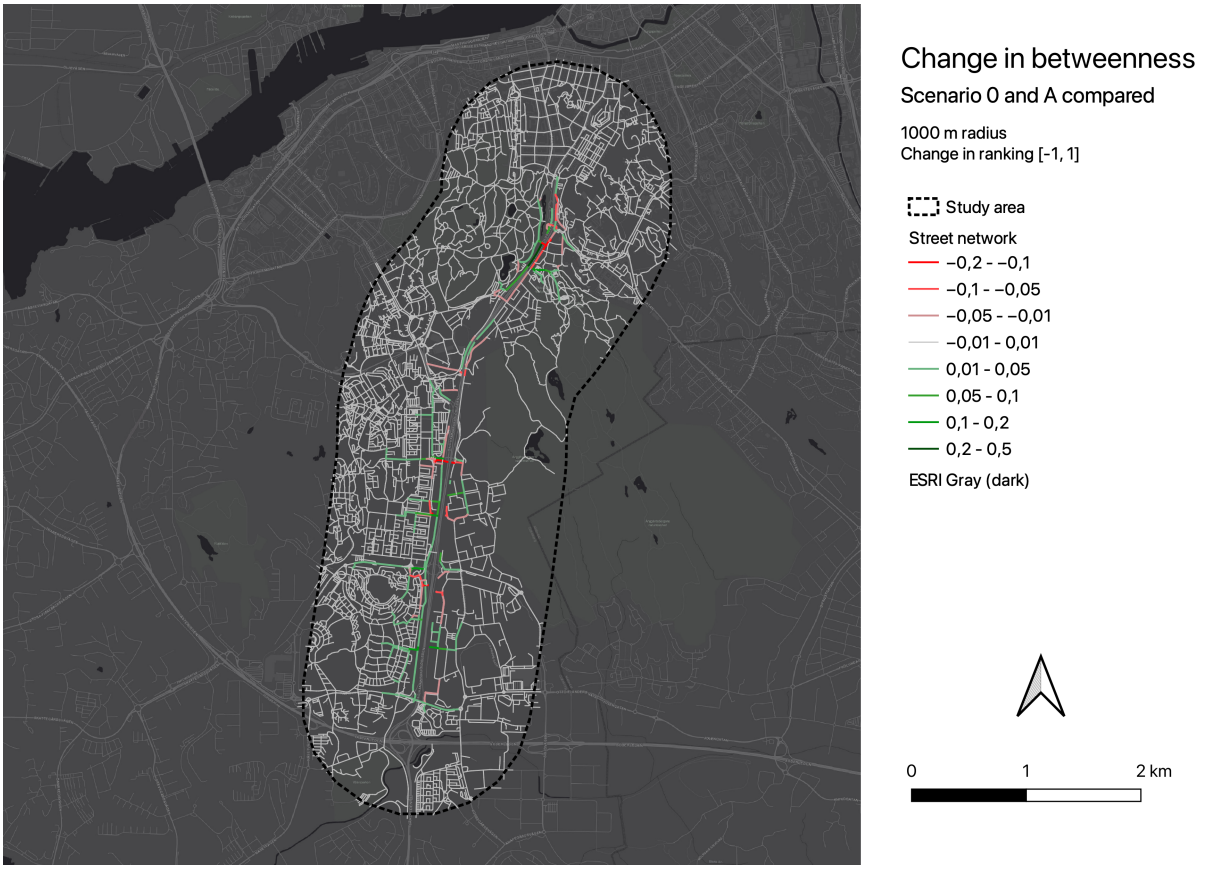


Figure 4.14: *Presents the comparison between scenarios 0 and A for indicator Betweenness.*

In addition, the results presented in figure 4.14 suggest that the potential boulevardisation has an impact on the Betweenness along the route as well. Several of the segments located on the western side of Dag Hammarskjöldsleden in the middle and southern areas demonstrates smaller improvements in comparison to scenario 0. These segments are of particular interest since they form parts of a cycle route important for the local traffic. Worth noticing when examining the results for Betweenness presented in figure 4.14 is that only the segments found in both scenarios are presented in the maps. This means that the segments representing the actual crossing facilities are not visualised on the maps since the crossing facilities are altered between the different scenarios.

4.3.2 Comparisons of scenarios B and C

The following sub-section presents the results for the comparisons between scenarios B & C.

Choice

When investigating the results for the comparison between scenarios B and C regarding indicator Choice, considerable changes can be detected. Similarly to the comparisons for scenarios 0 & A, a significant improvement is seen for the facility category grocery stores in the southern area, see figure 4.15. However, the results for the comparison between scenarios B and C demonstrate larger improvements than for scenarios 0 and A. In addition to the larger improvements in the southern area can minor improvements be seen in a majority of the middle part of the study area. The improvements can be detected both in connection to the route of the planned boulevard and in the surrounding areas. Generally, a predominant part of the identified changes concerning Choice can be categorised as improvements, but a few exceptions exist. One area where increased barrier effects are found is located just southwest of the interchange Marconimotet. The increases demonstrated in this area are most likely an effect of the differences between scenarios B and C regarding both facilities and street network due to the non-buildable area described in section 3.6. Similar patterns regarding the results for choice of grocery stores presented in figure 4.15 can be seen for several of the other examined facility categories, exemplified by choice of sport facilities presented in figure 4.16.

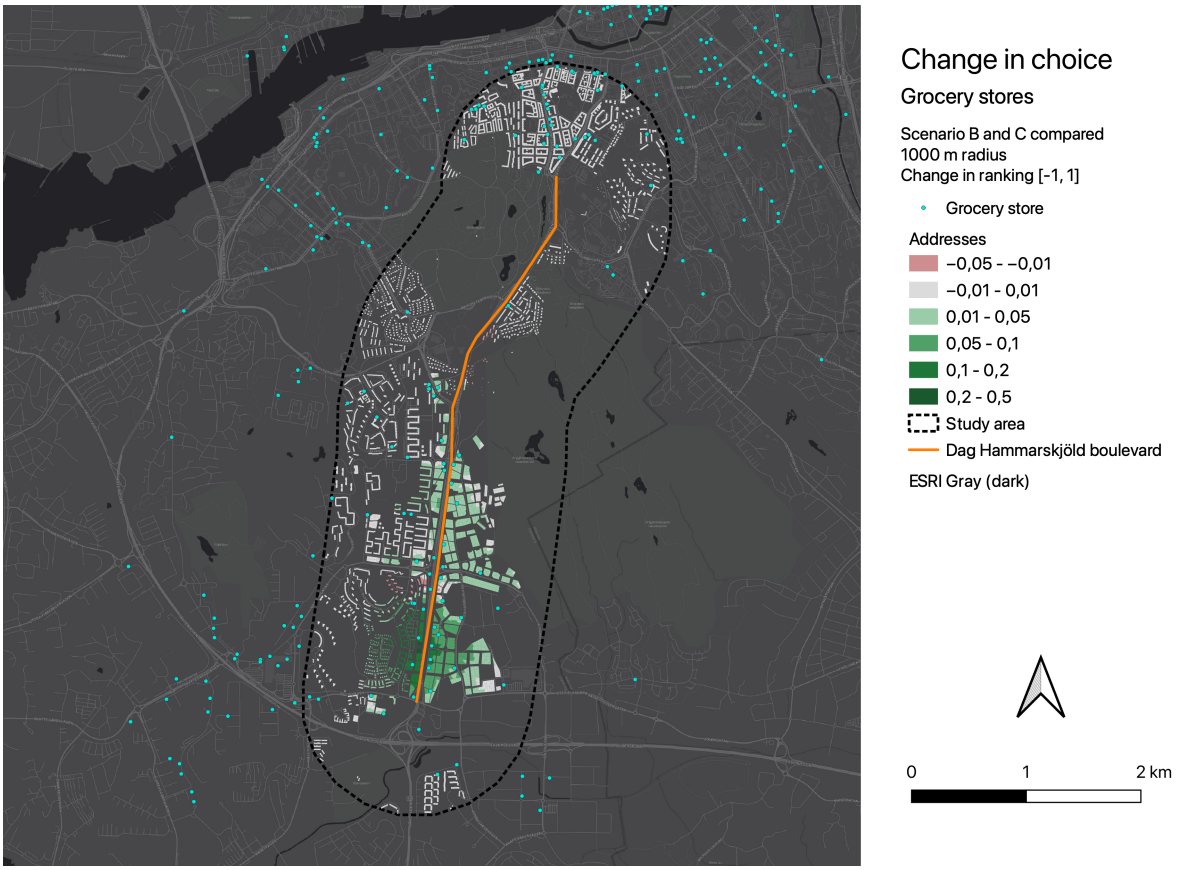


Figure 4.15: *The changes between scenario B and scenario C in regard to choice of grocery stores for indicator Choice.*

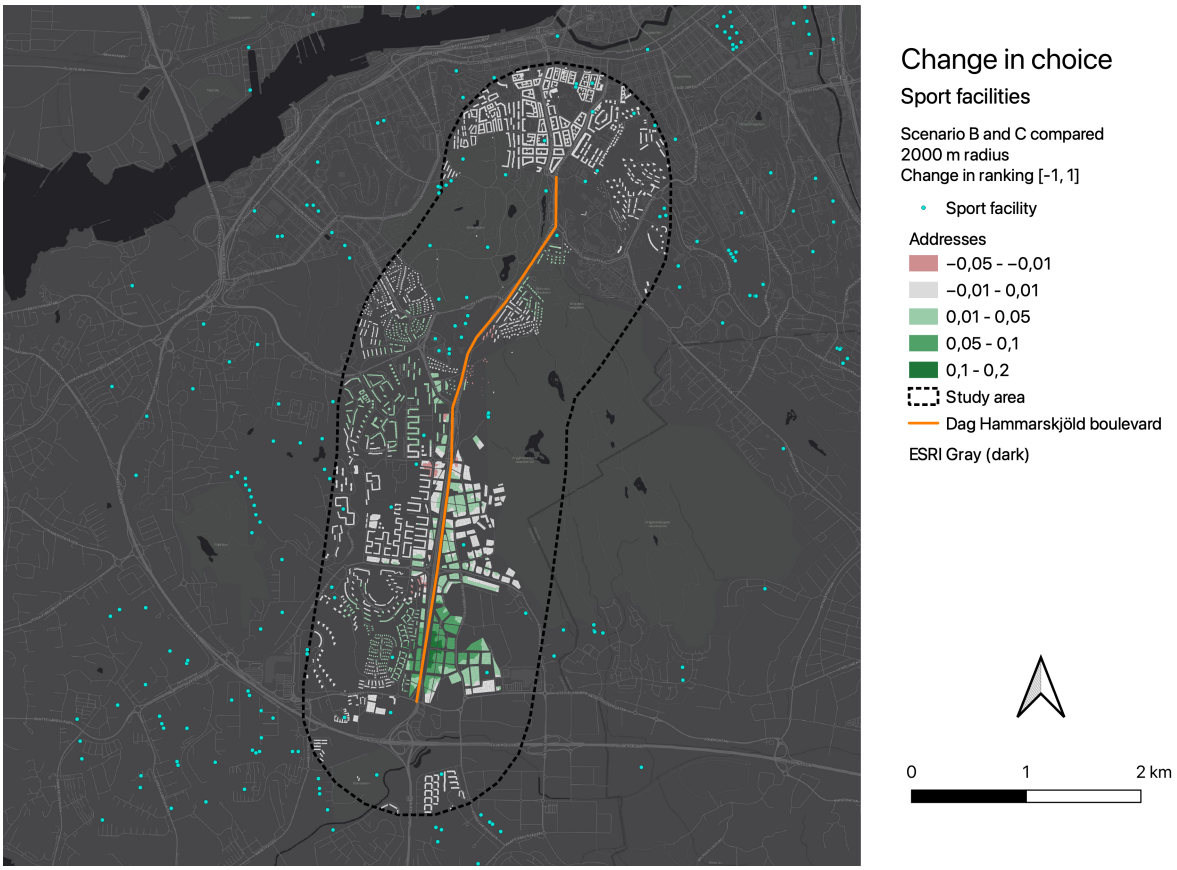


Figure 4.16: *The changes between scenario B and scenario C in regard to choice of sport facilities for indicator Choice.*

Another interesting aspect of the results is associated with the differences in characteristics between the different facility categories for indicator Choice, exemplified by a comparison of gyms and bars, restaurants, and cafes. Gyms presented in figure 4.17, is the facility category that demonstrates the largest improvements when scenarios B & C are compared. Besides the major improvement in the southern area found in several of the other facility categories, the result for gyms shows an area with large improvements in connection to the planned boulevard in the middle section. However, areas affected by changes for most of the other facility categories remain unchanged for gyms, especially in connection to the street A Odhners gata on the eastern side of Dag Hammarskjöldsleden.

When examining the results for bars, restaurants, and cafes presented in figure 4.18, different patterns appear. The results for bars, restaurants, and cafes demonstrate smaller but more uniform changes that extend over a larger area. The differences in regard of indicator Choice for facility categories gyms and bars, restaurants, and cafes demonstrates the impact on the barrier effects associated with frequency and location of the different types of facilities. These are presented as cyan vector-points in the figures 4.17 and 4.18 respectively.

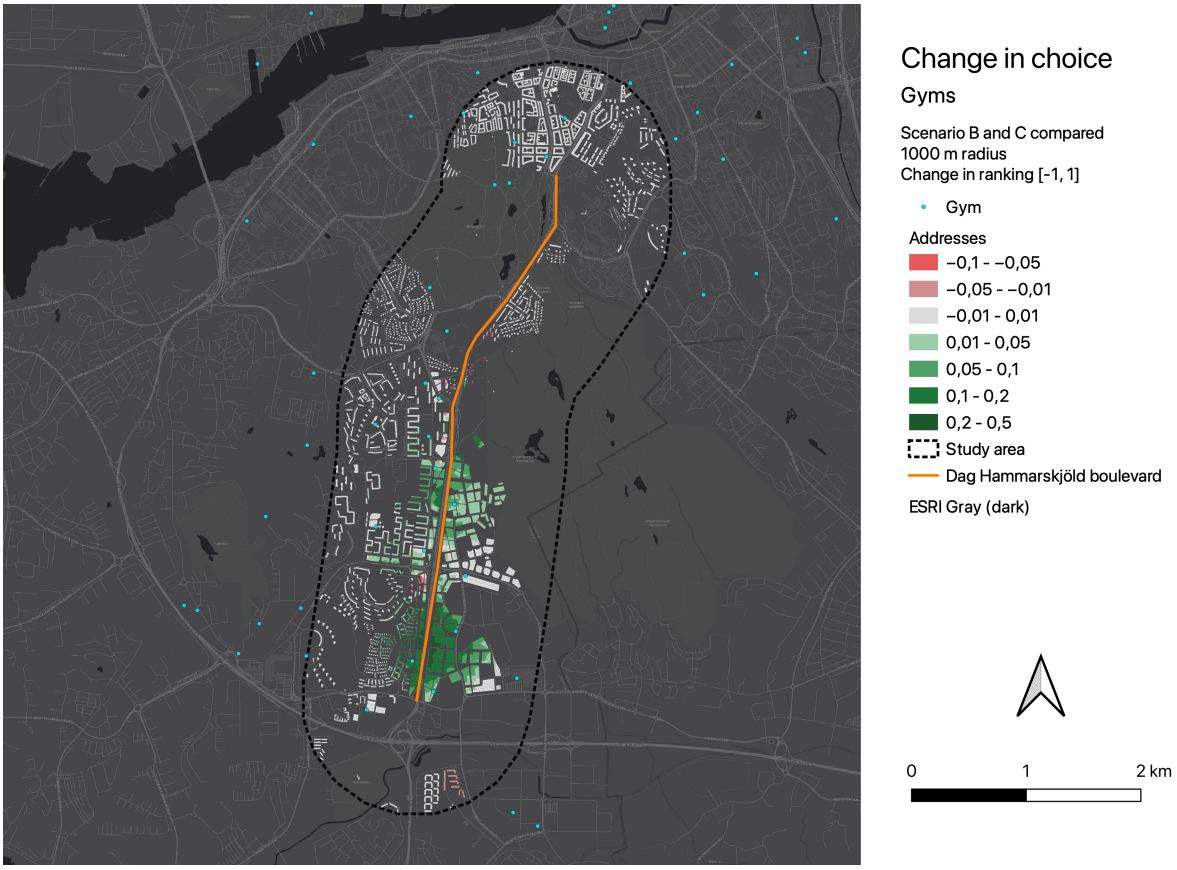


Figure 4.17: *The changes between scenario B and scenario C in regard of gyms for indicator Choice.*

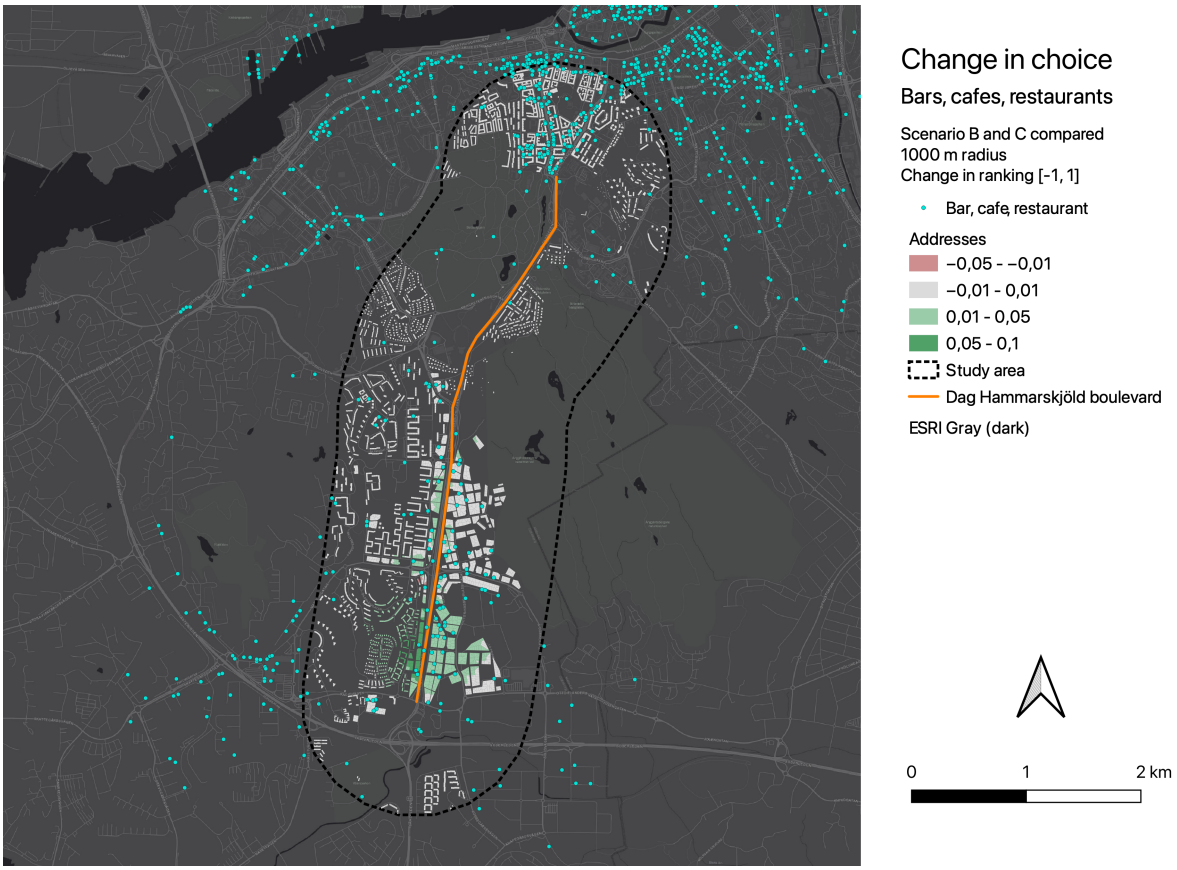


Figure 4.18: *The changes between scenario B and scenario C in regard of bars, restaurants, and cafes for indicator Choice.*

Catchment

When the results for indicator Catchment are analysed, the same pattern reoccurs independently on facility category. One example of these results is presented in figure 4.19, which accounts for the results associated with facility category daycare. The results demonstrate an increase in Catchment for the facilities added in scenarios B & C, located within the middle part of the study area. This addition of facilities is a part of the planned future urban development of the study area described in section 3.6. However, the most conspicuous results are found in the southern part of the study area, where major improvements can be detected. In comparison with the results for indicator Choice, the result for Catchment shows no divergence between facility categories with different frequency and spatial distribution regarding the facilities. These similarities can be exemplified using facility categories parks and schools, presented in figure 4.20 and figure 4.21 respectively.

