THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Divisive connections

Theory and tools for the quantification of barrier effects in transport infrastructure projects

Job van Eldijk

Department of Architecture and Civil Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023

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JOB VAN ELDIJK
ISBN: 978-91-7905-777-0

Doctoral Dissertation Chalmers University of Technology
Doktorsavhandlingar vid Chalmers tekniska högskola
Ny serie nr 5243
ISSN 0346-718X

Department of Architecture and Civil Engineering
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Author contact: job.van.eldijk@ramboll.se

Cover: Swedish road sign for motorways, “E1. Motorväg”
(source: www.transportstyrelsen.se)

Chalmers digital print
Gothenburg, Sweden 2023

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Abstract

Transport infrastructure increases regional accessibility but at the same time it creates barriers that reduce local accessibility. These barriers reduce social contacts between people, and limit access to services and leisure. Barriers make cycling and walking less attractive, which has negative impacts on health, and can lead to increased emissions from cars. Assessments of barrier effects are commonly based on general descriptions and rough estimations, although methods for the quantification of these effects have been developed. Reasons for not using these methods are: limited dissemination, difficulty in separating barrier effects from other effects, and differences in the terminology that is used to describe them. This thesis aims to make existing academic knowledge and tools regarding the quantification of barrier effects more applicable in practice.

The thesis presents a conceptual model that defines five determinants of barrier effects: Transport features, Crossing facilities and street network, People's abilities, Land use, and People's needs, and defines three levels of barrier effects. Further, the thesis lists indicators and methods for quantifying barrier effects. The model and indicators are studied in two case studies. In the first, four of the indicators were operationalised in a transport infrastructure project using conventional GIS tools. In the second, the indicators were studied in an ongoing transport infrastructure project using an action research approach. In this study, participants reported how the barrier effects analyses contributed to the impact assessments with transparent and precise support, which allowed the stakeholders to solve a long-standing conflict about the localisation of the infrastructure. One of the central issues that was revealed is the need for collaboration in order to create input material for the analyses.

Based on these results, the main finding of this thesis is that knowledge of both social and technical processes in the assessment of barrier effects is required for making existing academic knowledge and instruments more applicable in practice.

Keywords: barrier effects, severance, transport infrastructure, impact assessment, decision support

Sammanfattning

Transportinfrastruktur ökar den regionala tillgängligheten men skapar samtidigt barriärer som minskar den lokala tillgängligheten. Dessa barriärer minskar sociala kontakter mellan människor och begränsar deras tillgång till samhällstjänster och fritidsanläggningar. Barriärer gör cykling och gång mindre attraktivt vilket har negativa effekter på hälsan och kan leda till ökade utsläpp från bilar. Bedömningar av barriäreffekter baseras vanligtvis på generalla beskrivningar och grova uppskattningar, trots att metoder för kvantifiering av dessa effekter har utvecklats. Anledning till att dessa metoder inte används är att de inte har spridits, att det finns svårigheter att skilja barriäreffekter från andra effekter och att olika termer används för att beskriva barriäreffekter. Denna avhandling syftar till att göra befintlig akademisk kunskap och verktyg avseende kvantifiering av barriäreffekter mer tillämpbara i praktiken.

Avhandlingen presenterar en konceptuell modell som definierar fem styrande faktorer för barriäreffekter: Transportanläggningar, Passager och gatunätet, Människors förmågor, Markanvändning och Människors behov och definierar tre nivåer av barriäreffekter. Vidare listar avhandlingen indikatorer och metoder för att kvantifiera barriäreffekter. Modellen och indikatorerna studerades i två fallstudier. I den första undersöktes hur fyra av indikatorerna kunde användas in ett transportinfrastrukturprojekt med hjälp av konventionella GIS-verktyg. I den andra studerades indikatorerna i ett pågående transportinfrastrukturprojekt. I denna studie beskrev deltagarna hur barriäreffektanalyserna bidrog till konsekvensbedömningarna med transparenta och konkreta effektbeskrivningar, vilket gjorde det möjligt för parter att lösa en långvarig konflikt om projektet. En av de centrala frågorna som kom fram i studien gällde det samarbete som krävs för att skapa underlagsmaterial till analyserna.

Baserat på detta resultat är den huvudsakliga slutsatsen av denna avhandling att kunskap om både de sociala och tekniska processerna avseende bedömning av barriäreffekter krävs för att göra befintlig akademisk kunskap och verktyg mer tillämpbara i praktiken.

List of publications

The thesis is based on the work presented in the following appended papers:

Paper I: 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 14:1 https://doi.org/10.1186/s12544-021-00517-y
Contributions: Job van Eldijk: literature retrieval, reading, conceptualisation, methodology, writing - original draft, writing - review & editing; Jorge Gil: writing - original draft, writing - review & editing, supervision; Lars Marcus: review & editing, supervision.

Paper II: van Eldijk, J., Gil, J.; Kuska, N.; Sisinty Patro, R., 2020, Missing links: Quantifying the barrier effects of transportation infrastructure. Transportation Research Part D 85 (2020) 102410. https://doi.org/10.1016/j.trd.2020.102410
Contributions: Job van Eldijk: conceptualization, methodology, formal analysis, investigation, data curation, writing - original draft, writing - review & editing, visualization; Jorge Gil: conceptualization, methodology, formal analysis, writing - original draft, writing - review & editing, supervision; Natalia Kuska: formal analysis, investigation, data curation, visualization; Rashmita Sisinty Patro: formal analysis, visualization.

Paper III: van Eldijk J, Gil J (2020) The social dimension of barrier effects of transport infrastructure. IOP Conference Series: Earth and Environmental Science 588 https://doi.org/10.1088/1755-1315/588/2/022071
Contributions: Job van Eldijk: conceptualization, methodology, formal analysis, investigation, data curation, writing - original draft, writing - review & editing, visualization; Jorge Gil: conceptualization, methodology, formal analysis, writing - original draft, writing - review & editing, supervision.

Paper IV: van Eldijk, J., Lundberg, A. (2023) From trench war to dialogue: a study of the assessment of barrier effects in a transport infrastructure project (manuscript). Submitted to Case Studies on Transport Policy
Contributions: Job van Eldijk; interviews, coding, methodology, writing - original draft, writing - review & editing; Anna Lundberg: transcription, coding, writing - original draft, writing - review & editing.

Other work of the author related to the research but not included in the thesis:

van Eldijk J (2019) The wrong side of the tracks: quantifying barrier effects of transport infrastructure on local accessibility. Transportation Research Procedia 42:44–52. https://doi.org/10.1016/j.trpro.2019.12.005

The natural distribution is neither just nor unjust; nor is it unjust that persons are born into society at some particular position. These are simply natural facts. What is just and unjust is the way that institutions deal with these facts.

John Rawls

Preface

When I walked through the door of what was then the Department of Architecture, on January 6th, 2016, the day that I had designated The First Day of My PhD Studies, I imagined there might be a rather solitary period ahead of me. The procedures of dealing with formalities and signing contracts between my employer and Chalmers were proceeding quite slowly, and I had decided that the best way to push the processes forward was a kind of embodied self-fulfilling prophecy, which was to physically locate myself in the place where I wanted to be and to start working on what I wanted to work on. Even if I could only connect to the internet via my mobile and I had no idea what I was going to do. It was the start of a period of seven years that proved to be the opposite of solitary. On the contrary: during the 6.352 hours that I have spent on my PhD studies, I had the privilege to meet, collaborate, be supported by and support, engage and share with a great multitude of beautiful, brilliant and wonderful people. In fact - as I will return to in the concluding personal reflection at the end of this thesis - I often had the feeling that my role in this research project has been to join the dots, to carry knowledge and experience from one field to the other, from one person to another. For all these memorable meetings and moments I feel deep gratitude.