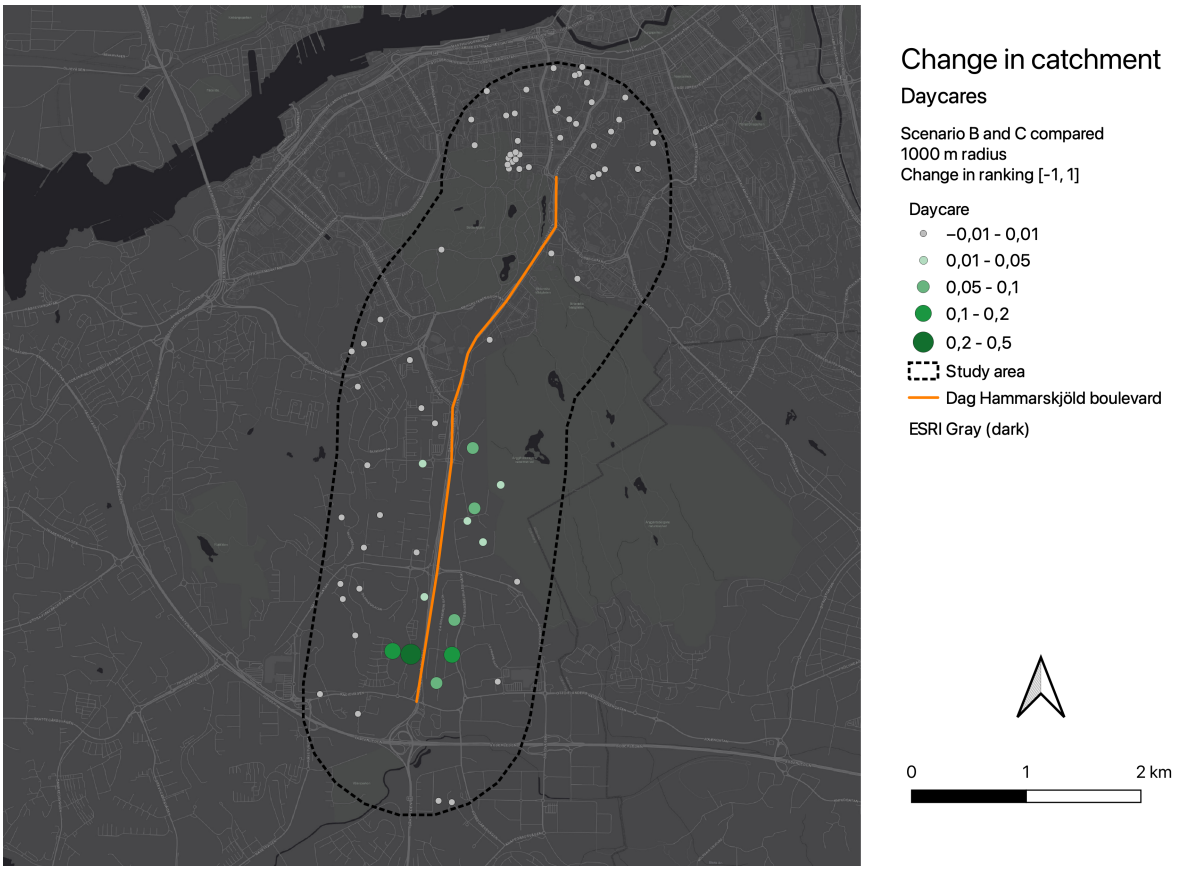


Figure 4.19: *The changes between scenario B and scenario C in regard of daycare for indicator Catchment.*

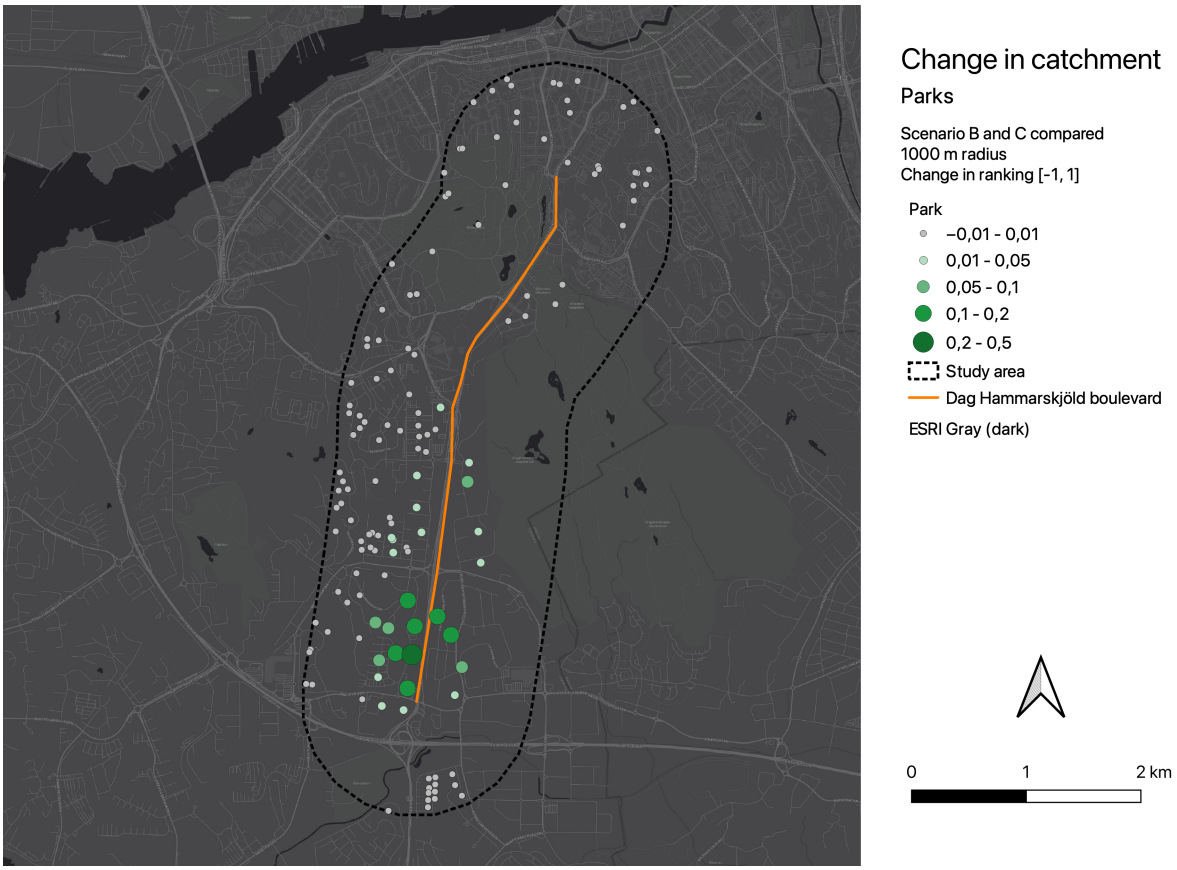


Figure 4.20: *The changes between scenario B and scenario C in regard of parks for indicator Catchment.*

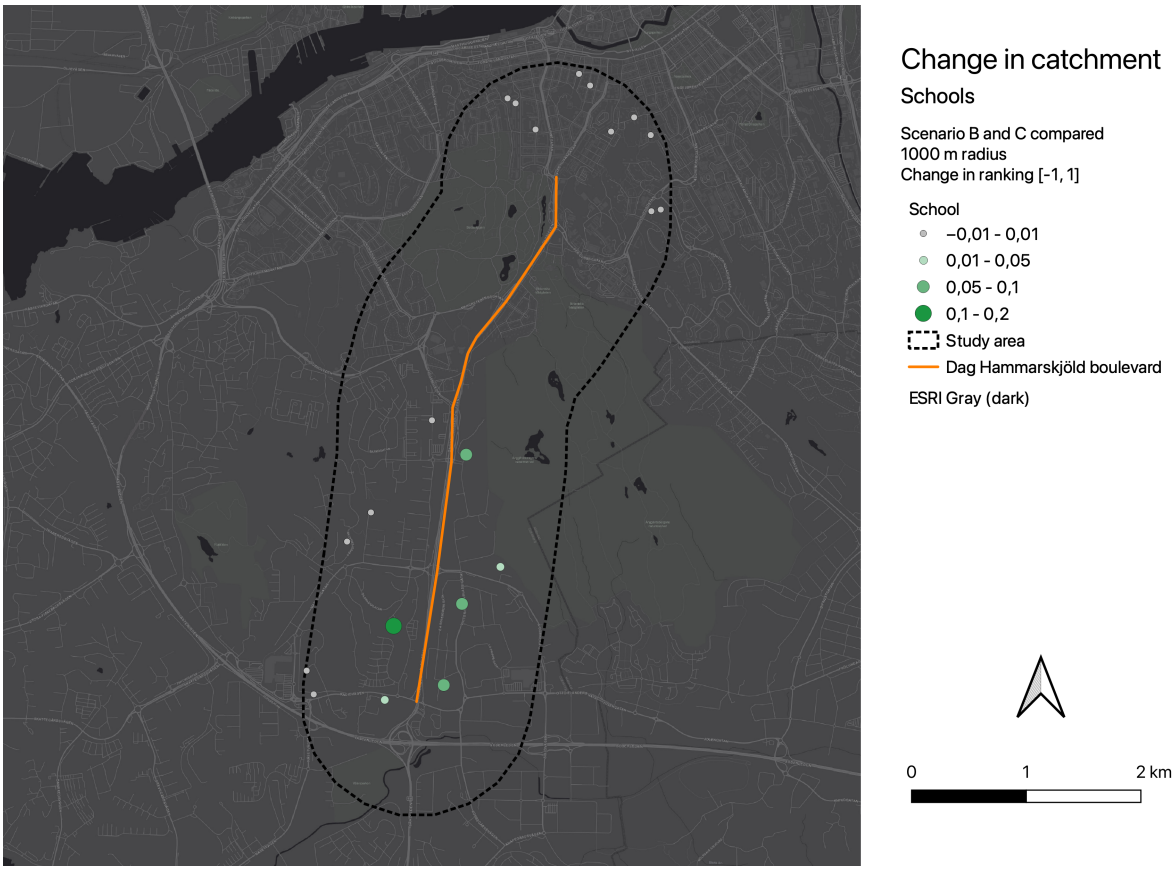


Figure 4.21: *The changes between scenario B and scenario C in regard of schools for indicator Catchment.*

General remarks regarding accessibility

When comparing the results for indicators associated with accessibility, general conclusions can be drawn. Both indicators demonstrate improvements for essentially the entire middle and southern parts of the study area. The improvements are mainly found in direct connection to the planned boulevard. However, smaller improvements can also be detected further away from the planned boulevard. The largest improvements are found in the southern area, where the potential boulevardisation rapidly increases the accessibility. Before the potential boulevardisation, no crossing facilities existed between the interchanges Marconimotet in the north and Radiomotet in the south. This lack of crossing facilities results in a distance of approximately 1000 meters along Dag Hammarskjöldsleden where crossing is impossible for pedestrians and cyclists. The crossing facilities added through the boulevardisation in scenario C have an especially large impact in the southern area due to the very limited possibilities to cross the barrier in scenario B, hence the large improvements seen for example in figure 4.15 and figure 4.20.

The improvements in the middle part of the study area are smaller in comparison with the southern area, which can be explained by the higher frequency of crossing facilities along this section of the existing freeway. However, the addition of crossing facilities from the boulevardisation generates fairly large improvements in the accessibility in the middle part as well, especially locally in connection to the new crossing facilities. The local improvements are visible for example when examining gyms, see figure 4.17.

The changes in accessibility due to the potential boulevardisation remain very limited for the northern part of the study area for both indicators Choice and Catchment. This is most probably due to the lack of changes in the urban development in this part of the study area.

Proximity

The results for the comparison of scenarios B & C concerning indicator Proximity demonstrate greater diversity along the planned boulevard in comparison with the results for indicators Choice and Catchment. Both areas displaying decreases and increases in the network distance can be identified along the planned boulevard in the middle and southern parts, exemplified by facility category grocery stores presented in figure 4.22. The alterations between decreases and increases in network distance create difficulties to detect any pattern in the results besides the local variations. Since Proximity measures the shortest distance along the street network from an address point to the closest facility belonging to a certain category, smaller differences in either the location of address points, facilities, or the network can contribute to substantial differences in the results. The changes seen for most facility categories are likely the results of smaller differences in the spatial conditions between the two scenarios, caused by the non-buildable area presented in section 3.7. An example of the extent of these differences can be presented for facility category gyms, where the largest reduction in network distance is 255 meters and the corresponding largest increase is 158 meters. A significant share of the largest differences along the planned boulevard is detected in connection to the interchange Marconimotet, hence corresponding to the area where the largest spatial difference between scenarios B & C due to the non-buildable area can be found.



Figure 4.22: *The results for the comparison between scenario B and scenario C in regard of grocery stores for indicator Proximity.*

When comparing the results for different facility categories regarding Proximity, smaller variances are detected. For facility categories with lower frequency of and more sparsely located facilities, exemplified by gyms presented in figure 4.23, the effects of the potential boulevardisation are less distributed along the route of the planned boulevard. The changes are concentrated in a smaller number of areas, demonstrating a greater magnitude of the changes. The lower frequency of facilities for these categories increases their sensitivity to changes between the scenarios, exemplified by the addition of new crossing facilities through the boulevardisation.

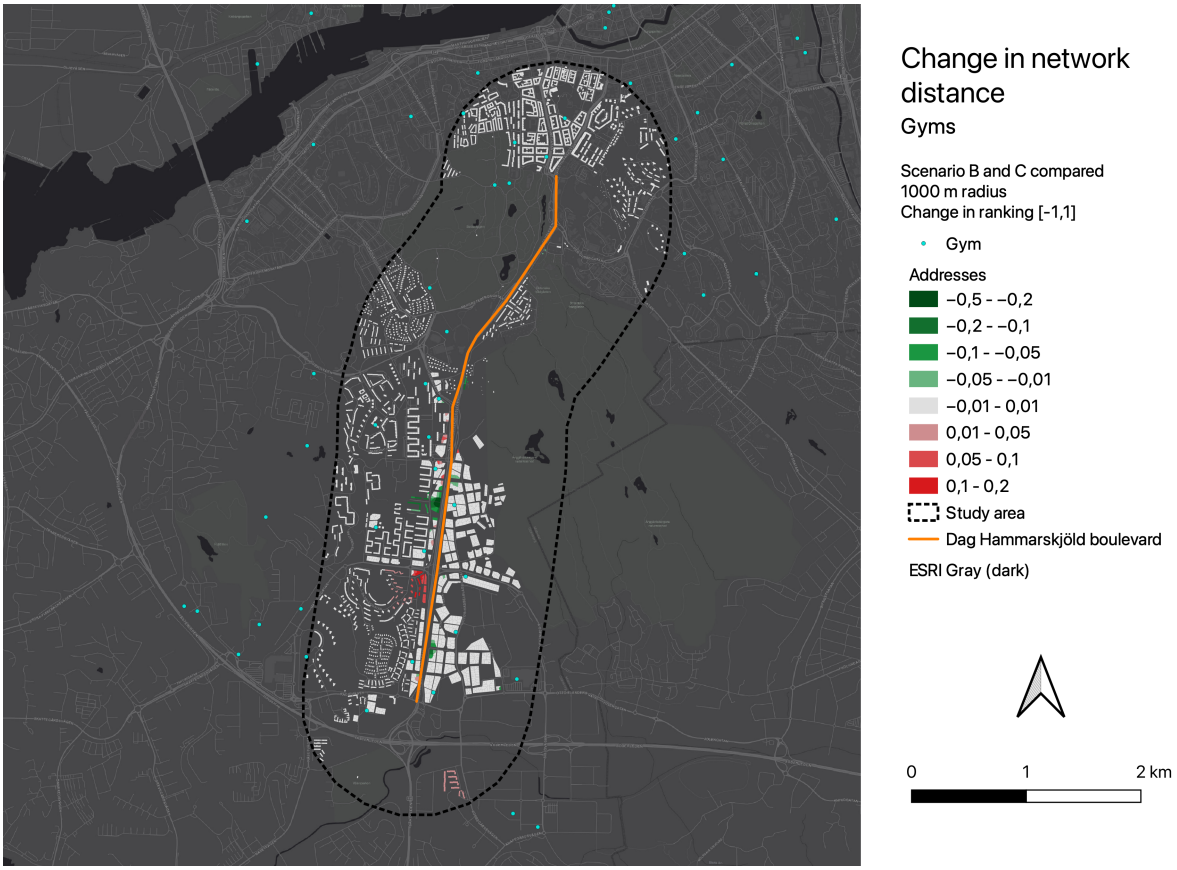


Figure 4.23: *The results for the comparison between scenario B and scenario C in regard of gyms for indicator Proximity.*

To better understand the actual differences in network distance caused by the boulevardisation, one should further examine the non-normalised results. Figure 4.24 presents the results for the absolute values for facility category gyms in comparison to figure 4.23, displaying the corresponding normalised results. The results seen in figure 4.24 demonstrate that the largest reduction in network distance is found to be 255 meters and the corresponding largest increment 158 meters. These external values on each of the fringes of the results spectrum constitute results with a substantial impact on the barrier effects caused by the boulevardisation. However, for a majority of the areas affected by the boulevardisation the impact is considerably lower, hence only having a limited influence on the barrier effects. Still, the minor differences should not be neglected. Important information regarding different statistical aspects of the results can be seen in the statistical summarises found in appendix F.