My first words of thanks are to my supervisors Jorge Gil and Lars Marcus, for seven years of supervision (collected in 81.604 words of meeting notes). Thank you, Jorge, for teaching me how to think and work scientifically, for your guidance through the world of research, for your conceptual clarity, for making me limit Paper IV to barrier effects and not include the accessibility of the station, and for the term 'severance' that opened up a wealth of references. Thank you, Lars, for your support that spanned from applications for funding before the project had even started, to introducing cost-benefit analysis as a topic in the project, to the clarification of design science in the Kappa, to pointing to the many practical uses of theory. Thanks to my many colleagues at SMoG: Meta, Gianna, Jonathan, Flávia, Geruza, Axel, Alexander, Evgeniya, Ahmed, Leo, Kailun, Patricia, Mariana, and at ACE: Bri, Gilliam, Elke and Janneke. Our fika have both been a source of joy as well as offering new thoughts and perspectives on my research. Thank you, Liane Thuvander, for your dedicated support as examiner during some of the crucial phases of the project.

Also at Ramboll, I have been able to count on great support. Thank you, Anna Lundberg, for making it possible to switch from a quantitative study of barrier effects to a qualitative study of the experiences of practitioners in an infrastructure project; for always asking “For who?”; for the times you lent me your ear (tid för prat?) and for the occasional “snark” that added work joy. Thank you, Natalia, for the hours in the “GIS cave” in the early phase of the project, where we tried to come up with ways to make the indicators work (yes, change is New minus Old divided by Old). Thank you, Roshni, for giving this thesis a great graphical form. Thanks to my company supervisors, in the first phase, Lars Nilsson, who led me via the “effektkataloger” from the 1980s to Johnny Korner, and in the second phase, Harald Lundström, who observed that a barrier always defines two things: something that hinders and something that is hindered – an observation that is still one of the pillars of this thesis. I would also like to thank my other colleagues at Ramboll, especially my managers Cecilia Frederiksen and Tea Cole, for your belief in me and unwavering support, from the first time I introduced the idea of doing a PhD in 2013, to the present phase in which we are integrating the results of the project in practice of our company.

Thank you, Elien Groot, for proofreading and correcting every text that I have written in the project and taking care of all “concrete”, “red thread”, “reaching a consensus” and removing the word ‘yet’ from the text every single time. Thank you, Paulo Anciaes at UCL for your support, your theoretical input at my 50 % seminar that put me on the accessibility path, and for our exchanges about the latest book of Irvine Welsh. Thank you, Jari Kuosmanen, for your guidance regarding qualitative research methods and positive support in our meetings under the trees between our cottages. Thank you, Erik Elldér, for your thorough review of my papers and Kappa at my 90 % seminar, and for changing Paper III to Paper I. The thesis would not be possible either without the input of the 22 practitioners at Ramboll, Atkins, White Arkitekter, Trafikverket and the Municipality of Linköping during the interviews for Paper IV. Thanks to Angerfist for a workflow at 180 bmp.

A warm thanks to my dear friends, in Sweden and abroad, my Swedish family, and my mother, brother and sisters in the Netherlands, for your love and supporting thoughts and questions. And thanks to my late father, another moment that would have been so great to have shared with you. And thank you to my boys, Jonathan and Ruben, for your cheers and enthusiasm when a paper was published and support when a paper was rejected. Thank you, Jonathan, for the idea to use math for the model (why don’t you just write it like Road plus People

equals?). Thank you, Ruben, for letting me know it was time to stop (a cyborg, that's just like you, dad: half human, half laptop). And finally, all my love and thanks to my wife Johanna for your endurance ("can I talk research?"), for choosing the right colours of my diagrams when I could only focused on its content, for your warm interest which has allowed my ideas to grow and for your love and support during all these evenings, weekends and holidays when I have been occupied both physically and mentally: du är min bästa kompis!

Acknowledgements

This work was supported by the Ramboll Foundation, Ramboll Sweden AB, InfraSweden2030, Trafikverket and Trafikverket's Skyltfond. The funding organisations have had no involvement in the design of the study or the interpretation of the results. I would like to express my sincere gratitude for this financial support that has made it possible to perform this research project and write this thesis.

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On the road I sense a car approaching
I think I hear it roar
I hesitate,
I do not want to add to the statistics
Thus on the edge of the road I stand
Wanting to cross
Lacking the courage to go
And the road stretches on
Oblivious to my problem.

Bidu Ibrahim, 2012

1. Introduction

1.1 Background

During the 19th and 20th centuries, new modes of transport were developed, such as the train and the motorcar, which offered unprecedented opportunities for fast and high-capacity transport over long distances and were instrumental to the economic and social developments that are now taken for granted. However, the introduction of these vehicles also had negative impacts on life in cities. Trains require railways which led to land clearance, limiting urban expansion (Héran, 2011; Palau et al., 2016), cutting off neighbourhoods, and creating borders that reduce urban vitality (Jacobs, 1961). Many examples of this can be found, for example, around terminal stations in London (Bolton, 2018). The private motorcar, on the other hand, initially had a more incremental impact on the structure of cities, as it could be driven on existing streets. But as the number of cars increased during the first half of the 20th century, the safety problems that arose due to the joint use of the streets by cars, pedestrians and cyclists led to a dramatic rise in fatal traffic accidents (Buchanan, 1963, Norton 2008). The general response to this conflict was to separate car traffic from other modes by constructing separate street networks for car traffic (Héran, 2011) and by dividing streets into spaces dedicated to different modes. From our present-day perspective this may appear to be a logical solution, however, in the 1910s streets were dominated by pedestrians, cyclists, playing children, carriages and trams, and cars were few. The acceptance of cars in streets required a change in the general public's idea of streets, from places for all, to places where design, planning, and formal and social rules are dominated by car traffic. In this process of social reconstruction, the car industry and automobile clubs played a pivotal role (Norton, 2008).

As a natural continuation of the process of separation, motorway networks exclusively for car traffic were built during the years before and after WWII. Traffic separation remains the basic rationale of traffic planning approaches in many countries, an example are the guidelines for safe transport planning in the Netherlands (SWOV, 2018). Although these separate networks of motorways and arterial roads improve traffic safety, they, like railways, also create strong barriers that divide cities and form hindrances in local traffic. Notorious examples are Route 40 – “the Highway to Nowhere” – in Baltimore (Miller, 2018), the “Minhocao” in Sao Paulo, the Central Artery in Boston and the Cross Bronx Expressway in New York.

Concurrent with the rise of the car as mode of transport, traffic separation developed as more than just a way to increase traffic safety. Rather, it has become a central principle for urban planning. Early examples are the iconic 1928 Radburn layout of Charley Stein & Henry Wright in the US (Marshall & McAndrews, 2016), the concept of the neighbourhood unit of William E. Drummond in the 1920s (Johnson, 2002) and the CIAM Athens Charter from 1933 (Héran, 2011). As the importance of the organisation of traffic increased, so did the influence of the traffic engineer on urban planning. Lilleby (2001) describes this development as a shift from dealing with the planning of buildings and streets as an integrated whole, to treating buildings and streets as separate projects, involving urban planning and traffic planning as separate disciplines, with the tower building and the motorway as clear symbols. The strong influence of traffic systems on urban development was also recognised by the American historian Mumford, who criticised the fact that the planning of highway systems in the US was treated solely as a technical matter to be solved by engineers (Mumford, 1963), and urged the involvement of urban planners and architects in their design.

Due to growing awareness of their ecological and social impacts during the 1960s and 1970s, motorways were no longer seen as self-evident heralds of progress (Nederveen, 2007). In the 1960s in the US, after decades of division and destruction of low-income and minority communities (Miller, 2018), a wave of ‘freeway revolts’ occurred, in which residents gathered in protest against planned freeway projects (Handy, 2003). Motorway projects also provoked civil protests in Europe (Héran, 2011). In the decades that followed, the pace of motorway construction diminished, especially in cities. Besides greater awareness of social impacts, the insight grew that the ‘predict and provide’ policy which had been the basis for transport planning for decades, was neither ecologically sustainable (Vigar, 1999) nor a durable solution for congestion, as it became clear that building more roads just leads to more traffic (Zipper, 2021). Today, motorways in cities are increasingly being demolished or placed in tunnels, such as the Central Artery in Boston, the A7 in Hamburg, and the Rio Madrid in Madrid and in several cities in the US similar treatment of motorways are considered or planned (Crowther, 2021). Although these projects offer valuable mitigation of the effects of infrastructural barriers, many motorways and railways in cities around the world remain unchanged and continue to have negative impacts on their built environments. Also, more transport infrastructure continues to be built, and these projects offer new challenges of weighing the benefits of transport infrastructure against its costs.

1.2 Problem definition

Transport infrastructure, such as motorways, railways and arterial roads, improves accessibility on an inter-urban and regional scale but at the same time it can create barriers that reduce accessibility for pedestrians and cyclists on a local scale. These barriers cause a series of negative effects, such as delays, detours, and extra effort and discomfort when crossing. In turn, these effects reduce opportunities for social contacts and limit accessibility to shops, services and leisure. Barriers can also make active modes like cycling and walking less attractive, which can reduce physical activity and increase car use. Less active travel and fewer social contacts have been found to have negative impacts on health and well-being (Higgsmith et al., 2022; Mindell & Karlsen, 2012). Increase in car traffic can lead to increased emission of traffic noise and air pollution with impacts on both a local and global scale. Together, these effects of infrastructural barriers have a detrimental effect on the transition to a more sustainable and just society and reduce the possibilities to reach several sustainable development goals (SDG). Barriers limit possibilities to create, for example, fine-gridded pedestrian and bicycle networks in sustainable cities and communities (SGD 11). The societal participation of women and their access to services and jobs (SDG 5 - Gender Equality) is reduced by barriers, as, due to the role in households that they take or are given, women generally use modes like walking and cycling for their transport needs and do not have easy access to a car. The importance of attention to barriers in pedestrian and cycle networks has further increased due to the focus on active modes and on local accessibility within transport research and transport planning (Elldér et al., 2020; Larsson et al., 2022; Willsher, 2020).

Several methods for quantifying barrier effects have been developed; however, these methods are rarely used in practice. Instead, impacts of transport infrastructural barriers are commonly assessed in the form of general descriptions based on rough estimations (Anciaes, Jones, et al., 2016). The lack of use of methods for quantifying barrier effects is in contrast to the assessment of other externalities of transport infrastructure, such as noise and air pollution, for which standardised quantification methods have been developed and legal threshold levels and a system for legal and financial penalties have been established. Several reasons have been suggested for the limited use of methods for quantification of barrier effects. The problem is complex, and it is difficult to separate barrier effects from other externalities of the transport system. The methods have not been disseminated widely, as they are often hidden in technical reports, or published in languages other than English (Anciaes, Jones, et al., 2016). Practitioners have also been reported to regard barrier effects as being intertwined with accessibility planning, rather than as a standalone issue (James et al., 2005). Another aspect is that barrier effect assessments often require collaboration between organisations that have different perspectives and responsibilities within the infrastructure project - usually the national transport administration and local authorities - and require collaboration between different technical disciplines, such as traffic planning and urban planning (Anciaes, Boniface, et al., 2016; van Eldijk et al., 2022). Further, research on barrier effects is hampered by the fact that different scientific disciplines, such as public health, geography and urban planning, use different concepts and terminology to describe the problem (Anciaes, Boniface, et al., 2016).

The lack of use of methods for the quantification of barrier effects is increasingly in conflict with the transition that can be observed within transport planning from government to governance, that is, from centralised, hierarchical decision processes to multi-actor, dialogue-based decision processes (Pettersson & Hrelja, 2020). This transition requires transparency and standardisation of the instruments and methods used for impact assessments, to make the assessments easier to communicate and allow for more perspectives to be included. The lack of standardised assessment methods creates the risk that barrier effects are undervalued or even omitted from impact assessments and consequently from decision making processes. This lack can lead to misjudgements in the planning and design of mitigation measures such as bridges and tunnels, making these measures ineffective in practice or even leading to an aggravation of the barrier problem (Héran, 2011).

1.3 Aim and research questions

In response to the problem discussed above, the overall aim of this thesis is to make existing academic knowledge and tools for the quantification of barrier effects more applicable in practice. Greater exchange between research and practice can enhance the possibilities for more transparent and accurate assessments of barrier effects, based on quantitative and transferable methods. With these methods, possibilities can be improved for including barrier effects in the decision processes regarding transport infrastructure investment. With this aim in view, four research questions are formulated:

1. What are the determinants of barrier effects of transport infrastructure?
2. Which indicators of barrier effects of transport infrastructure have been formulated in the literature and how can these be categorised?
3. How can these indicators of barrier effects of transport infrastructure be operationalised in practice?
4. How do planning practitioners experience the quantification of barrier effects in transport infrastructure projects?

1.4 Central concepts and scope

Barrier effects and severance

The term ‘severance’ is frequently used in the literature to describe the barrier effects of traffic and infrastructure, often in combination with a specification such as community severance, social severance, secondary severance and psychological severance. There doesn’t appear to exist any consensus about the definition of the term, as a review of 60 different definitions shows (Anciaes, 2015). To avoid confusion and the risk that the use of specialised terms diverts attention from more important issues (Anciaes, Boniface, et al., 2016), the term barrier effects is used in this thesis. A barrier is defined as an element that hinders someone on their way to somewhere. Barrier effects are the effects of such an element. In contrast to ‘severance’, the concept ‘barrier effects’ is easily translated into other languages and is widely used in the literature as “trennwirkung” (German), “effet de coupure” (French), “barriérewerking” (Dutch), “effetto di taglio” (Italian), “barriäreffekter” (Swedish), “efeito barreira” (Portuguese), “efecto barrera” (Spanish) or “屏障效应” (Mandarin).