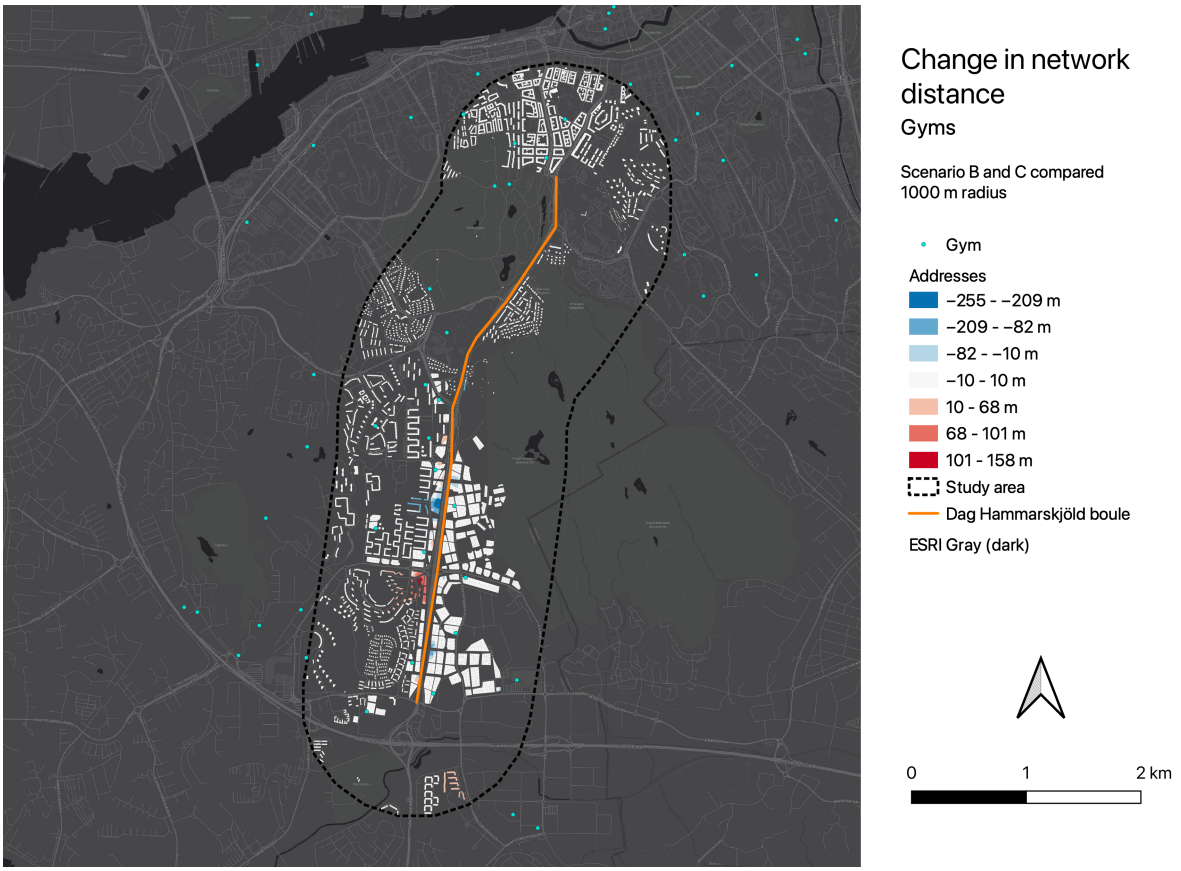


Figure 4.24: *The results for the comparison between scenario B and scenario C in regard of gyms for indicator Proximity. The are expressed in absolute values.*

Proximity for parks

As mentioned in section 4.3.1, facility category parks constitutes an exception concerning indicator Proximity since they are planned in accordance with the recommendations presented in Göteborgs stad, park- och naturförvaltningen (2014). These specific conditions mean that the Proximity of parks remains practically unchanged, see figure 4.25. Figure 4.25 demonstrates that the recommendation, defined as the access to parks for all residents within 300 meters without the need to cross any major barrier is fulfilled for a majority of the study area. However, the area surrounding the planned boulevard in the middle part of the study area poses an exception, probably caused by the lack of land for parks due to the high density of the urban development in the area.

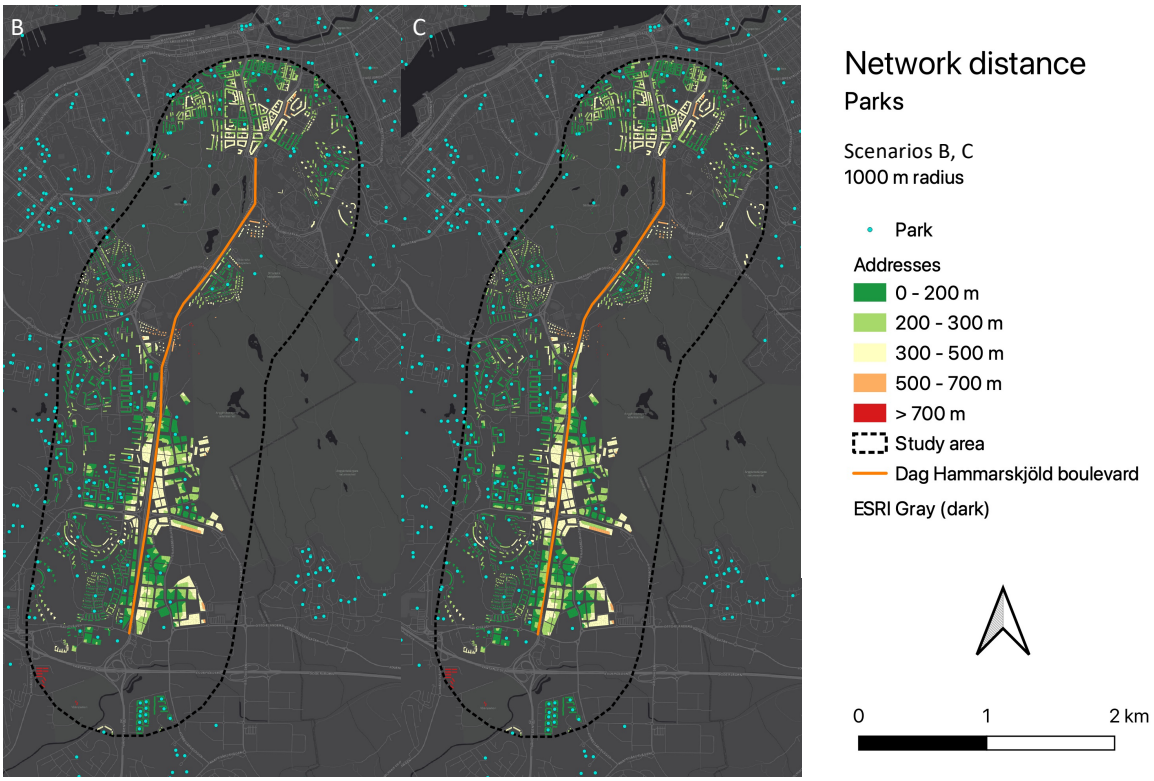


Figure 4.25: *The results for indicator Proximity for scenarios B and C in regard to facility category parks.*

Detour factor

For the analysis of the DF, considerable differences in the network can be detected between the two scenarios where Dag Hammarskjöldsleden remains a freeway, see scenarios B & C in figure 4.26. These differences concerning the network can be explained by the planned urban development in the area presented in section 3.6 and section 3.7. The results for scenario B demonstrate a significantly lower average DF in comparison to scenario 0, due to the finer and more developed street network in scenario B.

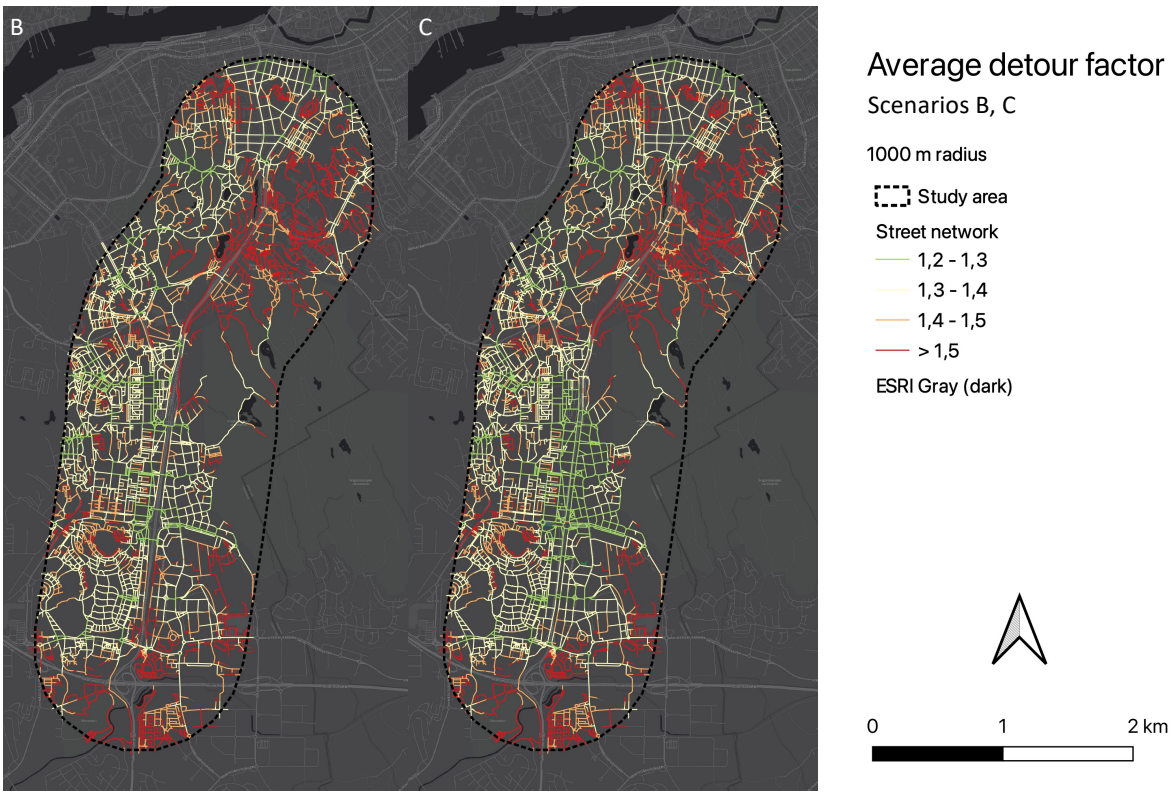


Figure 4.26: *Presents the Detour factor for scenarios B and C.*

When the results between scenarios B and C regarding indicator DF are compared, the improvements from a potential boulevardisation are considerable. The improvements from the boulevardisation can be seen both in connection to the planned boulevard and the areas subject to the planned urban development in the entire middle and southern parts of the study area. The positive effects of the boulevardisation are especially evident when the middle part of the study area is exclusively analysed. Almost all segments affected by the planned urban development located in the middle area have a DF of 1.3 or lower after the boulevardisation, which is a major improvement. A low DF is ensuring an effective network for pedestrians and cyclists, hence creating perquisites for lively street life and increasing the attractiveness of the area. Additionally, similar improvements can be identified in the southern area, where the average DF is considerably lower after the boulevardisation. In comparison with the middle area are low values of DF achieved in smaller areas in the southern part, even after the boulevardisation. This is however mostly a result of the low initial DF of the southern part in scenario B and not the lack of effect from the boulevardisation. The results in figure 4.26 demonstrate only minor improvements in the

northern part, meaning that a potential boulevardisation has a very limited effect on the DF in this part of the study area.

As previously mentioned in section 4.3.1, Trafikverket et al. (2015) has created guidelines for the DF to determine the attractiveness of the pedestrian street network. The comparison between the guidelines from Trafikverket et al. (2015) and the DF for each of the scenarios is presented in figure 4.27. A majority of the network fulfils the requirements for average DF already before the boulevardisation in scenario B. High DF can be seen in several areas, especially in the southern and northern parts of the study area. Only a limited number of segments located in the park Slottsskogen achieve a low DF. When the results for scenario B are compared with C, improvements can be detected. A majority of the network still only achieves average DF, but the areas with high DF are fewer and smaller. Additionally, substantial areas that achieve the requirements for low DF have emerged in connection to the planned boulevard. The two largest areas where the low DF are achieved are located in the middle part of the study area in connection to the two current interchanges Flatåsmotet and Marconimotet. Based upon the results presented in figure 4.26, one can conclude that an additional large share of the middle area is close to achieving the guidelines for low DF since they have a measured DF below 1.3.

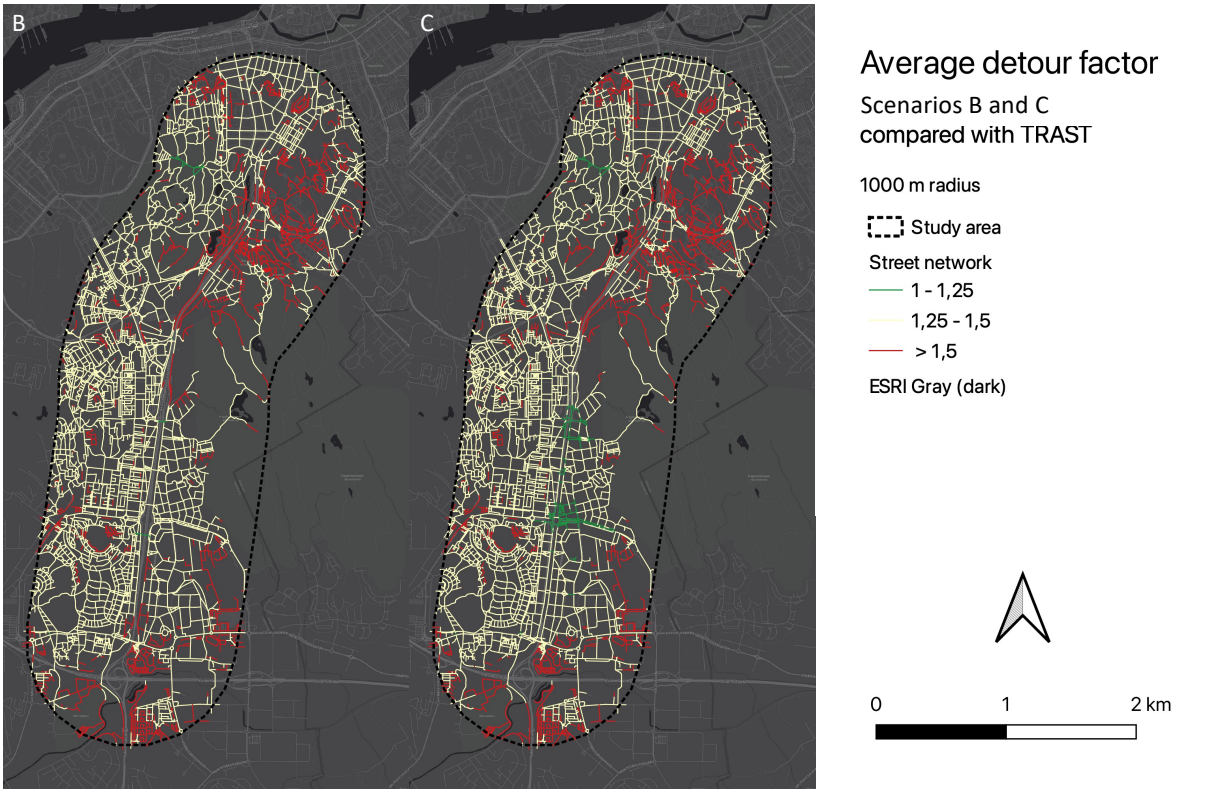


Figure 4.27: *Presents the Detour factor for scenarios B and C in comparison with the guidelines presented in Trafikverket et al. (2015).*

Betweenness

When the results for the comparison between scenarios B & C concerning the final indicator Betweenness are analysed, similarities to the results presented in section 4.3.1 can be found. Investigating the results in figure 4.28, alterations between improvements and reductions can be detected in connection to the planned boulevard, varying between the different parts of the study area. The result for the northern area indicates decreasing Betweenness in connection to added crossing facility close to the current interchange Annedalsmotet. However, improvements can be detected for segments located close to the added crossing facility in the park Slottskogen and the nearby neighbourhood. The differences suggests that the parts of the current flows seen in connection to Annedalsmotet will be transferred to these adjacent if the transformation towards a boulevard is conducted.