Transport infrastructure

In the thesis, the term "infrastructure" is used for all constructions built for transport purposes, such as motorways and railways, also roads and tramways. Waterways, such as canals, also function as transport infrastructure and can create barriers for movement of people, but as contemporary transport planning very rarely involves the construction or relocation of waterways, these infrastructures are left outside the scope of the thesis. However, the theory and tools presented here can prove to be relevant for the assessment of the impacts of bridges crossing waterways. Appendix A presents a further overview of categories of barriers.

Pedestrian and bicycle traffic

Central to the problem addressed in this thesis are the impacts of infrastructure on local accessibility. In many European cities, the modes that dominate at this scale are walking and cycling and therefore the thesis will focus predominantly on these modes. Car traffic (Rajé, 2004) and public transport (Brand & Preston, 2002) can also be affected by barriers. However, drivers of these modes are often able to use the motorways and arterial roads that create the barrier, and these infrastructures therefore form less of a hindrance.

Animals and ecosystems

The thesis focuses on the barrier effects that motorways, arterial roads, railways and tramways, exert on the movement of people. Motorways and railways also create barriers for animals and ecosystems. These impacts have been studied extensively (Forman & Alexander, 1998; Rytwinski & Fahrig, 2012), and fall outside of the scope of this thesis.

The Swedish Transport Administration

Trafikverket, the Swedish Transport Administration (STA), occupies a central position in the planning and construction of transport infrastructure in Sweden, and plays a significant role in the case studies presented in Paper II, III and IV. The collaboration with the STA during the research projects is described in chapter 3. Some further information about the character of the STA and the conditions for its operations may therefore be useful.

The STA is responsible for the long-term planning of transport systems for road traffic, rail traffic, shipping and aviation in Sweden, as well as the construction of national motorways and railways (trafikverket.se). The STA is responsible for the roads between cities and villages, and for roads within cities that have a function in regional transport. In the countryside these are mostly large roads but sometimes also small roads are included. Investments in the STA's facilities are based on decisions by the Swedish parliament[1], thus making Swedish municipalities dependent on the state regarding the financing of large-scale infrastructure. In turn, the STA is dependent on the participation of municipalities, as infrastructure projects need to correspond with municipal land use plans, and in Sweden municipalities are the only organisations that can adopt these plans. Collaboration and dialogue are therefore of central importance in the projects of the STA. Several processes for pre-studies that can create conditions for this collaboration have been established (Sandberg, 2014).

In the political goals that guide the work of the STA, accessibility is specifically mentioned: "The design of the transport system, its function and use must contribute to providing everyone with basic accessibility of good quality and usability as well as to economic development throughout the country. The transport system must be gender neutral and respond equally to women's and men's transport needs." And one of the more specific goals is: "The conditions for choosing public transport, walking and cycling must be improved." (Trafikanalys, 2012)

1.5 Thesis outline

Next is section 2, which describes the knowledge fields that form the theoretical background of the thesis, and that the thesis aims to make a contribution towards. Section 3 presents the research design of the project and the role played by the exchange with practice, and is followed by section 4, which contains a summary of the papers that form the basis of this thesis. A concluding discussion, contributions to theory and practice, and an indication of further research are presented in section 5.

1 Although, some infrastructure projects are financed through congestion taxes and other charges.

2. Theoretical background

The first section of this chapter presents how research on barrier effects of transport infrastructure has developed over time and points out the need for a theoretical framework. The second section presents accessibility as a framework and highlights the main theoretical underpinnings of accessibility. The third section explores the role that the quantification of barrier effects can play in supporting social impact assessments of transport systems.

2.1 Research on barrier effects of transport infrastructure

Research on the barrier effects of transport infrastructure is relatively limited and fragmented, compared to the literature on other externalities of transport infrastructure and traffic, such as noise (Berglund et al., 1999; Smith et al., 2022) and air pollution (Chandia-Poblete et al., 2022; Jeong et al., 2022). Perhaps as a consequence of a lack of incremental development of knowledge, several large-scale reviews of the literature on barrier effects have been undertaken (Beca Carter Hollings & Ferner Ltd, 1998; Héran, 2011; James et al., 2005; Marsh & Watts, 2012; Quigley & Thornley, 2011). Although most research on barrier effects were isolated initiatives, some conceptual steps in the development of the thinking about barrier effects can be perceived.

Identifying and describing the problem

Much attention has been given to describing the problems of barrier effects. Among the earliest texts on barrier effects is Jacobs' (1961) description of the "border vacuums", created when transport infrastructure blocks local traffic and thereby reduces urban vitality. Mumford (1958) delivered a fierce critique on the devastating effects of highways on cities in the US. The limitations due to the dominance of traffic engineering in the planning and design of transport systems were flagged up in the highly influential report "Traffic in Towns" by Buchanan et al. (1963). Despite the growing criticism of motorways, Buchanan et al. proposed that problems created by car traffic in cities should be solved by adapting cities to car traffic, creating hierarchical road networks and "environmental areas" where car traffic would be limited.

In response to the problems created by transport infrastructure in cities, several different system-analytic approaches were proposed for the study and quantification of barrier effects during the 1960s and 1970s (Ellis, 1968; Korner, 1979; Thomas & Schofer, 1970). The fundamental observation underlying these approaches is that:

> …barrier effects are not an independently existing by-product of the traffic system (in the way exhaust gases are), but a phenomenon which occurs in human perception of or in response to (attitudes, behaviour) the hindering/deterrent properties of transport infrastructure and its traffic. (Korner, 1979, p. 19).

Barrier effects can be described as not just a by-product of transport systems, with a unit of measure of itself, like noise and pollution. Rather, barrier effects are an emergent phenomenon that arises in the meeting of the properties of a barrier, the properties of its surrounding built environment, and the properties of the people who want to cross (Korner, 1979).

Although some researchers restricted their scope to motorways and people exclusively (Watkins, 1972), or to railways and land use (Moon, 1975), the majority of studies reviewed in this thesis (Paper I) involve, albeit in various formulations, the three determinants that are identified by Korner: the separating infrastructure and its traffic, land use and people. In some studies, the role of the local street network is included (Bowers, 1974; Lee & Tagg 1976) while some split the determinant 'people' into two properties: 'difficulty to cross' and 'need to cross' (Boon et al., (2003).

In the literature, different ways of categorising levels and types of effects have been proposed, to wit, physical and psychological effects (de Boer et al., 1984; Tate, 1997); physical effects, direct and indirect economic effects (O´Leary jr, 1969); primary, secondary, tertiary effects (Korner, 1979); direct effects, differential personal effects, social-ecological effects and socio-political effects (King, 1982). Researchers have also listed different sets of categories of barrier effects in their descriptions, from just one category ("Behaviour changes", Lassière & Bowers, 1972), or four categories ("no change, change in location, change of mode, change of need", Boon et al., 2003), or 12 categories (ranging from route change to "overall community impact", Read & Cramphorn, 2001), to 25 categories (ranging from changes in safety to changes in social network, Marsh & Watts, 2012).

Social dimension

In essence, barrier effects are human responses to the built environment. Consequently, several research initiatives have focused on the social dimension, using qualitative research methods such as interviews and surveys. The impacts of motorways on social contacts and activities of residents and the size of their perceived neighbourhood were quantified by Lee and Tagg (1976). Appleyard and Lintell (1972), like Bryan (1951), showed that the intensity of traffic flows on streets correlates to the number of social relations across the street. It is, however, unclear in these studies how different externalities of traffic – noise, air pollution, risk of accidents, barrier effects – contribute to these social barriers. Boon et al. (2003) investigated to what extent residents experienced a motorway and a canal as a barrier to reaching destinations in a nearby city. Nimegeer et al. (2018) studied the impacts of a new motorway on active travel, and Mouette & Waisman (2004) studied the effects of separating properties (such as flow and speed) of a busy road on modal choice and suppression of trips, amongst others. Loir & Icher (1983) also emphasise the human dimension of barrier effects, pointing out how various social groups are affected differently by barriers. Similarly, Cline (1963) describes how the transformation of streets from multifunctional spaces to monofunctional transport corridors changes them from centres that connect people in a neighbourhood to elements that separate people. The psychological dimensions of barriers can make people feel cut-off from important facilities (Tate 1997).

Developing tools for measuring barrier effects

Growing awareness of the barrier effects of transport infrastructure during the 1960s (Cline, 1963) led to the adoption of policy changes regarding transport infrastructure projects. In 1969, the British Urban Motorways Committee recommended the inclusion of assessments of indirect social costs, specifying barrier effects. In the same year, the National Environmental Policy Act was adopted in the US, requiring federal agencies to assess the environmental effects of their projects, mentioning barrier effects explicitly (Korner, 1979). Since then, several methods for assessing barrier effects have been developed. A reoccurring indicator in these methods is the catchment area around different types of destinations. Catchment areas were proposed by Joyce & Williams in 1972 and were an important indicator in the method developed by Clark et al., (1991), which has been policy in the UK for many decades and was the starting point for several other methods (Marsh & Watts, 2012; Quigley & Thornley, 2011). Another aspect that has been the focus of a range of assessment methods are routes for pedestrians and bicycles, an early example of which is the computer-based analysis of impacts on pedestrian routes by Bor & Roberts (1972). The guidebook for the assessment of barrier effects provided by CROW (2011) also focuses on routes and on characteristics of the network of slow modes. Fäldner (1987) developed a method for calculating delay for pedestrians caused by traffic on roads. The method was developed further by Jarlebring et al. (2002), and although it was included in the guidelines for impact assessment of the STA, it has just been tested in two projects (Trafikverket, 2007, 2016). The method of Fäldner (1987), sometimes referred to as the Swedish Method, has been a central reference for several studies on barrier effects (Bein, 1997a, 1997b; Bein & Kawczynski, 1997; Forkenbrock & Weisbrod, 2001; Marsh & Watts, 2012; Quigley & Thornley, 2011; Rintoul, 1995; Tate & Mara, 1997; Tate, 1997). The use of statistics to measure the travel behaviour of different age groups is one of the aspects that made the method unique in its time. Anciaes (2011) developed a method for assessing the impact of motorways on residents' ability to reach shops that serve several neighbourhoods.

A separate branch of research can be distinguished which focuses exclusively on the crossability of busy roads. Crossability was identified as a central indicator by Buchanan et al. (1963) who defined 2 seconds as the limit for delay for pedestrians. De Boer et al. (1984; 2001) developed the Delft Method, with a set of metrics that quantify crossability, including traffic flow, speed, subdivisions of the road and visual conditions. The method for measuring the experience of barriers developed by Boon et al. (2003) was intended as a complement to the Delft Method. Impacts of traffic on the crossing behaviour of pedestrians were studied by Hine, (1996) and Russell & Hine (1996). The effects on crossability of bunching of vehicles in traffic flows were studied by Guo et al. (2001). A toolkit for the assessment of barrier effects of busy roads was developed by Mindell, Vaughan, et al. (2017), which includes a wide range of assessment techniques such as participatory mapping, in-depth interviews, spatial analysis, video surveys, street audits, health and neighbourhood surveys, and valuation based on stated preference surveys. Socio-economic statistics and travel data were used for measuring of barrier effects (King, 1982, Tirachini, 2015), while the degree of separation of land use was proposed as an indicator by Casado-Sanz et al. (2019).

Development of tools for the monetisation of barrier effects

In addition, methods for monetising barrier effects were developed, often through calculating the cost of lost time due to extra travel or delay (Fäldner, 1987), or extra travel costs (Ellis, 1968), also using hedonic modelling (Eliasson, 2009), contingent valuation (Grudemo et al., 2002) and choice modelling (Grisolía et al., 2015; Mindell et al., 2017). Recently, Anciaes et al. (2022) managed to calculate that the total cost of barrier effects of busy roads equals 1.6 % of BNP in the UK. Although a few of these methods also include some form of measuring of barrier effects, an important distinction is that here the objective is the valuation rather than the quantification of barrier effects. These methods are therefore not directly related to the topic of this thesis.

The overview of the literature makes it clear that barrier effects are a multi-factor phenomenon, and that inter-disciplinary and inter-organisational collaboration is needed for its assessment. For this collaboration it is important that there is consensus about the naming of the components and about the descriptions of how the components are related. These issues are related to RQ 1 and discussed in Paper I. In the next section, the concept of accessibility is proposed as the theoretical framework for the description of the relationship between the components of barrier effects. How this collaboration can be organised is related to RQ 4, and an example of such collaboration is presented in Paper IV.

2.2 Accessibility as the theoretical framework for barrier effects

As described in the previous section, the components of barrier effects are transport infrastructure and its traffic, the street network, land use and people. These components can be aligned within the framework of accessibility (Handy & Niemeier, 1997), where the infrastructure and the street network form the impedances between people as agents and land use as attractions. Locating these components within an established field such as accessibility may deepen understanding of barrier effects, and improve the application of the tools for assessment that have been developed.

A shift in transport planning has taken place over the last decades, from a focus on mobility and efficient movement of people and goods, to accessibility, which has been defined as the ease with which people can reach their destinations (Levine, 2019). This shift can be related to a growing awareness that a one-sided optimalisation of mobility can lead to a reduction of accessibility, as it fosters dispersed low density land use. Many national and regional transport administrations are now defining accessibility as a central goal for policy and investment (Inayathusein & Cooper, 2018; Trafikanalys, 2012). Several models for assessing accessibility have been proposed, generally involving attractions, agents and different forms of impedances between these two components (Handy, 2003). Geurs & van Wee (2004) identify four components: land use, transport, temporal constraints (such as opening hours and working hours), and individual conditions (such as abilities of people.) Ideally, instruments for measuring accessibility should take in all of these components. Other criteria for accessibility instruments are operationalisation (ease of use in practice, for example), interpretability and communicability, and relevance to social and economic indicators (ibid.). The term accessibility is also associated with the physical disabilities of people that restrict their possibilities of making use of transport systems, a well-established topic within the practice of transport planning and theory (Unsworth et al., 2021). This aspect can be regarded as 'individual conditions' in Geurs & van Wee's model (2004) and is treated as such in this thesis.

Haugen (2012) distinguishes three approaches to attaining accessibility: mobility, proximity and remote access using information and communication technology. Mobility typically demands resources, which creates a growing conflict with sustainable development. However, also proximity demands some form of mobility. The point where a mobility approach is needed for attaining access is dependent on the individual's abilities, and what they perceive as being far or near, as well as what type of amenity they want to access. Silva & Larsson (2018) observe that accessibility instruments need to focus more on local accessibility, especially in relation to transport infrastructure projects that aim to improve regional accessibility. An example of what consideration of local accessibility can offer is the study by Elldér et al. (2022), on how local accessibility affects people's choice to travel by bicycle or on foot.