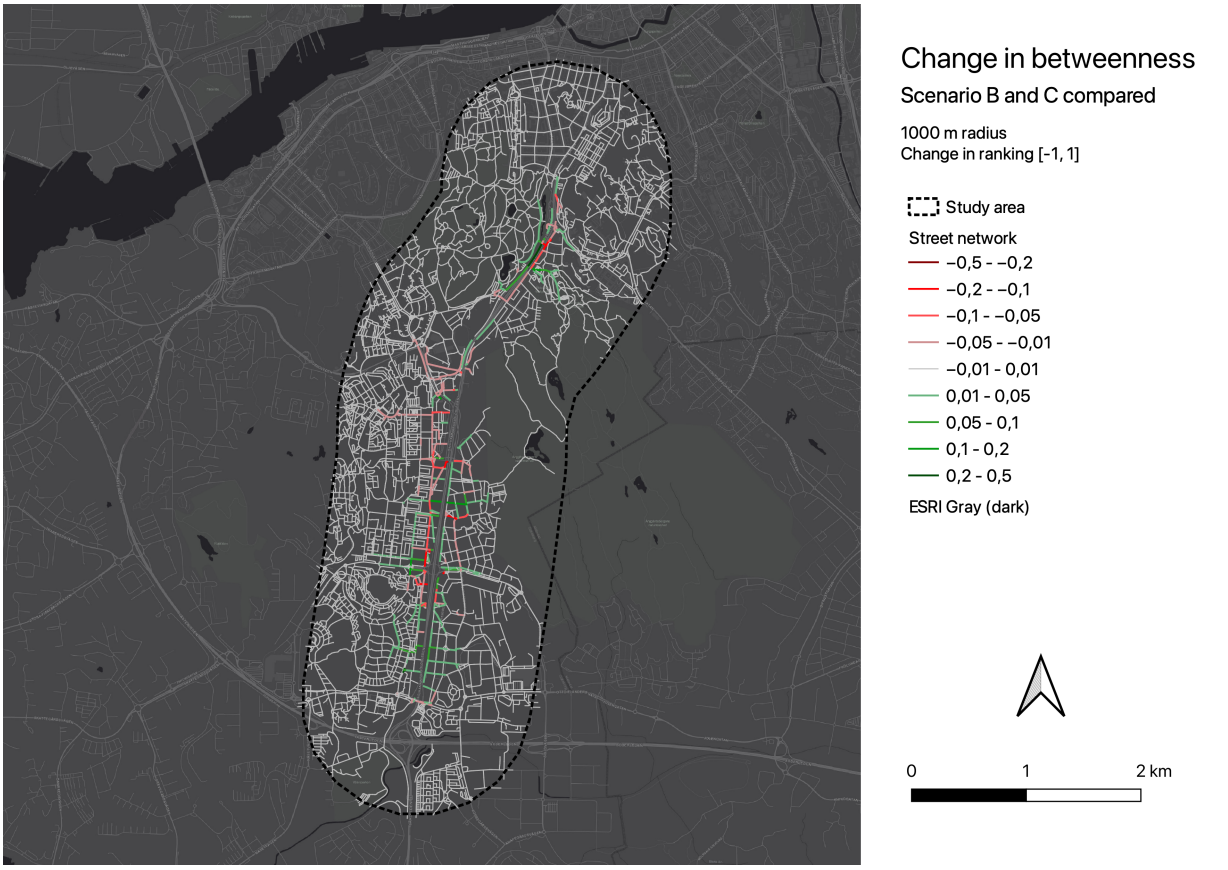


Figure 4.28: *Presents the comparison between scenarios B and C for indicator Betweenness.*

When examining the middle part of the study area, all improvements are located in connection to the added crossing facilities, see figure 4.28. Most of the deteriorations are on the other hand found on segments located along the boulevard, suggesting a transfer of flows of pedestrians and cyclists from along towards across the planned boulevard. The results can be interpreted as an indication of the potential increase of the ability to cross the barrier created through the boulevardisation. For the southern part, the results are dominated by the improvements found in association with the crossing facilities added through the boulevardisation, hence demonstrating the potential of the increased ability to cross the barrier from the transformation towards a boulevard.

5 Discussion

Based on the scenario analysis results and the theoretical framework, this section addresses a discussion of the following topics to answer the research questions: how barrier effects are affected by the boulevardisation of Dag Hammarskjöldsleden and how it can be improved, about boulevardisation as a tool to reduce barrier effects, how van Eldijk's conceptual model can be applied in similar projects, limitations of the work, and further work.

5.1 Reflections on the boulevardsiation

5.1.1 Boulevardisation reduces the barrier effect in the southern part of the study area

From what can be seen in the results of the Catchment, Choice and DF analyses, there are clear indications of improvements in the very south area between the interchanges Marconimotet and Radiomotet when there are future urban development. Hence, the boulevardisation will contribute to the fulfilment of the projects objectives. It is probably because in scenario B the distance between the crossings at the interchanges Radiomotet and Marconimotet is about 1000 m, while in scenario C, two new crossings are implemented and the distances between these crossings are no more than 440 m. Distance between crossings is also one of the indicators van Eldijk et al. (2022) has included in the table of barrier effect indicators, and the Catchment, Choice and DF analyses verify that.

The Betweenness indicator indicates that trips are more likely made in the horizontal direction in the south and that the boulevard with the new crossings is useful for the local travellers that want to cross the street in the area. Horizontal routes with existing crossings that will be removed get a lower Betweenness. This means that the Betweenness are redistributed to adapt to the new crossings. Also, the DF indicates that the more fine mesh network improves the street network attractively due to the boulevard design and the corresponding network to the new urban development. Hence, the boulevard design is beneficial from a barrier effect and street network perspective.

The improvements of barrier effects are also except the improved street network a cause of the simulated travel behaviour. This is due to people living and facilities on both sides in the middle and south sections. Hence, trips that cross the freeway/boulevard are generated and barrier effects are created. This means that with the future planned urban development, people living in these areas are more affected by the barrier effects than at present.

5.1.2 Improvements of the boulevard project

As discussed multiple times in this thesis, the key to reduce the barrier effects for pedestrians and cyclist is to improve the travel distance by implementing new crossing facilities. Thereby, having as many crossings as possible for pedestrians and cyclists are useful. The single most beneficial implementation of a new crossing is probably at the street F O Perssons gata since distance to cross the boulevard there will go from over 450 m to 30 m.

The new tramway along the boulevard is one of the key objectives in the boulevardisation project. It aims to promote green and sustainable transportation and improve traffic congestion. However, the trams will contribute to conflicts with the other traffic modes in the interchanges and it is valuable if the boulevard enables high speeds for the trams. Therefore, it is not possible to implement too many crossings for pedestrians or the speed of the trams will suffer.

This problem could be solved by build an elevated or underground tramway. The West Swedish Chamber of Commerce thinks that Gothenburg should have this approach of separating the tramway system in Gothenburg from the other traffic modes done in for examples German cities such as Cologne, Düsseldorf and Stuttgart (Västsvenska handelskammaren, 2015). Since the boulevard with the tramway is new infrastructure, there is an opportunity to build such a solution. A crossing-free tramway would also be beneficial in case it will be extended to areas south of the project. However, according to Göteborgs stad, trafikkontoret (2022), an elevated tramway would cost 2-3 times and tramway under the street 4-5 times higher than the planed tramway in the boulevard. The city of Gothenburg argues that a ground level separated tramway is also not compatible with the vision of an accessibility tramway which is a fundamental feature in the boulevard. Simultaneously, there is an ongoing process whether there will be and extension of the railway from the upcoming Haga station down to southern Gothenburg (Göteborgs stad, trafikkontoret, 2022). With the level separated tramway might be enough.

Furthermore, there is a wide and effective cyclist path along Dag Hammarskjöldsleden today. The path is also mainly separated from pedestrians and the motor-vehicle traffic which reduce the conflict making it attractive to cyclist along. With the boulevardisation will a new cyclist paths be built that would probably increase the conflict with pedestrians and motor vehicles because of the new intersections. There are green tree-lined medians between the cyclce paths and the road, defining the street to a boulevard, that increase the attractivity to cycle and drive. A median between the cyclists and pedestrians would also be a good design choice from a barrier effect perspective. If the tramway is built under the boulevard, it will be possible to build a wide cycling path in the middle of the boulevard instead of the tramway, making it a median boulevard described in section 2.3. Except the tramway, it would then look like Vasagatan as in figure 2.13.

5.1.3 The advantages with boulevards in comparison to other measures

When examining the results presented in section 4.3.1 and section 4.3.2, the reductions of barrier effects from the addition of crossing facilities is elucidated. However, since the performed calculations and corresponding analyses presented in section 4 only measure the results in geospatial terms, the type and design of the crossing facilities remain disregarded. Based upon the results seen in section 4, one can argue that any type of measure where crossing facilities are added would contribute to reductions of barrier effects. An alternative design approach, resulting in similar reductions of barrier effects, could be to let Dag Hammarskjöldsleden remain a freeway but add the same number and location of crossing facilities as suggested in the boulevard design proposal presented in Ramboll & Göteborgs Stad (2021). The added crossing facilities would predominately be constituted of bridges and underpasses.

However, the reality is far more complex than that, especially when the perceived barrier effects presented in section 2.1 are considered. Perceived barrier effects are complicated to address, since the appreciation on an individual level associated with the psychological aspects and differences in appreciation composes a major contribution to the conclusive results. Both these factors are difficult to include in computational models. Several illustrations of psychological aspects related to the appreciation of crossing facilities are presented in section 2.1, where examples are the general aversion to ground-level separated crossings like bridges and underpasses, and the increased barrier effects caused by dynamic properties such as large traffic flows and high travel speeds for vehicles travelling along the barrier. When both the measurable and perceived barrier effects are considered, the benefits of boulevardisation become illuminated. The concept of boulevards presented in section 2.3 highlights the additional values related to boulevardisation. Examples are crossing facilities in level, reductions in volumes and travel speed for road traffic, and promotion of sustainable transportation through improved conditions for walking and cycling. Additionally, a transformation towards a boulevard generate benefits for the surrounding urban development through an increased attractiveness of surrounding residential areas and businesses as well as improved integration between the two sides separated by the barrier. In comparison to boulevards, few of the measures which can contribute to reductions of barrier effects in geospatial terms can improve all these aspects relating to the overall improvement of the area surrounding the barrier, hence resulting in an advantage for boulevards for projects similar to Dag Hammarskjöldsleden.

5.2 Learnings on boulevards and barrier effects

5.2.1 The importance of travel demands

Based on the results, there are few or no changes in when the boulevardisation is conducted without the future land use development (scenario A) regarding the indicators Proximity, Choice and Catchment. The main reason is that there are low travel demands to cross the barrier with the current urban development because the facilities and residences are mainly located on the western side. Without a demand and trip generation to cross the barrier, there are no barrier effects caused, see the conceptual model about barrier effect in the theoretical background 2.1. Although, Choice and Proximity analyses for grocery stores are the most distinct exceptions with clear changes in the case study. This is because there are currently grocery stores located on the east side, hence the changed street network between the scenario 0 and A due to the boulevardisation reduces the travel distance. Because few indicators show improvements from scenario 0 to scenario A, boulevardisation will not significantly improve the barrier effects Dag Hammarskjöldsleden generate, since it does not generate major barrier effects with the current urban development.

5.2.2 The impact of land use

As said in the theoretical background, see section 2.1, a trip is dependent on several factors such as demands, the location of the origin, the location of the destinations and a network. Barrier effects can also be reduced by changing the land use by moving or building new facilities closer to the people that demand them. Thereby, trips that require crossing barriers can be prevented or improved. For example, if there were no schools on the

Gothenburg island Hisingen, then the pupils have to commute to the mainland and where the river Göta älv is causing major barrier effects. Therefore, by having schools on the island the barrier effects of the river are reduced. In the Dag Hammarskjöld boulevard project where a lot of new urban development will be implemented, it is beneficial to have a variety of facilities on both sides of the street to prevent barrier effects, for example that day-cares, schools and playgrounds. Evaluating how barrier effects can be reduced and prevented in the Dag Hammarskjöld boulevard project by analysing and evaluating the land use's impact could be something to study further on.

In addition, the location of the facility categories with few options such as gyms and schools can have a bigger influence on the change in barrier effects than the once with many options, for example bars, cafes and restaurants and parks. As an example, the proportional increase of the Choice indicator is larger from 1 facility to 2 facilities, than going from 10 facilities to 11 facilities. Change in Proximity can also be more affected by facility categories with small quantities, such as schools. Few options of schools also mean that a lot of trips will be generated to these. Considering that, it is extra important to plan the location of the facilities with few options to prevent barrier effects.

5.2.3 Considerations regarding boulevard designs

One of the main learnings from the analysis of the results is the importance of the design for boulevards to fully utilise their potential for reduction of barrier effects. When the comparisons between different scenarios are presented in section 4.3.1 and section 4.3.2, one can conclude that a substantial part of the total improvements was detected in direct connection to the crossing facilities, hence highlighting the importance of the crossing facilities. The frequency and distance between the crossing facilities are two major aspects of the boulevard design. A high number of crossing facilities increases the opportunities to cross the barrier, hence increasing access to services and important target points in the areas surrounding the barrier.

The increased number of crossing facilities contributes to improvements of the street network for pedestrians and cyclists by the reduction of distances in connection to the crossing of the barrier. However, the problems with barrier effects can not be solved merely by adding a large number of crossing facilities along the barrier, due to the complexity of interaction between different traffic modes. For boulevards, where the crossing facilities are designed on the same level as the barrier, does each crossing facility constitute a location where the conflicts between the traffic crossing the barrier and traffic travelling along occur. When examining the specific case of Dag Hammarskjöld's boulevard would a large number of crossing facilities greatly reduce the capacity for the road traffic and generate big difficulties for the planned tramway in the middle of the boulevard. It is therefore of high importance to find a good balance for the frequency of crossing facilities to ensure low barrier effects but at the same time preserve a good capacity for road traffic and tramways. The results presented in section 4.3.1 and section 4.3.2 demonstrate that suitable distances between crossing facilities range between 150-200 meters for areas with high density and many services, exemplified by the middle part of the study area, while 200-300 meters is suitable for areas with lower density, exemplified by the southern part.

Another important learning of the results is the importance of the location for crossing facilities. The comparisons seen in section 4.3.2 showed a local compression in connection to the crossing facilities for several indicators. To fully utilise the reductions caused by the crossing facilities, these should be placed in locations where the largest need to cross the barrier are found. As described in section 2.1, people's needs and land use compose the factors that create the need for the crossing of the barrier, hence acting as drivers of the barrier effects. By analysing the land use of the areas surrounding the barrier, important services, and target points can be identified. These services should be an important consideration for the boulevard design, placing the crossing facilities in their connection, hence ensuring high utilisation of the added facilities.

An additional learning of the thesis learning is the importance of cooperation between the design of the boulevard and the planning of the surrounding land use. As previously mentioned is the impact of the boulevardisation influenced by the interplay between the design of the boulevard itself and the surrounding urban development. The idea is basically to treat both the infrastructure and surrounding urban development as one joint project, not two separate projects planned independently of each other. When considered one joint project, the design and development develop simultaneously where alterations occur when the divergence between the included aspects is discovered. During the work presented in this thesis, the reductions of barrier effects have been achieved exclusively been the result of alterations in the street network. However, an alternative approach would be to perform changes in land use instead, especially in situations where alterations of the street network are impossible. Alterations regarding land use are often very complicated and expensive to perform after the planned buildings are constructed. However, changes to the urban development are simpler to perform in the planning stage, hence illustrating the gain from a joint project. The best approach to avoid barrier effects caused by transport infrastructure is to consider this problem early on in the project and make design choices that minimise the risk that barrier effects emerges at all.

5.2.4 The complexity of the Dag Hammarskjölds boulevard project

One interesting aspect of larger urban development projects like the Dag Hammarskjölds boulevard project is the associated complexity caused by the many factors that require consideration. Göteborgs stad, trafikkontoret (2022) gives plenty of good examples for situations where different interests and considerations contradict each other, creating problems related to the decision-making process. One good example of this seen throughout the project is the addition of crossing facilities. As presented in the results seen in section 4.3.1 and section 4.3.2, the addition of crossing facilities greatly contribute to the reductions of barrier effects targeted with the boulevardisation. However, crossing facilities also constitute obstacles for road traffic and future tramways travelling along the route of the current freeway. The continuous conflicts between the traffic travelling along and across the future boulevard will lower the travel speed and increase travel time for the road traffic as well as decrease the capacity and frequency of the tramway. These problems become even more problematic when emergency vehicles are considered, possibly reducing their accessibility.

Based upon the examples presented above and similar situations, a general framework for the decision-making process is needed to ensure that all relevant aspects are considered before important decisions are made. One useful idea could be to invite concerned parties to better understand their priorities and to broaden the understanding of the potential gains and drawbacks in various aspects generated by different decisions. Additionally, a ranking of the importance of all the considered aspects could be used within the decision-making process in situations where contradictions between aspects occur.

5.3 Practical applications for van Eldijk's conceptual model

As mentioned in the theoretical background in section 2, barrier effects constitute complex and advanced processes that are difficult to understand and address. To mitigate and reduce their negative impact using the learnings from van Eldijk's conceptual model presented in van Eldijk et al. (2022), it is of high importance to understand the contribution of these findings in each stage of the planning process. One useful area of application is as a decision basis used as support for decision-making processes. The early stages of the planning process are often characterised by the investigation of different identified alternatives, not seldom with a rather limited basis. A simple but useful way to better understand the impact on barrier effects from different alternatives connected to transport infrastructure projects is through the creation of models. These models could be used to calculate the possible reductions in barrier effects from different solutions and design suggestions, similar to the work presented in this thesis. Even with rather limited data regarding the urban development and street network, calculations of the effects can be performed, hence providing some sort of basis that simplifies the decision-making. However, the accuracy and level of detail for the results of these analyses are highly dependent on the data used in the model, meaning that the results from this stage should be regarded more as estimates rather than final results. With the increased understanding regarding barrier effects retrieved from the model creation and corresponding calculations, enough information exists to make decisions, hence moving the project forward.

Another interesting aspect is the choice of indicators used for the determination of barrier effects. van Eldijk et al. (2022) presents a large collection of indicators, measuring different levels of barrier effects. These indicators are determined using different measurement procedures, exemplified by geospatial analyses, site audits as well as surveys, and interviews. The great variety among the level measured and measurement procedure creates good opportunities to customise the conducted analysis of barrier effects dependent on the specific conditions and aims for each project. Hence, it is highly recommended to decide on the used indicators carefully dependent on the specific project to fully utilise the benefits from the analysis of barrier effects.