As with methods for the quantification of barrier effects, also the use of accessibility instruments in practice is limited (Te Brömmelstroet et al., 2019). A central challenge for the transfer of these instruments from their developers to users in practice has been described as the dilemma between rigour and relevance – in other words, the conflict between the developer's wish to have a complete and detailed instrument and the need of the practitioner to have an instrument that is easy to use and that gives quick results (Silva et al., 2017). These insights are also valuable for defining a strategy for increasing the use of existing tools for the quantification of barrier effects in practice.

Accessibility offers the theoretical framework of this thesis, and defines the scope for answers to RQ 1 and RQ 2. Further, it forms the central theoretical underpinning of Papers I and II. The criteria for accessibility indicators defined by Geurs & van Wee (2004) form the reference for the review of the barrier effect indicators that are applied in the case study in Paper II.

2.3 The need for quantitative support in social impact assessments

The assessment of barrier effects of transport infrastructure is a common topic in social impact assessments (SIA). SIA are described as “the processes of analysing, monitoring and managing the intended and unintended social consequences, both positive and negative, of planned interventions (policies, programs, plans, projects) and any social change processes invoked by those interventions” (Vanclay, 2003, p. 5). The purpose of SIA is more than passive assessment of impacts, but rather to contribute actively to sustainable development. Consequently, theories related to social impact assessments are intertwined with theories related to social sustainable development.

The interest in the social dimension of sustainable development has increased in recent years, after many decades of focus on its ecological dimension. In 2015, social sustainability goals were included in Agenda 2030 (Levin & Gil Solá, 2021). In relation to transport planning, the essence of social sustainability is to place people at the centre of planning efforts, rather than the traffic environment or vehicles. In social sustainable transport planning, people’s welfare is the overarching goal, where the transport system functions as an enabler (in some cases a prerequisite) for this welfare. From this perspective, the transport system becomes a commitment for municipalities, regions and states, to secure the welfare of its citizens (ibid.). In this commitment, a fair distribution of the benefits and costs of the transport systems becomes a central question for planning, as “[t]he most vulnerable groups in society tend to have fewer possibilities to make use of new transport infrastructure and can also be those groups that bear the most inconveniences of [the infrastructure]” (ibid, 17). Levin and Gil Solá list the impacts on accessibility, mobility and activities, health, individual economy, neighbourhood and communities, people’s identity, and conditions for a flexible everyday life as social consequences of transport systems (ibid.). The impact of transport infrastructure on accessibility is the subject of interest to this thesis.

A challenge for social sustainable transport planning is that it relates to both technical as well as social knowledge fields and that it requires different methods from those that exist for technological, economic, and environmental aspects. “[T]he literature reflects a great need to concretize knowledge and methods so that they become useful in a planning context, and that they need to complement existing, technically oriented knowledge and methods, and models for economic calculations.” (ibid, 23) Returning to the SIA of transport projects specifically, hindrances that are mentioned are “difficulties with disentangling the various elements of the appraisal process” (Atkins, 2009, 16) and that little has been done to translate the concepts from social theory to practical tools for assessment (Forkenbrock & Weisbrod, 2001). In their review of international research literature Levin and Gil Solá found that in assessments of transport projects “socio-economic issues are assessed with quantitative methods in much lesser extent than bio-physical issues” (2021). Geurs et al. (2009) point out the need to improve the methodological soundness of SIAs and propose a conceptual chain, consisting of the sequence: source – effect – impact – recipient. An effect becomes an impact when it exceeds the sensitivity level of the recipient. This distinction between effect and impact is valuable in determining which techniques are relevant for the assessment. The separation of different impacts is important for trustworthy assessments, however, the way social impacts of transport can accumulate must not be ignored (Héran, 2011).

The overview of the SIA literature creates a clear agenda for this thesis. The difficulties with disentangling the elements in SIA for the case of barrier effects are related to RQ 1 and are addressed in Paper I. The concretisation of knowledge and methods that is needed to improve their usefulness in practice relates to RQ 2 and 3 and is the topic of Paper II and III. Further, an example of the collaboration between stakeholders that is required for SIAs is described in Paper IV, which answers RQ 4.

3. Research design

As argued in the Introduction, the problematic lack of quantitative assessment of barrier effects in transport infrastructure projects is in principle related to a lack of exchange of knowledge between research and practice; tools for quantification have been developed but are rarely used. This limited exchange of knowledge between research and practice is not unique to barrier effects assessment, but is also a challenge for the research and practice of accessibility assessment (Bertolini & Silva, 2019), and for planning research in general (Straatemeier et al., 2010). The research activities that are presented in this thesis form a response to this lack of exchange of knowledge. Insight into what factors determine barrier effects (RQ 1), and into which barrier effect indicators have been developed (RQ 2), is created through reviews of the literature on barrier effects. Methods for operationalising the identified indicators have been developed using spatial analysis techniques (RQ 3). How these indicators function in practice and what they contribute to transport infrastructure projects in practice is studied through interviews (RQ 4). This chapter presents the methodological considerations behind this research process and the methods and data that were used.

3.1 Research process

The research design that was developed for this thesis can be described as an application of the experiential case study method developed by Straatemeier et al. (2010) for planning research. The method originates amongst others in the principle of Dewey that states that "practical knowledge can only be generated within actual experience" (ibid., p. 580). Further, the method is based on the observation that planning research must be seen as a design science, aimed at producing knowledge of the design and realisation of artefacts (similar to architecture and engineering) and/or the improvement of the performance of processes (as for example in medicine or management). This characterisation is in contrast to explanatory sciences whose aim it is to produce knowledge about causal relations, as most natural and social sciences do. The products of design sciences are typically prescriptions, whereas the products of explanatory sciences are typically descriptions, explanations and predictions. An essential aspect of the design sciences is that steps involving the implementation of interventions and reflection on their outcomes need to be included in the research process. However, these steps are frequently missing in planning research (ibid.). A clarification must be made regarding the distinction between design and explanatory science introduced by Straatemeier (ibid.). Fundamentally, design sciences are epistemological sciences rather than a form of knowledge production. They explain practice (skill), including practical design, as a process that brings together different forms of knowledge. The knowledge whether a planning design solution will work is usually not based on an 'hunch' but is based on a process involving different explanatory sciences.

The experiential case study method developed by Straatemeier et al. (ibid.) offers an approach for including in planning research the steps of implementation of interventions and reflection on their outcomes. The method consists of a sequence of four steps in which the research migrates between practice and research: 1) Observation and reflection: definition of research questions; 2) Forming abstract concepts; 3) Testing the abstract concepts in new situations; 4) Concrete experience: reactions from practitioners on the application of the new concepts. To produce knowledge that is grounded in practice, these four steps need to be executed in a sequence of several cases, where each case provides input for the next.

In the research project presented in this thesis, two of these experiential case study cycles were performed (see fig 1, the numbers in the text refer to numbers in the diagram). The project found its beginnings in the observation that barrier effects of transport infrastructure are usually assessed with general descriptions based on rough estimations, even though several methods for the quantification of barrier effects exist. From this observation RQ 1, 2 and 3 were formulated (1). Based on a comprehensive literature review (2), a model for barrier effects and a list of indicators of barrier effects were defined and applied in a case study (3) concerning a planning proposal for Lundbyleden, a motorway in Gothenburg. In the case study, four indicators that were described in the literature, were operationalised in a geographic information system (GIS). The results of the case study were published in Paper II and III[2] . Through presentations to practitioners and dialogue (4) with the officers of the STA who were working on a pre-study of the planning of Lundbyleden, the model and the analyses that were produced in the case study received response and feedback concerning the value of making barrier effects visible in the planning process. This ended the first cycle.

The input and the conclusions from the Lundbyleden case study allowed for further reflection on RQ 1 and 2 (5), which made it clear that a wider and systematised review of the literature on barrier effects (6) was needed. The review resulted in a revised version of the model of barrier effects and of the list

2 The research papers that are presented in this thesis are numbered according to a rhetorical sequence for presentation in the thesis, rather than to the historical order in which they were written or published.

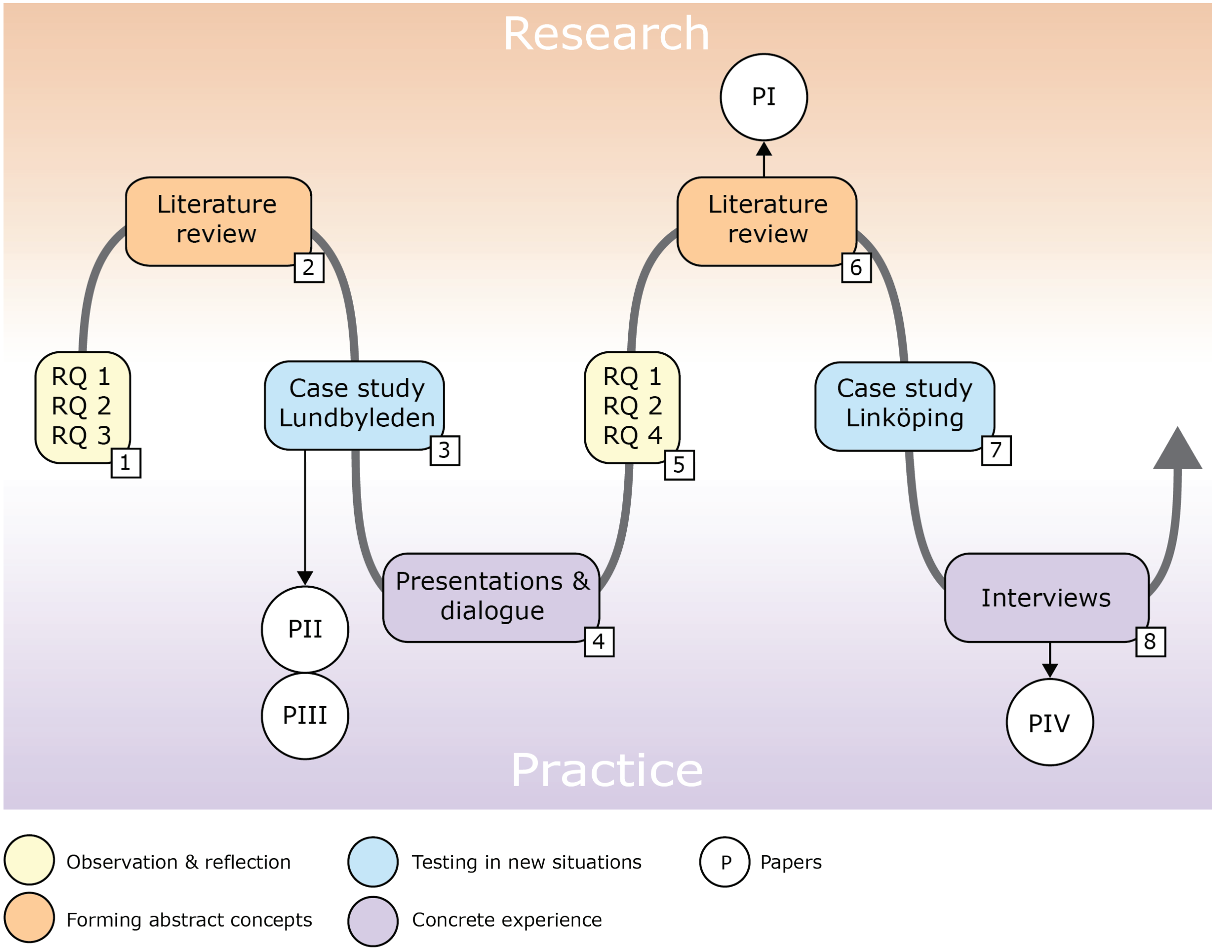


Figure 1 Diagram of the research process for this thesis based on the experiential case study method of Straatmeier et al., (2010). RQ1: What are the determinants of the barrier effects of transport infrastructure?; RQ2: Which indicators for the barrier effects of transport infrastructure have been formulated in the literature and how can these be catalogued?; RQ3: How can the indicators for the barrier effects of transport infrastructure be operationalised in practice?; RQ4: How is the quantification of barrier effects for the assessment of a transport infrastructure project experienced by planning practitioners?

of indicators that were published in Paper I. Based on the reactions of practitioners and the experiences in the Lundbyleden case study, also RQ 4 was formulated (5). Using an action research approach, the revised model and indicators were applied in a case study in Linköping (7). The experiences of the practitioners from the STA, the municipality and the consultants that were working with the barrier effect analyses were recorded through interviews (8) and published in Paper IV. This ended the second cycle.

Next to fact that the research topic requires an exchange between research and practice, the interest in this exchange is also determined by the facts that this research project is done as part of my employment at Ramboll and that the project is financed by the STA. This has, on the one hand, defined a strong focus on the utilisation of the results of the project, and on the other, created opportunities for continuous and extensive interaction with the practice of transport infrastructure planning that is a requirement for an experiential case study process. Further, my position as practitioner has formed my perspective on the research topic, which is that conflicts related to transport planning can be solved by expanding knowledge and developing efficient tools. This can be placed in contrast to a perspective that these conflicts must be described as inherent consequences of injustices in society for which there are no given solutions (King, 1982).

3.2 Methods and data sources

In this section, I will discuss the methods and the data sources that were used in the research process described above. The experiential case study process that was used in the thesis made it necessary to use both quantitative and qualitative research methods. In discussions about research methods, a dichotomy is often created between quantitative and qualitative research, which would make this combination in one research project challenging. But as Hammersley (2012) states, it is problematic to draw a sharp border between these two forms of inquiry. There are in fact deeper divides between different qualitative research methods than between quantitative and qualitative methods in general (ibid.). However, some fundamental differences between quantitative and qualitative methods can be pointed out. Typical of quantitative research is that it deals with the testing of hypotheses, uses numerical data, strives after procedural objectivity, studies systematic patterns, and is based on controlling variables within a studied phenomenon. In contrast, qualitative research studies real life situations instead of experiments, is based on observations rather than accounts of events, uses reports in the participants' own words, and takes the complexity and context-sensitive character of social life as a starting point. Table 1 gives an overview of the aims, data sources and methods used in the papers.