The five indicators used in this thesis were decided based on the aims of the project decided by The city of Gothenburg, presented in section 1.1. The five selected indicators Choice, Catchment, Proximity, DF, and Betweenness constitutes a beneficial foundation for the calculation, covering three main components for the determination of barrier effects: the accessibility to important services, the vicinity to important services, and an attractive street network for pedestrians and cyclists. For projects similar to the transformation of Dag Hammarskjöldsleden exemplified with other potential boulevardisations, the same

foundation of indicators can preferably be used for the determination of barrier effects.

Another useful application of the conceptual model and associated analyses are in a later stage in the planning process or on already built transport infrastructure where complications connected to barrier effects arise. In these stages are already a majority of the prerequisites decided, increasing the accuracy of the model, hence generating results with higher accuracy. The accurate models can be used for optimisations regarding the design in an attempt to minimise the current barrier effects. As seen in the analysis of the comparisons between scenarios 0 & A and B & C respectively, relatively smaller changes of for example the location of crossing facilities have the potential to substantially reduce barrier effects.

5.4 Limitations

5.4.1 Representation of destinations with large areas

One limitation in the GIS-model is that the facilities are represented with points. This influences the results especially on the indicator analyses with facilities with large areas, such as the park Slottskogen. In the model, the park is represented with a centroid, a point in the middle of its area. In reality though, the park is accessed when reaching one of the entrances, not necessarily by reaching the centroid. This results in increased distances to parks for address-points in several areas, exemplified with Linnéstaden. This could be solved by adding entrance points for the park or any other facility and merging them into one object to avoid double counting. If it is desired to save time, because of lack of data or clear entrances; points can be automatically generated on the edge of the facilities.

5.4.2 Lack of development plans

Because of the early stage of the project, there are as of today no official development plans on where different facilities and services will be located, such as schools and daycares, other than in the DPs. The variety of different development plans makes the level of detail in the model inconsistent. The method of placing new facilities in this project has been outside the DPs on assumptions based on how the area Högsbo/Flatås looks today, see section 3.7. In addition, where small businesses such as restaurants and cafes will be located are even harder to predict because these are dependent on where local entrepreneurs want to establish their business, even though they could indicate in DPs. The indicators Choice, Catchment and Proximity are highly dependent on the location of the facilities, and therefore will it affect the accuracy and reliability of the analyses. Still, the boulevardisation's impact on the barrier effects can relatively good be evaluated based on the proposed street network which is the most essential. Even though the locations of the facilities are not decided, the barrier effects of the street network can be evaluated with our model.

Furthermore, barrier effects could be evaluated more precisely once the boulevard has been implemented and when it is known where all facilities will be located, how many people there are in the area etc. Still though, barrier effects can be evaluated before the implementation as in this thesis and conclusions be drawn whether boulevardisation is a good tool to reduce them. In addition, by evaluating the barrier effects before the boulevard implementation is it possible to give feedback to the municipality that may contribute to the decision-making process.

5.4.3 Lack of street network feature data

Another limitation is the lack of street network feature data. As it has been modelled, the properties of the segments in the street network are equal for all pedestrians and cyclists. The difference is the location, length and if there are unlinks in the connections. For example stairs, elevation or the time to cross a signalised intersection are all affecting the barrier effects. Stairs and major differences in elevation can be a hinder for example cyclists and people in wheelchairs, hence they might avoid them. Another example is young children who need a safe path to their schools, meaning that the boulevard with high traffic volumes and some crossings that are potentially not signalised will influence these travel behaviours. Therefore, today's freeway and over and under crossings might be the best option for this group.

The time to cross a signalised intersection increases the total travel time, hence increasing the barrier effect. Some of these feature absences may be solved by having speed or resistance as a variable, and where the speed/resistance to cross a signalised intersection is high as an example. However, this requires using another plugin to create or gather data on such a street network.

5.4.4 No reference values of acceptable barrier effects

Only the DF and Proximity of parks have reference values that indicate the size and impact of the barrier effects. The indicators can only be observed without telling if they are high or low. Thereby, it is hard to tell how big of an impact Dag Hammarskjöldsleden has today on the barrier effects. Therefore, the comparison analyses in section 4.3 are crucial for the evaluation of what influence the boulevardisation has for influence on the barrier effects. Still, it is unknown how big the improvements actually are other than the absolute values presented in appendix F. Reference values are something that should be possible to produce for the different indicators as further work. The reference values could be the maximum distance between crossing facilities with regard to the surroundings, or what the distance should be to the closest grocery store by walking or cycling. Reference values make it possible to evaluate the barrier effects for a specific scenario and study when barrier effects become too big for new or current surrounding urban development.

5.5 Further work

5.5.1 Psychological aspects

Barrier effects are as described in the theoretical background something perceived. Except from travel distance and detour, they are also dependent on for example the speed of the motor vehicles, sight and aesthetics. These are not fully able to be calculated in GIS since they are something perceived and can vary from person to person. A survey may therefore be necessary to investigate these psychological aspects and where GIS may be convenient to summarise and illustrate the result of it. In the Dag Hammarskjöld boulevard project, a survey may be useful before and after the implementation of the boulevard. However, by evaluating the barrier effects once the boulevardisation is completed, it is harder to give feedback to the decision making process. Therefore, the survey might be useful as support for other boulevardisation projects. In addition, a survey might also be useful to evaluate the dynamic barrier effects which depends on variable factors such as traffic volume.

5.5.2 Trips made by motor vehicles

With the boulevard design where pedestrians and cyclist are prioritised, the boulevardisation will have a negative effect on the trips made by using motor vehicles. The speed and road capacity will most likely be lowered by the boulevardisation making the boulevard a longitudinal barrier. This will probably affect the people living in the south section and other regularly users of street. The barrier effects of boulevardisation on the motor vehicles could be something to study further on. This requires to perform other analyses since the trips made by motor vehicles made on another street network than pedestrians and cyclists, are usually longer and have other types of destinations like workplaces, supermarkets and malls. Therefore, a study of how trips made by motor vehicles are affected by the boulevardisation of the Dag Hammarskjöldsleden with the whole Gothenburg region as study area could be necessary if desired for future projects. According to traffic analyses made on the Dag Hammarskjöld boulevard project, the travel time will in general increase by 5 to 10 minutes from the interchange Järnbrottsmotet to Linnéplatsen Göteborgs stad, trafikkontoret (2022). Although, the traffic volume will decrease while the highway Västerleden and other highways see a volume increase.

6 Conclusion

The boulevard design containing new crossing facilities reduces the trip effort by improve the travel distance to cross the barrier, hence reducing barrier effects. It can be seen in the analyses that the addresses in the south with the biggest barrier effect reductions are located close to the new crossing facilities. Crossing facilities should be located with regard of the street network and the urban development to meet the trip demand of crossing a barrier.

However, there are few trips that consist of crossing the barrier with the current urban development. Therefore, boulevardisation of Dag Hammarskjöldsleden will have limited impact on the barrier effects in the area when the current industrial area is located on the east side of the barrier. Although, with the proposed new urban development, the barrier effects seem to be reduced by the boulevardisation due to the new demand of crossing the barrier and the boulevard design. This is because of new travel behaviour due to new facilities and residents on the east side, and the detour improvements of the street network. However, since there are few reference values to compare the analyses with, it can only be concluded that the boulevard will improve the barrier effects without knowing if they are acceptable.

Barrier effects are complex and depend on multiple factors, which van Eldijk's conceptual model explains. Therefore, there are also other parameters that needs to be considered when improving the barrier effects other than the crossings. Land use is one example which can be used to prevent trips that include to cross a barrier by having for example daycares on both side of the barrier. Evaluating barrier effects requires multiple analyses with different perspectives, where DF and Betweenness evaluate the attractivity of the street network, while Choice and Catchment the accessibility in the area. Comparing different scenarios before and after the design changes is also necessary to evaluate the barrier effects because of the lack of reference values. In addition, evaluating and improving the barrier effects are beneficial in the early design planning stages. This is because it is then possible to adjust the design and prevent barrier effects before they occur.

References

Anciaes, P. R., & Jones, P. (2018). Estimating preferences for different types of pedestrian crossing facilities. *Transportation Research Part F: Traffic Psychology and Behaviour*, *52*, 222-237. Retrieved from https://www.sciencedirect.com/science/article/pii/S1369847816303369 doi: https://doi.org/10.1016/j.trf.2017.11.025

Anciães, P. R., Jones, P., & Mindell, J. S. (2016). Community Severance: Where Is It Found and at What Cost? *Transport Reviews*, *36*(3), 293–317. Retrieved 2016-10-19, from http://www.tandfonline.com/doi/full/10.1080/01441647.2015.1077286 doi: 10.1080/01441647.2015.1077286

Boon, W., van Wee, B., & Geurs, K. (2003). *Barrièrewerking van Infrastructuur: A2 En Amsterdam-Rijnkanaal Barrière Voor Inwoners van Utrecht-Leidsche Rijn?*

Boverket. (2019). *Mångfunktionella gator* (Multi-functional streets. In Swedish). Retrieved 2022-02-08, from https://www.boverket.se/globalassets/publikationer/dokument/2019/mangfunktionella-gator.pdf

Calthorpe, P. (2002). *The Urban Network: A new framework for growth.* Calthorpe Associates.

CNU. (n.d.). *Montreal / bonaventure expressway.* Retrieved 2022-04-06, from https://www.cnu.org/highways-boulevards/model-cities/montreal-bonaventure-expressway

Dahlström, R.-M. (2016). Staten: Helsingfors stadsboulevarder sätter käppar i hjulen för hela landets trafik (The state: Helsinki's urban boulevards will shut down the country's traffic. In Swedish). *Svenska Yle*. Retrieved 2022-04-07, from https://svenska.yle.fi/a/7-1034028

Dhanani, A., & Vaughan, L. (2016). *Towards a walkability model for strategic evaluation of policy action and urban active transport interventions.* Bristol, UK: Universities' Transport Study Group (UTSG). Retrieved from https://discovery.ucl.ac.uk/id/eprint/1524124/

Forkenbrock, D. J., Benshoff, S., & Weisbrod, G. E. (2001). *Assessing the social and economic effects of transportation projects: Web document 31.* Retrieved from https://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w31.pdf

Gelinas, N. (2007). Lessons of boston's big dig. *City journal*. Retrieved 2022-04-06, from https://www.city-journal.org/html/lessons-boston\T1\textquoterights-big-dig-13049.html

Global Designing Cities Initiative, & NACTO. (2016). *Global Street Design Guide*. Island Press. Retrieved from https://globaldesigningcities.org/publication/global-street-design-guide/

Grevet, N. (2015). *Bonaventure expressway* [photograph]. Retrieved 2022-04-07, from https://www.flickr.com/photos/9174557@N03/20602420154

Guo, X., & Black, J. (2000). Traffic Flow Causing Severance on Urban Street. *Traffic and Transportation Studies*, 628-635. doi: https://doi.org/10.1061/40503(277)97

Guo, X., & Black, J. (2004). Proposta de uma metodologia de avaliação do efeito barreira. *Revista dos Transportes Públicos*, *26*. Retrieved from http://files-server.antp.org.br/_5dotSystem/download/dcmDocument/2013/01/10/B9BD823A-1D2B-4ED2-80F9-A44BB52404F6.pdf

Göteborg stad, trafikkontoret. (2014). *Göteborg 2035 trafikstrategi för en nära storstad* (Gothenburg 2035 Traffic strategy for a close major city) (No. 0894/11). Retrieved from https://goteborg.se/wps/wcm/connect/32f1301c-7e10-4f6d-a0fa-ee4f1c2f3f3a/Trafikstrategi_Slutversion_swe_web_140402.pdf?MOD=AJPERES

Göteborgs stad, miljöförvaltningen. (n.d.). *Livsmedelsverksamheter* (Food business. In Swedish) [Data set]. Retrieved 2022-02-17, from https://goteborg.se/wps/portal/start/kommun-o-politik/kommunfakta/oppna-data/oppna-data-soksida/oppna-data-datamangd#esc_entry=35&esc_context=6

Göteborgs stad, park- och naturförvaltningen. (2014). *Grönstrategi för en tät och grön stad* (Urban green space strategy for a dense and green city. In Swedish). Retrieved from https://goteborg.se/wps/wcm/connect/0bbf9fb8-a6a9-43bf-9548-34e7697d8f0e/Gr%C3%B6nstrategi_20140324.pdf?MOD=AJPERES

Göteborgs stad, stadsbyggnadskontoret. (n.d.). *Delområden Högsbo-Frölunda* (Areas Högsbo-Frölunda. In Swedish). Retrieved from https://oversiktsplan-forslag-antagande.goteborg.se/?m=oversiktsplan&x=146000&y=6393000&z=3&l=1%2C27%2C39%2C76%2C50%2C220%2C213%2C658%2C659%2C660%2C661%2C49%2C79%2C29%2C207%2C36%2C667%2C669%2C102%2C78%2C673%2C9%2C209%2C684%2C687%2C53%2C219%2C156%2C112%2C107%2C104%2C28%2C111%2C157%2C215%2C218%2C221%2C15%2C670%2C672%2C103%2C70%2C47%2C105%2C55%2C19%2C116%2C16%2C106%2C71%2C68%2C69%2C54%2C674%2C109%2C37%2C208%2C67%2C57%2C108%2C212%2C158%2C110%2C675

Göteborgs stad, stadsbyggnadskontoret. (2017). *Detaljplan för bostäder vid nymilsgatan inom stadsdelen järnbrott, en del av bostad2021* (Detailed development plan for Dwellings at the Nymil street within the sub-urban area Järnbrott, a part of BoStad2021. In Swedish). Retrieved from https://www5.goteborg.se/prod/fastighetskontoret/etjanst/planobygg.nsf/vyFiler/Järnbrott%20-%20Bostäder%20och%20%20förskola%20vid%20Nymilsgatan%20(BoStad2021)-Plan%20standardförfarande%20-%20inför%20antagande-Planbeskrivning/$File/02%20Planbeskrivning.pdf?OpenElement

Göteborgs stad, stadsbyggnadskontoret. (2018). *Detaljplan för bostäder vid distansgatan/marconigatan inom statsdelen järnbrott i göteborg, en del av bostad2021* (Detailed development plan for Dwellings at the Distans street / Marconi street within the sub-urban area of Järnbortt in Gothenburg, a part of BoStad2021. In Swedish). Retrieved from https://www5.goteborg.se/prod/fastighetskontoret/etjanst/planobygg.nsf/vyFiler/Järnbrott%20-%20Bostäder%20vid%20Distansgatan-Marconigatan%20(BoStad2021)-Plan%20utökat%20förfarande%20-%20inför%

20antagande-Planbeskrivning/$File/01.%20Planbeskrivning%20Distansgatan%20återremiss.pdf?OpenElement

Göteborgs stad, stadsbyggnadskontoret. (2019a). *Detaljplan för stadsutveckling nordväst om järnbrottsmotet del 2, bostäder, skola, verksamheter* (Detailed development plans for urban development north-west of Järnbrottsmotet part 2, dwellings, school, services. In Swedish). Retrieved from https://www5.goteborg.se/prod/fastighetskontoret/etjanst/planobygg.nsf/vyFiler/Järnbrott%20-%20Stadsutveckling%20nordväst%20om%20Järnbrottsmotet%20del%202-Plan%20standardförfarande%20-%20samråd-Planbeskrivning/$File/Planbeskrivning.pdf?OpenElement

Göteborgs stad, stadsbyggnadskontoret. (2019b). *Detaljplan för stadsutveckling vid olof asklunds gata inom stadsdelen högsbo i göteborg, en del av bostad2021* (Detailed development plan for Urban development at the Olof Asklund street within the sub-urban area Högsbo in Gothenburg, a part of BoStad2021. In Swedish). Retrieved from https://www5.goteborg.se/prod/fastighetskontoret/etjanst/planobygg.nsf/vyFiler/Högsbo%20-%20Stadsutveckling%20vid%20Olof%20Asklunds%20gata%20(BoStad2021)-Plan%20utökat%20förfarande%20-%20inför%20antagande-Planbeskrivning/$File/02_Planbeskrivning.pdf?OpenElement

Göteborgs stad, trafikkontor. (2018). *Rerevaneundersökning 2017* (Travel-habit survey 2017. In Swedish). Retrieved from https://goteborg.se/wps/wcm/connect/2d77832c-4521-432a-819f-6740ebcd320b/Resvaneunders%C3%B6kning-2017-final.pdf?MOD=AJPERES

Göteborgs stad, trafikkontoret. (2013). *Trafikstrategi för göteborg - underlagsrapport: Historisk tillbakablick*(Traffic strategy for Gothenburg - Background document: Historical retrospection. In Swedish) (No. 1:2:2013). Retrieved from https://goteborg.se/wps/wcm/connect/c434580f-f7a4-4f76-8252-01150715f0f3/Historisk+tillbakablick.pdf?MOD=AJPERES

Göteborgs stad, trafikkontoret. (2018). *Boulevarder och stadsutveckling* (Boulevards and urban development. In Swedish). Retrieved from https://www5.goteborg.se/prod/fastighetskontoret/etjanst/planobygg.nsf/vyFiler/Dag%20Hammarskjölds%20boulevard-Åtgärdsvalstudie-Bilaga%205%20Rapport%20Boulevarder%20och%20stadsutveckling%20180310/$File/Bilaga%205%20Rapport_Boulevarder%20och%20stadsutveckling_2018-03-10.pdf?OpenElement

Göteborgs stad, trafikkontoret. (2022). *Åtgärdsvalsstudie dag hammarskjölds boulevard* (Measurement-selection study Dag Hammarskjöld bouelvard. In Swedish). Retrieved from https://www4.goteborg.se/prod/Intraservice/Namndhandlingar/SamrumPortal.nsf/4A7217EF17054746C12587DD00332725/$File/Bilaga%203_Slutrapport%20AVS%20Dag%20Hammarskjolds%20boulevard.pdf?OpenElement

Hellogreenway. (2008). *After aerial photo of greenway* [photograph]. Retrieved 2022-04-06, from https://commons.wikimedia.org/wiki/File:After_Aerial_Photo_of_Greenway.jpg

Helsingfors stad, stadsplaneringskontoret. (2015). *Stadsboulevarder i helsingfors* (City boulevards in Helsinki. In Swedish). Retrieved from https://www.hel.fi/hel2/ksv/julkaisut/esitteet/esite_2015-4_sv.pdf

Hine, J., & Mitchell, F. (2003). *Patterns and practices.* Routledge.

Héran, F. (2011). *La ville morcelée - effets de coupure en milieu urbain.* Economica.

Jacobs, A. B., Macdonald, E., & Rofé, Y. (2003). *The Boulevard Book: History, Evolution, Design of Multiway Boulevards.* Cambridge, Mass.: MIT Press.

Korner, J. (1979). *Trafikanläggningars barriäreffekter: 1. problembeskrivning, begrepps-analys och teoriansats - en litteraturstudie.* (Barrier Effects of Traffic Facilites: 1. Problem Description, Concept Analysis and Theroy Theorem - A Literature Study. In Swedish) (Tech. Rep.). Gothenburg, Sweden: Chalmers University of Technology.

Lantmäteriet. (2021). *Fastighetskartan bebyggelse* (Property map Development. In Swedish) [Data set]. Retrieved 2022, from https://maps.slu.se/get

Lindeman, T. (2018). The unconventional beauty of montreal's new bonaventure expressway. *Bloomberg CityLab.* Retrieved 2022-04-06, from https://www.bloomberg.com/news/articles/2018-11-06/how-montreal-redesigned-the-bonaventure-expressway

Mass.gov. (n.d.). *The big dig: project background.* Retrieved 2022-04-06, from https://www.mass.gov/info-details/the-big-dig-project-background

Mazzonna, F., & Peracchi, F. (2012). Ageing, cognitive abilities and retirement. *European Economic Review*, *56*(4), 691-710. Retrieved from https://www.sciencedirect.com/science/article/pii/S0014292112000463 doi: https://doi.org/10.1016/j.euroecorev.2012.03.004

Moughtin, J. C. (2003). *Urban Design: Street and Square, Third Edition* (3rd ed.). Architectural Press.

Mulder, B.-F. (2015). *Spain -barcelona: La rambla* [photograph]. Retrieved 2022-01-28, from https://commons.wikimedia.org/wiki/File:Spain_-Barcelona,_La_Rambla_-_panoramio_(1).jpg

National Association of City Transportation Officials. (2020). *Designing Streets for Kids.* Island Press. Retrieved from https://globaldesigningcities.org/publication/designing-streets-for-kids/

Nelson, I., Malmqvist, D., & Stålner, B. (2016). *Täthetsmått för effektiv kollektivtrafik* (Density measurements for efficient public transport. In Swedish). Sveriges Kommuner och Regioner. Retrieved from https://tekniskhandbok.goteborg.se/wp-content/uploads/Tathetsmatt-for-effektiv-kollektivtrafik_2020-10.pdf

Open Street Map. (n.d.-a). *Housenumbers in gothenburg* [Data set]. Retrieved 2022, from https://overpass-turbo.eu/s/1gre

Open Street Map. (n.d.-b). *Leisure in gothenburg and mölndal* [Data set]. Retrieved 2022, from https://overpass-turbo.eu/s/1gAP

Open Street Map. (n.d.-c). *Restaurants and groceries in mölndal* [Data set]. Retrieved 2022, from https://overpass-turbo.eu/s/1gr2

Ramboll, & Göteborgs Stad. (2021). *Utformningsförslag Dag Hammarskjöld boulevard* (Design proposal Dag Hammarskjöld boulevard. In Swedish). Retrieved from https://www4.goteborg.se/prod/Intraservice/Namndhandlingar/SamrumPortal.nsf/4A7217EF17054746C12587DD00332725/$File/Bilaga%204%20Utformningsforslag_211201.pdf?OpenElement

Salard, E. (2020). *Covid-19 paris confinement, avenue de la grande armée* [photograph]. Retrieved 2022-01-28, from https://commons.wikimedia.org/wiki/File:COVID-19_Paris_confinement,_Avenue_de_la_Grande_Armée,_26_mars_2020_001.jpg

Shergold, I., & Pankhurst, G. (2009). *The Treatment of Social and Distributional Impacts in Appraisal and Evaluation - Literature Review - Final Report.*

SkolmatSverige. (n.d.). *Skolmatens historia* (The history of school lunch. In Swedish). Retrieved 2022-04-29, from https://www.skolmatsverige.se/om-oss/skolmatsveriges-bakgrund/

Spatial Morphology Group. (n.d.). *Building height* [Data set]. Chalmers University of Technology. (Contact: Jorge Gil - jorge.gil@chalmers.se)

Statistics Sweden. (2020a). *Antal personer per hushåll efter region och boendeform. År 2012 - 2020* (People per household with regard of region and form of housing. Year 2012 - 2020. In Swedish) [Data set]. Retrieved 2022-03-10, from https://www.statistikdatabasen.scb.se/sq/122535 (Kommun: 1480 Göteborg, boendeform: all, år: 2020)

Statistics Sweden. (2020b). *Digitala deso gränser* (Digital DeSO borders. In Swedish) [Data set]. Retrieved 2022-03-07, from https://www.scb.se/vara-tjanster/oppna-data/oppna-geodata/deso--demografiska-statistikomraden/

Statistics Sweden. (2020c). *Folkmängden per region efter ålder och kön. År 2015 - 2020* (Population per region with regards of age and sex. Year 2015 - 2020. In Swedish) [Data set]. Retrieved 2022-03-07, from https://www.statistikdatabasen.scb.se/sq/122411 (region: DeSo: 1480 Göteborg, 1481 Mölndal; ålder: totalt; kön; totalt; år: 2020)

Statistics Sweden. (2020d). *Genomsnittlig bostadsarea per person efter region, hushållstyp och boendeform. År 2012 - 2020* (Mean dwelling area per region, household type and form of housing. Year 2012 - 2020. In Swedish) [Data set]. Retrieved 2022-02-09, from https://www.statistikdatabasen.scb.se/sq/122412 (Kommun: 1480 Göteborg, hushållstyp: samtliga hushåll, boendeform: all, år: 2020)

Stavroulaki, I., Pont, M. B., Marcus, L., & Sun, K. (2020). *Non-Motorised network of Gothenburg* [Data set]. Chalmers University of Technology, Department of Architecture and Civil Engineering. Retrieved 2022, from https://doi.org/10.5878/x49h-pv07 doi: 10.5878/x49h-pv07

Stockholm stad, Södermalms stadsdelsförvaltning. (2019). *Parkplan på södermalm - gröna gaturum och parkstråk del 2* (Parks in Södermalm - Green urban spaces and park

paths part 2. In Swedish). Retrieved from https://start.stockholm/globalassets/start/om-stockholms-stad/sa-arbetar-staden/natur-parker-och-gronomraden/parkplan-sodermalm-del-2---grona-gaturum-och-parkstrak-del-2.pdf

Swedish Food Agency. (2022). *Offentlig livsmedelskontroll* (Public food-control. In Swedish). Retrieved 2022-03-29, from https://www.livsmedelsverket.se/foretagande-regler-kontroll/livsmedelskontroll/offentlig-kontroll (Information om kontroll av livsmedel)

Tirachini, A. (2015). Probability distribution of walking trips and effects of restricting free pedestrian movement on walking distance. *Transport Policy*, *37*, 101-110. Retrieved from https://www.sciencedirect.com/science/article/pii/S0967070X14002078 doi: https://doi.org/10.1016/j.tranpol.2014.10.008

Trafikverket. (2011). *Hållbarhet och trender i handel och service, en litteratur studie* (Commerce and service sustainability and trends, a literature study. In Swedish). Retrieved from https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwj018uL3eD1AhWBQvEDHQSFAboQFnoECAMQAQ&url=https%3A%2F%2Ftrafikverket.ineko.se%2FFiles%2Fsv-SE%2F11527%2FRelatedFiles%2F2011_070_Hallbarhet_och_trender_i_handel_och_service_en_litteraturstudie.pdf&usg=AOvVaw04dHrCuyC624GRq7D202DX

Trafikverket, Boverket, & SKL. (2015). *Trafik för en attraktiv stad - underlag till handbok.* (Traffic for an attractive city - Documentation to handbook. In Swedish) (3rd ed.). Retrieved from https://www.trafikverket.se/contentassets/347f069e6d684bfd85b85e3a3593920f/trast3_underlag_till_handbok.pdf

van Eldijk, J., Gil, J., Kuska, N., & Sisinty Patro, R. (2020). Missing links – Quantifying barrier effects of transport infrastructure on local accessibility. *Transportation Research Part D: Transport and Environment*, *85*, 102410. Retrieved 2020-06-12, from https://doi.org/10.1016/j.trd.2020.102410 doi: 10.1016/j.trd.2020.102410

van Eldijk, J., Gil, J., & Marcus, L. (2022). Disentangling barrier effects of transport infrastructure: synthesising research for the practice of impact assessment. *European Transport Research Review*, *14*. doi: 10.1186/s12544-021-00517-y

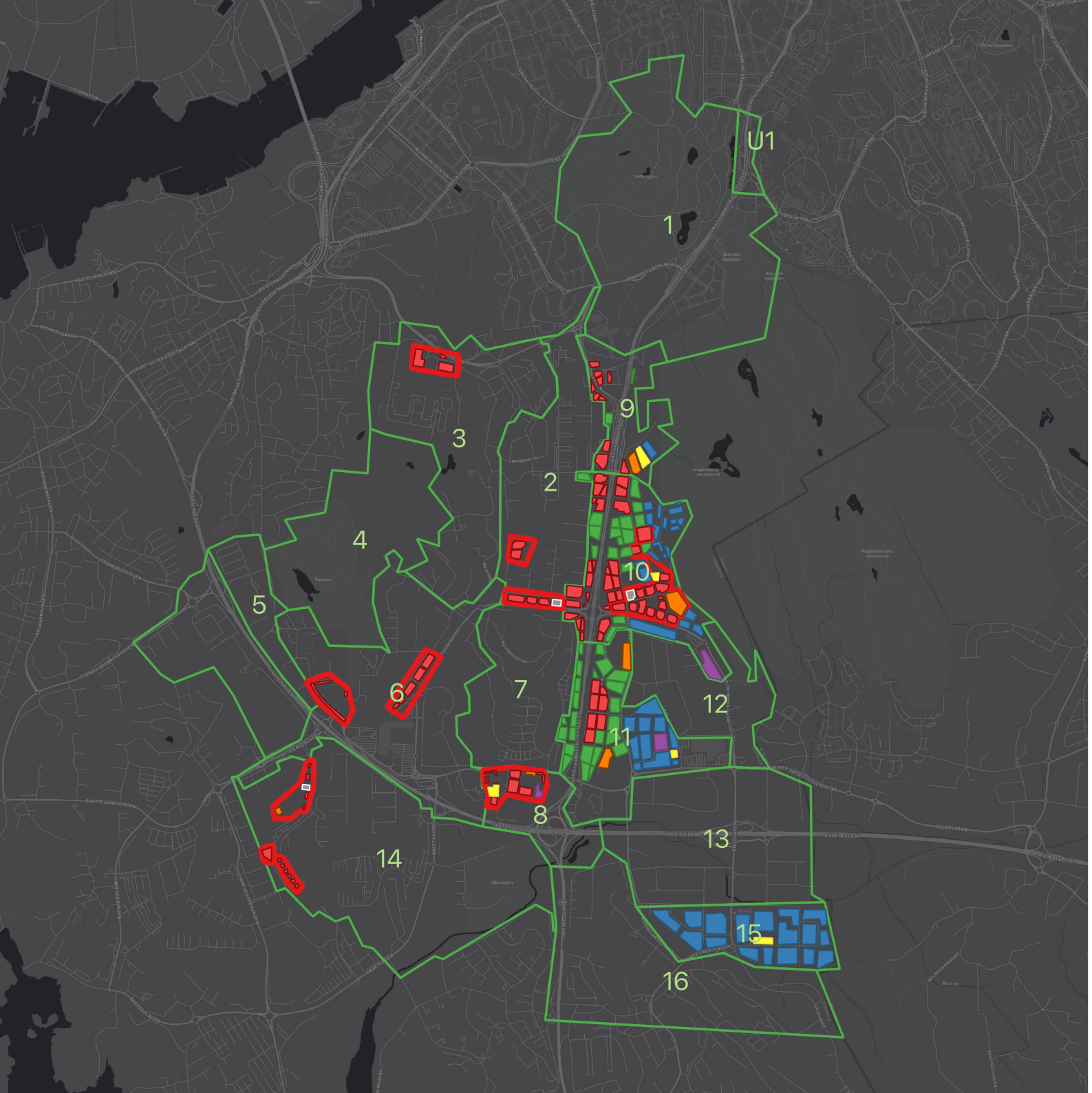
Västsvenska handelskammaren. (2015). *Tysk effektivitet och fransk elegans - kollektivtrafik i miljonstaden göteborg* (German efficiency and French elegance - Public transport in the Gothenburg, a city with a million people. In Swedish). Retrieved 2022-05-20, from https://www.vastsvenskahandelskammaren.se/globalassets/formular/infrastruktur/rapporter/tysk-effektivitet-och-fransk-elegans.pdf

Webster, T. (2014). *Sønder boulevard bus* [photograph]. Retrieved 2022-01-28, from https://commons.wikimedia.org/wiki/File:S\T1\onder_Boulevard_Bus_(15724325598).jpg

WSP, & Parsons Brinckerhoff. (2017). *Complete Streets Design Guide.*

Appendices

A Development plans



New urban development

Scenario C

- High density
- Medium-high density
- Low density
- Leisure
- Parking
- Daycare
- School
- Detailed development plan
- Comprehensive plan area

ESRI Gray (dark)

0 1 2 km

A.1 Comprehensive plan areas



Figure A.1: *CP-areas, based on Göteborgs stad, stadsbyggnadskontoret (n.d.)*

Table A.1: *Current and future population in the CP and current and predicted new population in the model. The data is based on Göteborgs stad, stadsbyggnadskontoret (n.d.).*

Area	Current type (→ future type)	Current pop., CP	Current pop., model	Future pop., CP	Future pop., model
1. Änggården and Slottskogen	park, residential	1300	1406	1000-1500	1406
2. Högsbo - Flatås	residential	9300	9474	11000-13000	12067
3. Högsbohöjd and Kaverös	residential	11000	11146	13000-15000	13977
4. Ruddalen	park		5		5
5. Grimmered's industrial area	industrial		0		0
6. Frölunda	residential, commercial	12300	12456	21000-24000	22485
7. Järnbrott	residential	3500	3834	3500-4300	3834
8. Järnbrott, south	residential		81	1500-2000	1613
9. Marklandsgatan with surroundings	residential	200	282	2000	1993
10. Högsbo industrial area, north	industrial → residential		0	8000-11000	10996
11. Högsbo industrial area, south	industrial → residential		4	8000-11000	9516
12. Högsbo industrial area, east	industrial		5		5
13. Area along Söderleden	industrial, commercial		0		0
14. Tynnered	residential	11400	11677	16000-18000	17042
15. Sisjöns industrial area, south	industrial → residential		0	1000-2000	1486
16. Askim, north-east	residential	4400	4612	4500-6000	4612
U1. Linnéplatsen to Annedalsmotet	investigation		0		0
		53400	55007	100150	103099

A.2 Detailed development plans (DP)

Table A.2: *People per household in Gothenburg (Statistics Sweden, 2020a)*

Type of dwelling	People per household
Tenancy	2
Condominium	1.8
Special dwelling (student housing)	1.3

Table A.3: *Population is calculated with values in table A.2*

Detailed development plan	Dwelling	Tenancy	Condominium	Student housing	Population
Distansgatan, Marconigatan	430	143	287		803
Nymilsgatan	300	150	150		570
Järnbrottsmotet	850		850		1530
Olof Asklundsgata	1900		1900		3420
Opaltorget - Parkhuset	85		85		153
Briljant-Smaragdgatan	380		270	110	629
Rubingatan	220		220		396
Munspelsgatan	500		500		900
Mandolingatan	700	700			1400
Högsbohöjd	700	350	350		1330
	6065	1343	4612	110	11131

A.2.1 Other used detailed development plans

Tynnered

Opaltorget - https://www5.goteborg.se/prod/fastighetskontoret/etjanst/planobygg.nsf/vyFiler/Tynnered%20-%20stadsförnyelse%20vid%20Opaltorget-Plan%20-%20inför%20antagande-Illustrationsritningar/$File/05_Illustrationsritning.pdf?OpenElement

Briljant- och Smaragdgatan - https://www5.goteborg.se/prod/fastighetskontoret/etjanst/planobygg.nsf/vyFiler/Tynnered%20-%20%20Bostäder%20vid%20Briljant-%20och%20Smaragdgatan%20(BoStad2021)-Plan%20standardförfarande%20-%20inför%20antagande-Plankarta%2C%20illustrationsritning%20och%20grundkarta/$File/01.%20PlanIllGrund.pdf?OpenElement

Rubingatan - https://www5.goteborg.se/prod/fastighetskontoret/etjanst/planobygg.nsf/vyFiler/Tynnered%20-%20Bostäder%20vid%20Rubingatan-Plan%20standardförfarande%20-%20samråd-Plankarta/$File/Plankarta_Illustration%20Rubingatan.pdf?OpenElement

Frölunda

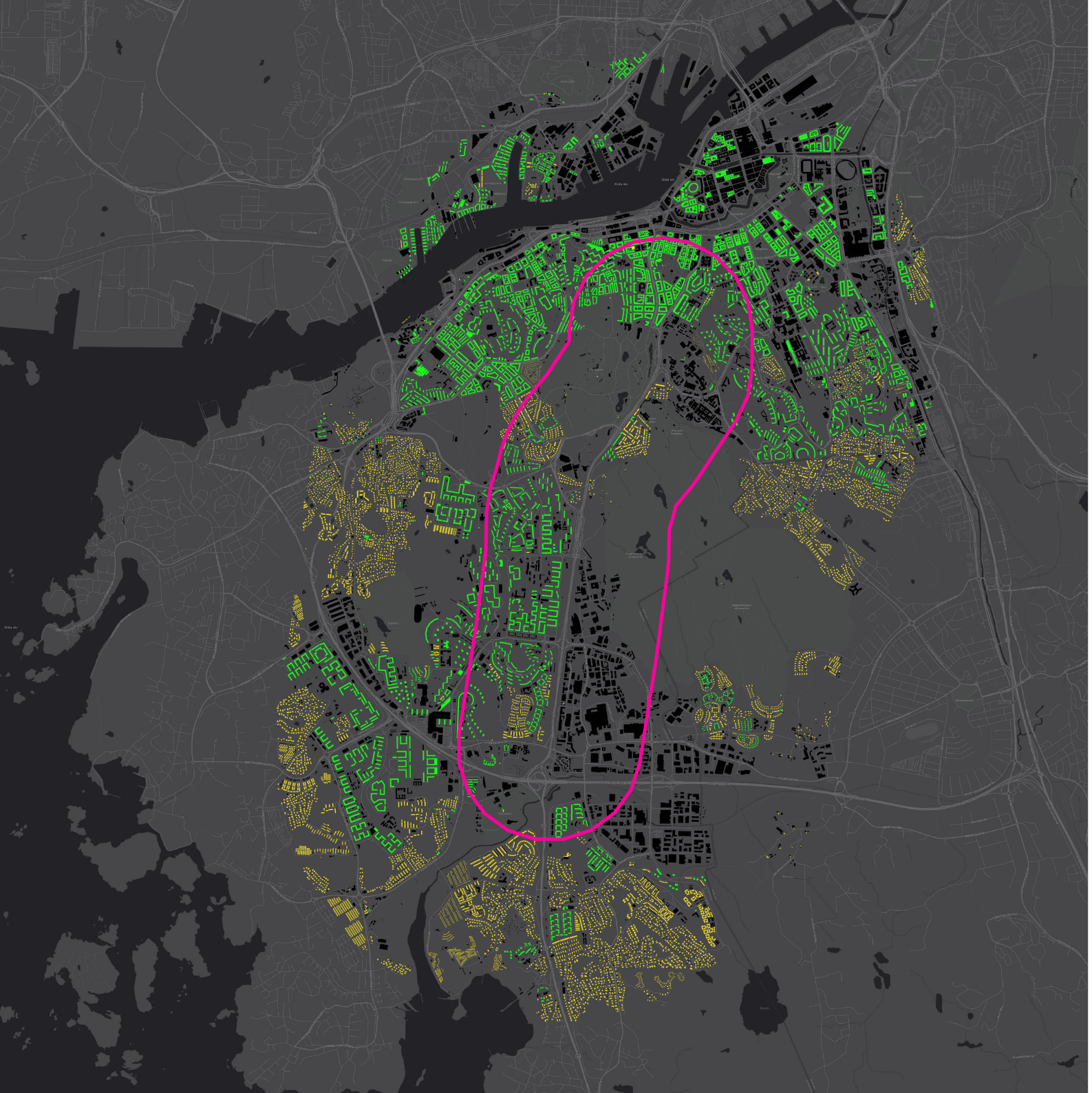
Mandolingatan - https://www5.goteborg.se/prod/fastighetskontoret/etjanst/planobygg.nsf/vyFiler/Järnbrott%20-%20Bostäder%20vid%20Mandolingatan%20(BoStad2021)-Plan%20utökat%20förfarande%20-%20inför%20antagande-Illustrationsritning/$File/04%20Illustrationsritning.pdf?OpenElement

Munspelsgatan - https://www5.goteborg.se/prod/fastighetskontoret/etjanst/planobygg.nsf/vyFiler/Rud%20-%20Bostäder%20vid%20Munspelsgatan%20(BoStad2021)-Plan%20utökat%20förfarande%20-%20inför%20antagande-Planbeskrivning/$File/Ny_Planbeskrivning20Munspelsgatan%20Antagande%20rev%2020170628.pdf?OpenElement

Högsbohöjden

Högsbohöjden - https://www5.goteborg.se/prod/fastighetskontoret/etjanst/planobygg.nsf/vyFiler/Järnbrott%20-%20%20Bostäder%20i%20Högsbohöjd%20(BoStad2021)-Plan%20utökat%20förfarande%20-%20inför%20antagande-Plankarta%2C%20illustrationsritning%20och%20grundkarta/$File/01%20Alla%20kartor.pdf?OpenElement

B Existing buildings



Existing buildings

- Buffer 1000m
- Apartment building
- Detached house
- Other

ESRI Gray (dark)

0 1 2 km

C Address-points

To calculate the number of residents per address in scenario 0, four data sources were used: the national land survey (Lantmäteriet, 2021) (I) to obtain the information of which buildings are aimed for housing (apartment buildings and detached houses), SMoG (Stavroulaki et al., 2020) (II) to obtain GFA of the buildings, Open Street Map (n.d.-a) (III) to obtain location of address-points and Statistics Sweden (2020c) (IV) for population data.

The following steps were performed in the calculations and modifications of the datasets to obtain the number of residents per address-point:

1. Remove all data in I, II, III and IV outside the analysis area, see figure 3.2.
2. Join attributes by location with II as the base layer and I as joined layer.
3. Remove all buildings in II except: apartment buildings (Bostad; Flerfamiljshus, Bostad; Småhus med flera lägenheter) and detached houses (Bostad; Småhus kedjehus, Bostad; Småhus radhus).
4. For buildings without GFA data
   (a) Complement the data of number of floors by using Google Street View [7] inside the study area
   (b) Outside the study area, assume 5 floors per apartment building and 2 floors per detached-house
   (c) Calculate the GFA = area of the polygon · number of floors.
5. Calculate weighted GFA $[m^2]$ = GFA · factor from table 3.5.
6. Distribute the population within respectively DeSo-area with regard of the buildings' weighted GFA.
7. Move address-points in III inside the polygons of II.
8. Count address-points III in polygons II.
9. Create centroid points of buildings without address-points and set these to have one address-point.
10. Calculate the population per address-point.
11. Assign scenario-attributes to the points.

[7] https://www.google.com/maps/@57.6498314,11.9335499,3a,75y,38.02h,93.42t/data=!3m6!1e1!3m4!1sCz3huu00JOl7AIZ-OUfvqA!2e0!7i16384!8i8192?hl=sv

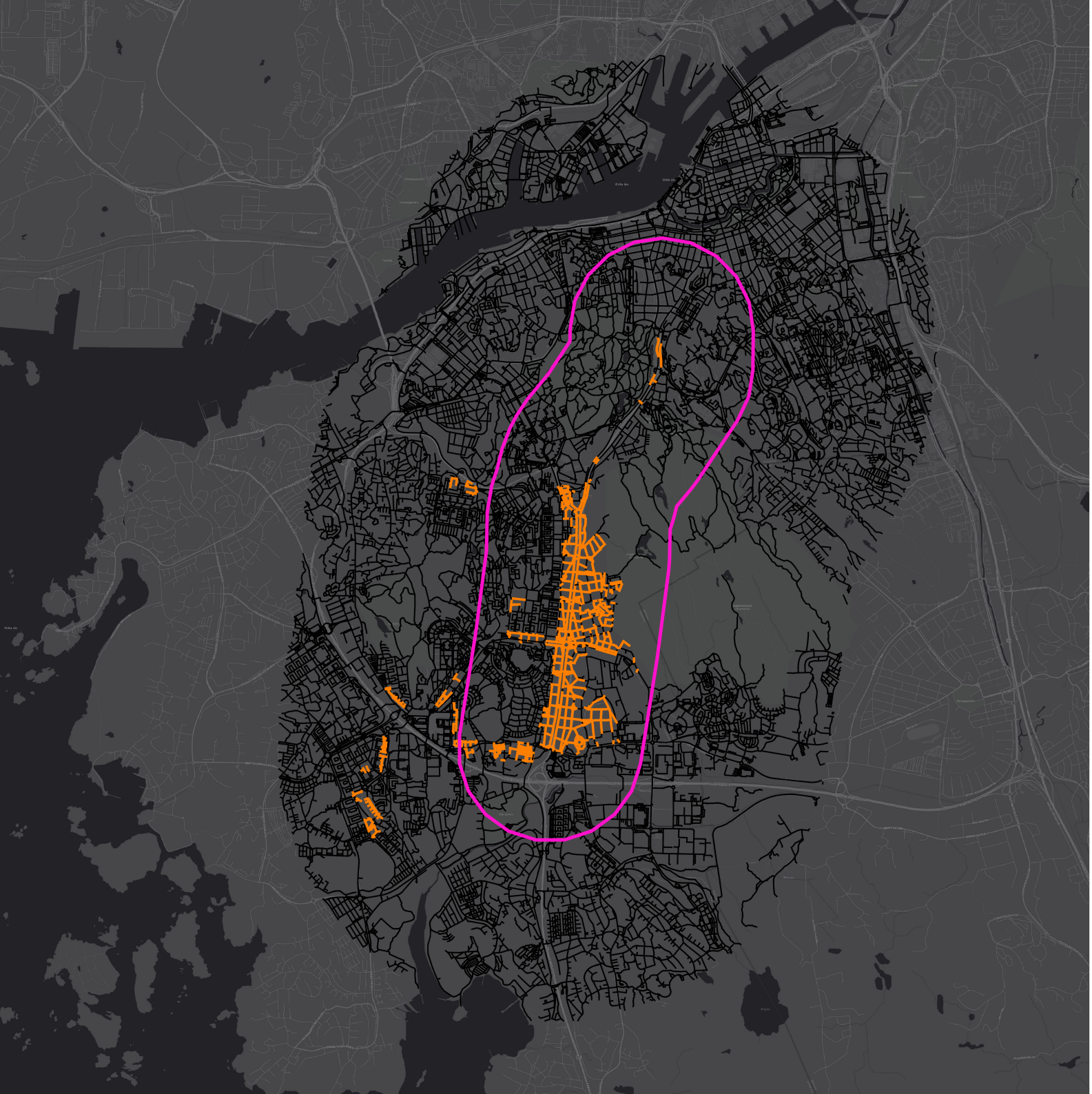
The following steps were performed to estimate the number of residents per entrance for the future urban development in scenario C:

1. Draw polygons for the new buildings based on the plans in table 3.4 (the DPs, design proposal and the CP).
2. Calculate the area per building.
3. Calculate an weighted area using the factors in table 3.6.
4. Use the DPs to deploy entrance-points (Göteborgs stad, stadsbyggnadskontoret, 2018, 2017, 2019a).
5. For buildings without any plans of entrances/addresses:
   (a) Place lines with offsets of 2m towards the centre of the buildings.
   (b) Place random points on the lines with at least 10m between them in the low-density residential areas and 20m between them in the medium-high- and high-density residential buildings.
6. For buildings within area 2, 3, 6, 8 and 14:
   (a) Deploy the population of the DPs, see table A.3 in appendix A.2, to the new buildings based on their weighted area.
   (b) Calculate population per entrance-point.
   (c) Deploy the rest of the future population that is stated in the CP, see table A.1 in appendix A.1, to the current address-points (scenario 0) except in area 8 with regard of their data of current population.
7. For buildings in area 9, 10, 11 and 15:
   (a) Deploy the future population in the CP to the buildings based on their weighted area.
   (b) For buildings in area 10: deploy the population in the Olof Asklund DPs, see table A.3 in appendix A.2, to the buildings with regard of their weighted area.
   (c) Calculate population per entrance-point.
8. Assign scenario-attributes to the entrance-points.

To model scenario B:

1. For the new buildings in the non-buildable area, see figure 3.5, copy these and adjust the nodes of the polygons so the buildings are outside the non-buildable area.
2. Copy and move the entrance-points in the non-buildable area to the closest building.
3. Assign scenario-attributes to the entrance-points.

D Street network



Street network

Scenario C

Study area (buffer 1000m)

Existing street

New street

ESRI Gray (dark)

0 1 2 km

D.1 Model creation

The following steps were performed in the modifications and corrections of the street network used in scenario 0:

1. Remove parts of the network outside the analysis area.
2. Correct the street network regarding changes in the built area.
3. Correct the street network with focus on the areas with an incomplete street network
4. Further develop the street network within the study area.
5. Assign scenario 0 to the segments

The following steps were performed in the corrections and creation of the street network used in scenario C:

1. Compare the street network used in scenario 0 with the plans of future urban development presented in table 3.4.
2. Change the assigned scenario for the segments that are affected by the differences between scenarios 0 and C.
3. Create the street network used in scenario C by adding segments according to the development plans.
4. Assign scenario attribute to the added segments.

The following steps were performed in the corrections and creation of the street network used in scenario A:

1. Compare the street network used in scenario 0 with the suggested design presented in Ramboll & Göteborgs Stad (2021).
2. Changes in the assigned scenario for the segments that differ between scenario 0 and the suggested boulevard design.
3. Changes in the assigned scenario for the segments in scenario C that is a part of the suggested boulevard design to also to part of scenario A.
4. The addition of segments at reasonable locations to connect the segments from the suggested boulevard and the segments in scenario 0.

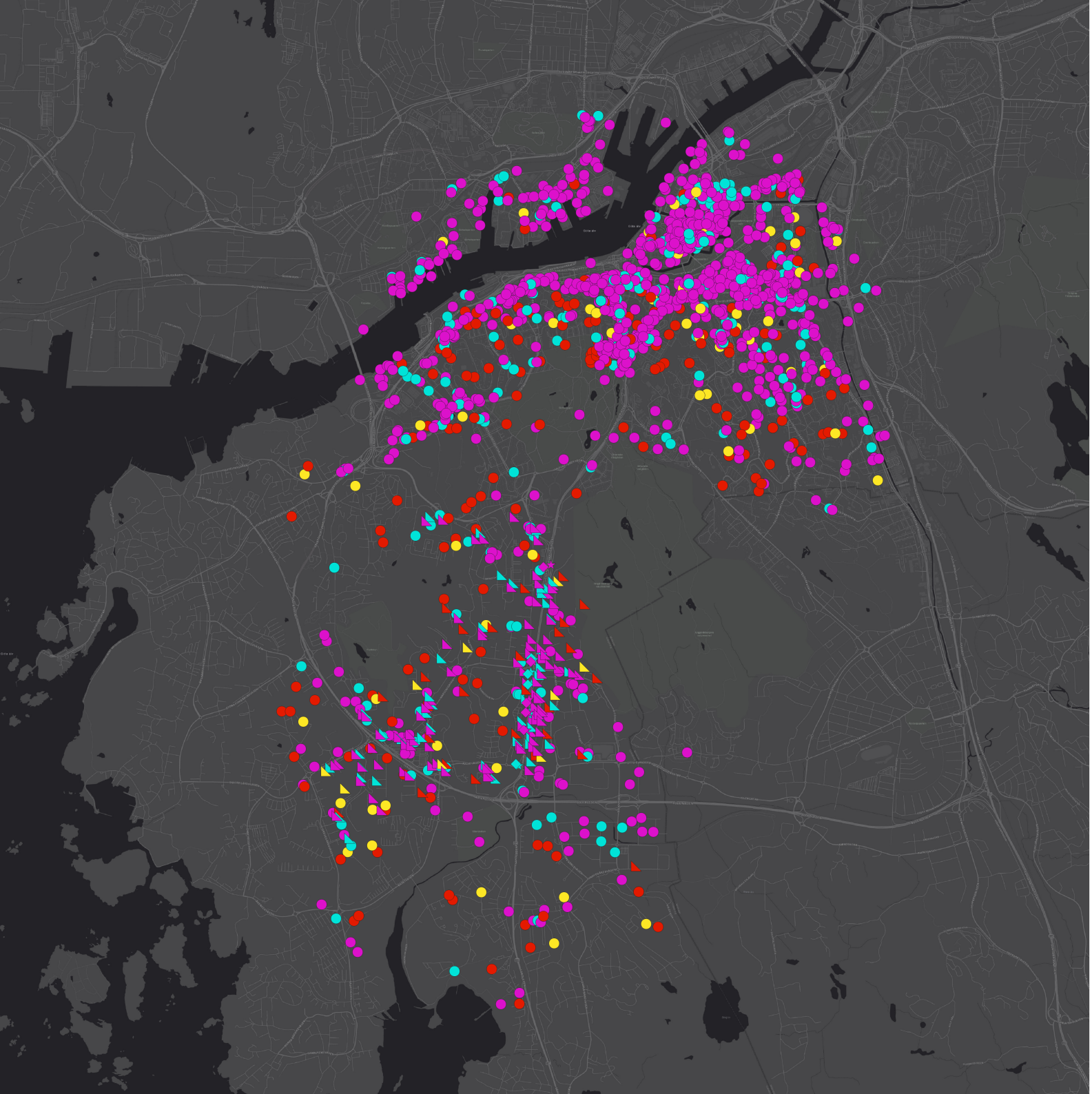
The following steps were performed in the corrections and creation of the street network used in scenario B:

1. Comparison of the street network used in scenario C with the non-buildable area.
2. Change in the assigned scenario for the segments interfering with the non-buildable area, except for the crossing facilities of the current freeway found in scenario 0.
3. Changes in the assigned scenario for the segments in the areas with changed urban development due to the implications caused by the non-buildable area.
4. Creation of the street network corresponding to the changes in the area surrounding the non-buildable area.

The following steps were performed in the corrections and creation of the unlinks used in the different scenarios:

1. Assign a scenario to all unlink-points
2. Correct the assigned scenario for the unlinks dependent on the corresponding changes in the street network dependent on the conditions in the different scenarios.
3. Add unlink-points corresponding to changes in the street network.

E Facility categories



Facility categories

per scenario

School
- 0,A,B,C
- B,C

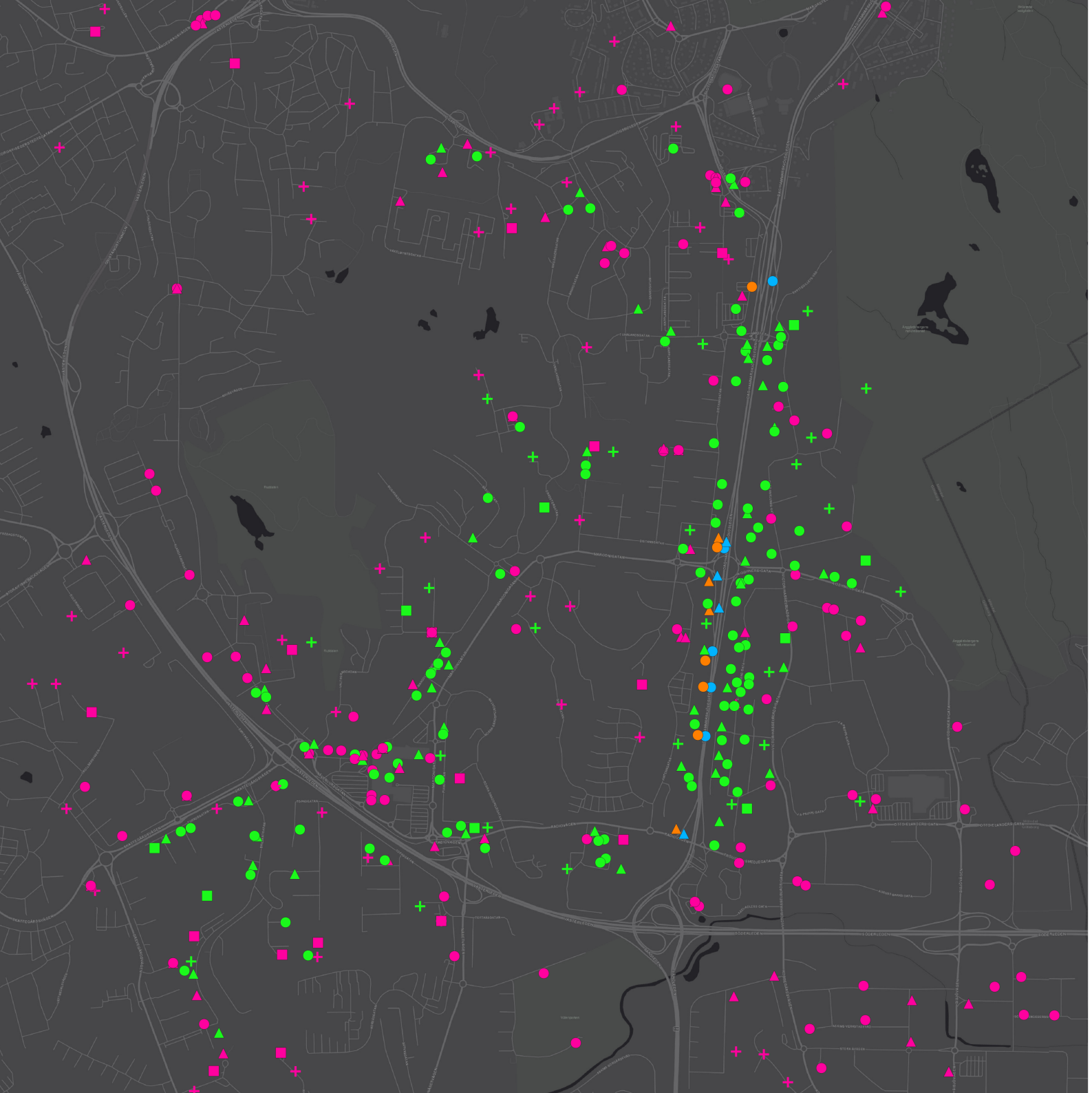
Daycare
- 0,A,B,C
- B,C

Grocery store
- 0,A,B,C
- B
- B,C
- C

Bar, cafe or restaurant
- 0,A,B,C
- B
- B,C
- C

ESRI Gray (dark)

0 1 2 km



Facility categories

per scenario

C
- Grocery store
- Bar, cafe or restaurant

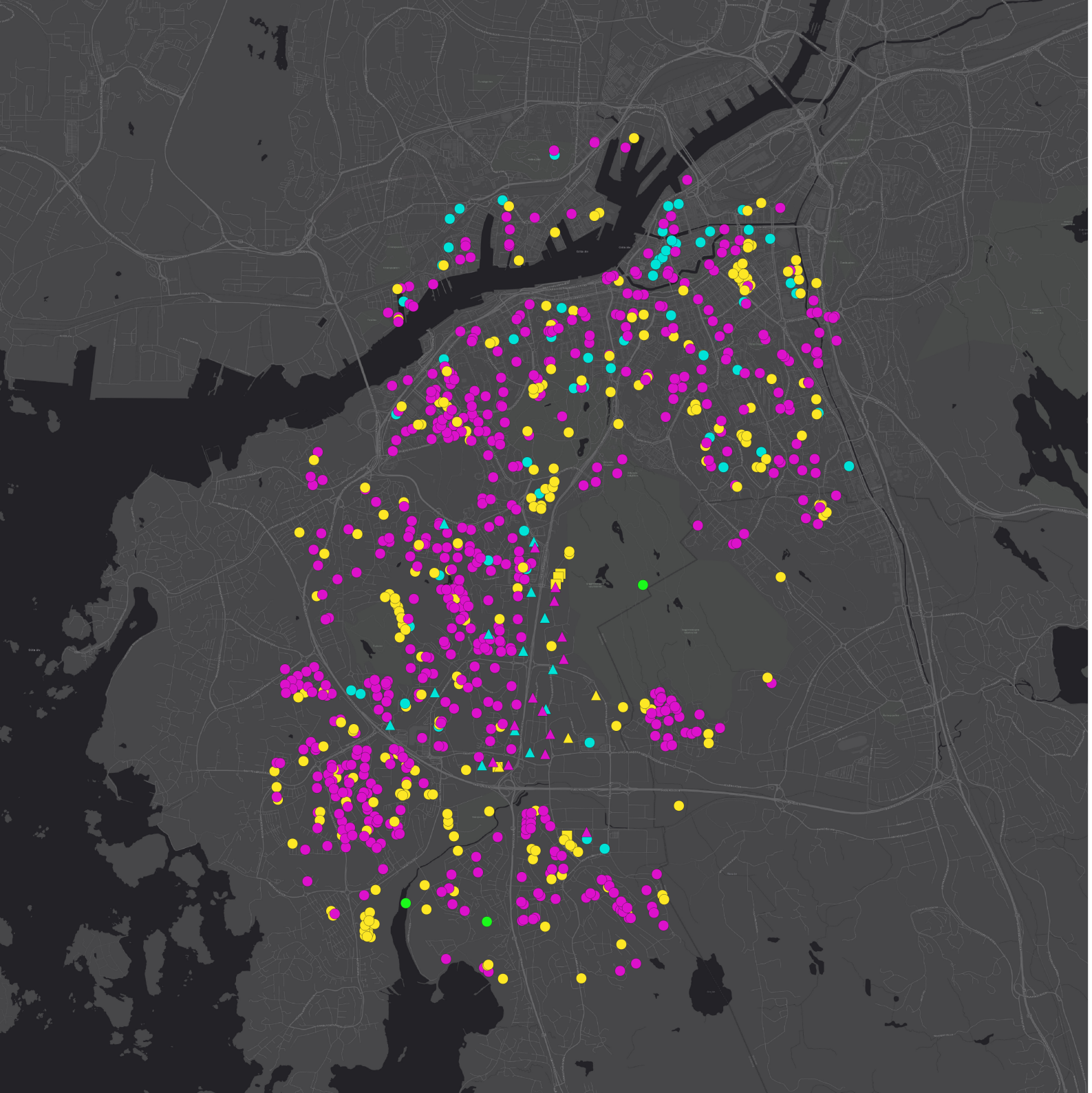
B
- Grocery store
- Bar, cafe or restaurant

B,C
- Daycare
- Grocery store
- School
- Bar, cafe or restaurant

0,A,B,C
- Daycare
- Grocery store
- School
- Bar, cafe or restaurant

ESRI Gray (dark)

0 0,5 1 km



Facility category

per scenario

Gym
- 0,A,B,C
- B,C

Park
- 0,A,B,C
- B,C

Sport facility
- 0,A
- 0,A,B,C
- B,C

Nature reserve
- 0,A,B,C

ESRI Gray (dark)

0 1 2 km

E.1 Model creation

The following steps were conducted in regard of facilities related to education and food businesses:

1. Add facilities related to education and food businesses for the City of Gothenburg obtained from Göteborgs stad, miljöförvaltningen (n.d.).
2. Remove facilities related to education and food businesses located outside of the analysis area.
3. Remove facilities related to education and food businesses not included in the chosen facility categories, see table 3.7.
4. Adjust the attribute table by removing fields containing unuseful information.
5. Add facilities related to education and food businesses for the City of Mölndal obtained from Open Street Map (n.d.-c).
6. Remove facilities related to education and food businesses located outside of the research area for the facilities related to education and food businesses associated with the City of Mölndal.
7. Adjust attribute table by removing fields containing unuseful information for the facilities related to education and food businesses located in the City of Mölndal.
8. Create one layer for the facilities related to education and food businesses by joining the layers for the City of Gothenburg and City of Mölndal respectively.
9. Remove duplicates identified by examining the attribute table of the joint layer.
10. Assign scenario-attributes to all facilities related to education and food businesses.
11. Change the scenario-attribute for the facilities related to education and food businesses affected by the planned differences to the built environment.
12. Calculate the frequency of each type of facility per population, see table 3.8.
13. Determinate the location for the new facilities related to education and food businesses using table 3.8 and table A.1.
14. Add new facilities related to education and food businesses based on the DPs.
15. Distribute the remaining facilities related to education and food businesses to complement the DPs and for the areas found in the CPs were a DP does not exist with table 3.8.
16. Assign scenario-attributes to the added facilities related to education and food businesses.

The following steps were conducted in regard of the leisure facilities:

1. Obtain data for the leisure facilities for both the City of Gothenburg and the city of Mölndal from Open Street Map (n.d.-b).
2. Remove data located outside the analysis area.
3. Remove data not included in the chosen categories, see table 3.7.
4. Adjust the attribute table by the removing fields containing unuseful information.
5. Calculate area for the polygons using formula $\$area$ in the field calculator.
6. Create centroids for polygons.
7. Assign 50 m^2 as the area to the playgrounds presented as points.
8. Merge the layers containing centroids and points respectively to one joint layer.
9. Assign scenario-attributes to all leisure facilities.
10. Change the scenario-attribute for the facilities affected by the planned differences to the built environment.
11. Calculate the frequency of gyms per population, see table 3.8.
12. Determine the location for the new gyms using table 3.8 and table A.1.
13. Distribute the added gyms based on the CP.
14. Create new parks as polygons in suitable locations according to the design proposal for the Dag Hammarskjöld boulevard project following the guidelines presented in Göteborgs stad, park- och naturförvaltningen (2014).
15. Calculate the area for the new parks using formula $\$area$ in the field calculator.
16. Create centroids for the new parks.
17. Merge the layer containing the centroids for the new park and the existing layer for the leisure facilities into one joint layer.
18. Add new leisure facilities included in category Sports at suitable locations in regard of existing buildings and planned density.
19. Assign scenario-attributes to the added leisure facilities.

F Statistical summaries of the GIS-analyses

F.1 Statistical summaries of indicator calculations of the individual scenarios

Table F.1: *Statistical summary of the Proximity analyses*

Facility category	Scenario	mean	median	min	max
Bars, cafes, restaurants	0	310.1	299.0	4.5	964.3
	A	310.5	299.4	4.5	964.3
	B	240.9	223.6	4.5	964.3
	C	241.9	224.8	4.5	964.3
Daycares	0	308.8	274.7	4.5	944.7
	A	309.1	274.8	4.5	944.7
	B	271.8	253.7	4.5	944.7
	C	272.7	255.2	4.5	944.7
Grocery stores	0	347.7	303.9	7.4	992.2
	A	342.1	303.9	7.4	992.2
	B	271.0	246.6	7.4	992.2
	C	272.7	247.9	7.4	992.2
Gyms	0	516.1	472.4	15.3	999.9
	A	517.6	473.0	15.3	999.9
	B	415.2	385.3	15.3	999.9
	C	415.1	384.2	15.3	999.9
Parks	0	213.8	185.5	9.5	983.6
	A	213.8	185.6	9.5	983.6
	B	224.7	199.6	9.5	983.6
	C	224.1	200.4	9.5	983.6
Schools	0	439.8	406.5	15.2	999.8
	A	439.8	406.6	15.2	999.8
	B	438.6	412.2	15.2	999.8
	C	438.5	412.8	15.2	999.8

Table F.2: *Statistical summary of the Choice analyses*

Facility category	Scenario	mean	median	min	max
Bars, cafes, restaurants	0	23.1	3.5	0.0	122.8
	A	23.1	3.6	0.0	122.8
	B	22.5	9.7	0.1	122.8
	C	23.2	11.5	0.1	122.8
Daycares	0	5.1	2.8	0.0	16.3
	A	5.1	2.8	0.0	16.3
	B	4.9	3.2	0.1	16.3
	C	5.0	3.4	0.1	16.3
Grocery stores	0	5.3	2.3	0.0	21.9
	A	5.3	2.3	0.0	21.9
	B	6.3	5.0	0.0	21.9
	C	6.6	5.6	0.0	21.9
Gyms	0	0.9	0.7	0.0	3.2
	A	0.9	0.7	0.0	3.2
	B	1.3	1.3	0.0	3.2
	C	1.4	1.4	0.0	3.2
Parks[a]	0	27122.8	10005.9	0.0	984830.5
	A	27123.8	10005.9	0.0	984830.6
	B	26516.1	15441.2	3.4	984830.6
	C	27136.9	16587.9	3.4	984830.5
Schools	0	1.3	0.9	0.0	6.0
	A	1.3	0.9	0.0	6.0
	B	1.3	1.0	0.0	6.0
	C	1.3	1.1	0.0	6.0
Sport facilities	0	10.6	11.3	2.6	16.4
	A	10.7	11.3	3.6	16.5
	B	9.6	9.9	3.4	16.4
	C	9.7	10.0	3.4	16.5

[a] in m^2

Table F.3: *Statistical summary of the Catchment analyses*

Facility category	Scenario	mean	median	min	max
Bars, cafes, restaurants	0	3174.8	0.0	0.0	11474.6
	A	3176.5	0.0	0.0	11474.6
	B	4290.1	3740.2	0.0	11474.6
	C	4353.8	3764.3	0.0	11474.6
Daycares	0	819.6	0.0	0.0	11069.8
	A	819.6	0.0	0.0	11069.8
	B	1043.3	0.0	0.0	11069.8
	C	1064.1	0.0	0.0	11069.8
Grocery stores	0	762.0	0.0	0.0	11403.6
	A	763.1	0.0	0.0	11403.6
	B	1298.2	0.0	0.0	11403.6
	C	1293.9	0.0	0.0	11403.6
Gyms	0	279.3	0.0	0.0	10630.4
	A	2496.4	2262.3	0.0	10630.4
	B	566.4	0.0	0.0	10630.4
	C	594.1	0.0	0.0	10630.4
Parks	0	2217.1	1411.0	0.0	10366.1
	A	2217.1	1411.0	0.0	10366.1
	B	3129.0	3292.6	0.0	10366.1
	C	3219.4	3279.8	0.0	10366.1
Schools	0	190.1	0.0	0.0	10863.7
	A	190.1	0.0	0.0	10863.7
	B	272.7	0.0	0.0	10863.7
	C	280.2	0.0	0.0	10863.7
Sport facilities	0	2863.9	0.0	0.0	26878.2
	A	2872.3	0.0	0.0	26878.3
	B	3565.0	0.0	0.0	26878.2
	C	3611.0	0.0	0.0	26878.3

F.2 Statistical summaries of the difference calculations

Table F.4: *Statistical summary of the Proximity difference analyses*

Facility category	Scenarios compared	mean	median	min	max
Bars, cafes, restaurants	0, A	0.39	0.00	-7.53	128.21
	B, C	0.60	0.00	-102.62	116.44
Daycares	0, A	0.20	0.00	0.00	82.36
	B, C	0.11	0.00	-135.65	151.77
Grocery stores	0, A	-5.71	0.00	-378.26	99.62
	B, C	1.61	0.00	-139.56	93.64
Schools	0, A	-0.20	0.00	-141.61	7.79
	B, C	0.16	0.00	-134.06	43.91
Gyms	0, A	0.66	0.00	-47.46	137.00
	B, C	0.06	0.00	-254.98	158.27
Parks	0, A	-0.16	0.00	-141.61	22.95
	B, C	-0.46	0.00	-230.28	99.08

Table F.5: *Statistical summary of the Choice difference analyses*

Facility category	Scenarios compared	mean	median	min	max
Bars, cafes, restaurants	0, A	0.72	0.00	-1.62	11.37
	B, C	0.72	0.00	-1.62	11.37
Daycares	0, A	0.00	0.00	-0.28	0.26
	B, C	0.10	0.00	-0.20	1.53
Grocery stores	0, A	0.04	0.00	-0.49	0.85
	B, C	0.33	0.00	-0.66	5.14
Schools	0, A	0.00	0.00	-0.01	0.14
	B, C	0.03	0.00	-0.07	0.77
Gyms	0, A	0.00	0.00	-0.27	0.14
	B, C	0.02	0.00	0.00	1.00
Parks[a]	0, A	-0.53	0.00	-442.39	427.64
	B, C	557.60	0.00	-1454.93	13483.01
Sport facilities	0, A	0.05	0.00	-0.79	0.88
	B, C	0.15	0.05	-0.55	1.79

[a] in m^2

Table F.6: *Statistical summary of the Catchment difference analyses*

Facility category	Scenarios compared	mean	median	min	max
Bars, cafe, restaurants	0, A	1.71	0.00	-41.63	347.08
	B, C	63.72	0.00	-8978.06	3929.03
Daycare	0, A	-0.09	0.00	-51.63	7.63
	B, C	20.80	0.00	-99.71	2830.14
Gorcery store	0, A	1.08	0.00	-11.69	548.76
	B, C	-4.35	0.00	-9106.22	2963.78
School	0, A	0.01	0.00	0.00	1.57
	B, C	7.52	0.00	-1.08	1326.29
Gym	0, A	2217.07	1411.01	-11.27	10366.05
	B, C	27.63	0.00	-60.73	2644.98
Park	0, A	2872.34	0.00	0.00	26878.35
	B, C	0.00	0.00	0.00	0.00
Sport facility	0, A	0.00	0.00	-4.54	2.12
	B, C	90.36	0.00	-67.63	2841.63

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2022
www.chalmers.se



CHALMERS
UNIVERSITY OF TECHNOLOGY