Table 1 Overview of aims, methods and data sources used in the papers.

	Paper I	Paper II	Paper III	Paper IV
Research Questions	1,2	3	3	4
Aim	Create: 1) model of barrier effects; 2) overview of barrier effects; 3) overview of indicators of barrier effects	Define a way to operationalise a selection of barrier effect indicators	Define a way to operationalise a barrier effect indicator focused on a specific social group	Define a way to Study how the barrier effect indicators are experienced by practitioners
Method	Systematised literature review	Spatial analysis using GIS	Spatial analysis using GIS	Action research, interviews
Data Source	TRID, Scopus, WoS, experts	Road centre line map, OSM, municipal development plans and planning proposals	Road centre line map, OSM, municipal development plans and planning proposals	Interviews and transcriptions of these interviews

Systematised literature review – Paper I

For the first case study, I performed a scoping literature review that made it apparent that barrier effects are a complex research topic involving many factors. To be able to capture the phenomenon in all its aspects, I performed a systematised literature review (Grant & Booth, 2009) with general search terms. The literature search produced a large number of references (n=267). In order to maintain an overview of the material, in an annotated bibliography and a spreadsheet for each publication I recorded which barrier effects, which determinants of barrier effects were identified, and which indicators and/or methods for assessment were described. While reading the literature, this list of points for analysis evolved and became more specific, which made it necessary to re-read a number of publications. More details about the methods used in the review can be found in Paper I.

Spatial analysis – Paper II & III

The task in the case study presented in Paper II and III was the operationalisation of four barrier effect indicators that were found in the literature, using conventional GIS tools. All four indicators related to the three basic elements of accessibility: attractions (destinations), actors (people) and impedances (transport networks), and can be categorised as two types of accessibility measures: spatial separation and cumulative opportunities (Papa et al., 2015). The networks that were used in the case study originated from Open Street Maps (OSM) as this dataset provided more detail about the non-motorised network than the dataset from the Swedish National Road Database, which is another common alternative in Sweden. More details about the networks and the adjustments that were made can be found in Berghauser Pont et al., (2017). The destinations that were used in the study originate from OSM, as this data set was the most complete. As the objective of the case study was to develop techniques for the application of the indicators in practice, the case that was taken from practice had to be reduced. The analyses only looked at cycling and driving, but not walking; the effects of amenity values in the street network were not included, and the needs and abilities of people were based on general assumptions.

Action research – Paper IV

An opportunity to collect concrete experience about how the model and the barrier effect indicators function in practice arose when the STA assigned Ramboll, my employer, to carry out a route study for a high-speed railway through the town of Linköping. In the project, I was given a role as accessibility analyst, which allowed me to test the model and the indicators in an action research-based case study. Action research is a form of inquiry that is "done by or with insiders in an organisation or community, but never to or on them." (Herr & Anderson, 2015, p. 3) Through its insider perspective, the agenda of an action research project involves the study of the social practice of an institution or community (research), as well as the improvement of or change in this practice (action). This double burden creates a tension between the rigour and the relevance of the research, which requires a critical and reflexive approach from the researcher (ibid.).

Within action research, the bias and subjectivity of the researcher are fundamental conditions that must be examined critically rather than avoided, as is the assumption for quantitative research. As Herr and Andersson (ibid.) express this:

> As researchers, we acknowledge that we all enter research with a perspective drawn from our own unique experiences, and so we articulate to the best of our abilities these perspectives or biases and build a critical reflexivity into the research process. (ibid., p. 73).

A limitation of action research is that it can lead to the unreflective reproduction of 'best practices' that support the current social order in an institute or community. Further, when a researcher studies changes in social practices that are brought about by interventions that they are responsible for, there is a risk of self-promotion. Another limitation concerns the possibility to generalise findings of action research, as applies to qualitative research in principle (Hammersley, 2012). However, qualitative knowledge can become transferable when it is presented as a documentation of a successful collaboration and its result (Herr & Anderson, 2015).

In the action research of the Linköping case study I worked in the following ways with the five criteria for action research of Herr and Anderson (ibid.):
1) Outcome validity: the process and the results of the application of the barrier effect indicators in the project contributed to solving a long-standing conflict between the STA and the municipality. With the support of the interviews, I described this process for both organisations in a series of presentations. The next phase, in which a technical plan for the railway will be developed, will show if the outcomes of the research project will lead to change in social practices.
2) Process validity: I involved the participants of the study throughout the research project. After the interviews were

done, I had several follow-up interviews with participants, reflecting with them on facts that had been presented during the interviews and on events that took place in the project.
3) Democratic validity: All the practitioners, apart from two, from both the stakeholder organisations that used the barrier effect analyses in the project, were interviewed. However, the perspective of the regional planning authority was only included in a limited way as the representative of the region had been introduced to the project at a late stage. Apart from a survey among school children, the perspective of the general public was absent in the research project.
4) Catalytic validity: It is difficult to assess if and to what extent the research changed my understanding and that of the interviewees of the social practice concerning the assessment of barrier effects in the infrastructure project. However, the rich insights that were presented during the interviews can be seen as an indication of these changes.
5) Dialogic validity: At every step of the project, the research setup and the methods that were used were reviewed by several researchers. To avoid the risk of unreflective reproduction of 'best practices' and of self-promotion, I did the analyses of the transcriptions together with the co-author of Paper IV. The validity of the research will be reviewed once more before publication of Paper IV. More details about the research methods that were used in the Linköping case study are presented in Paper IV.

Interviews – Paper IV

The technique of interviewing was used in the action research project presented in Paper IV. As is the case in action research, and also within theories on interviewing techniques, bias, and subjectivity are seen as conditions rather than aspects that must be avoided. An example is the appropriateness of asking leading questions, commonly mentioned as a point of criticism of interviews as a research method. However, this disregards the active role of the interviewer in the process; "knowledge is constructed and co-authored and co-produced through an interpersonal relationship [between] interviewer and interviewee" (Kvale, 2007, p. 89).

In the Linköping case study, I conducted semi-structured interviews with 22 practitioners from the STA, the municipality, and the consultancies that were assigned by the STA, using a guide for the interviews made up of a standard introduction, and a collection of questions grouped into three main themes. The guide was tested in interviews with two colleagues prior to the case study, and during the interviews, the guide was adjusted several more times. The interviews fulfilled the criteria of Brinkman and Kvale (2018) to the following extent: 1) The majority of interviews can be characterised as spontaneous and relevant conversations where the interviewees offered rich and specific answers to the questions; 2) The questions were fairly short but as interviewer, I was clearly present during the conversations; 3) On principle, I asked the interviewees to give examples of their experiences, the assumption being that experiences that are illustrated by an example have a higher validity as support for inferences; 4/5) I concluded each interview with a detailed summary of what had been discussed; often this prompted further elaborations of points raised or corrections of my understanding or interpretation; 6) At the start of each interview, I requested the participant to be explicit about what they said, and to also include events and aspects that were familiar to us. The resulting transcriptions of the interviews are self-supporting stories. More details about the interviewing methods can be found in Paper IV.

Coding – Paper IV

The analysis of the interviews was done through coding, a technique which can be described as attributing meaning to each individual phrase in a transcription of an interview for the purpose of theory building (Saldaña, 2016). We used thematic analysis as coding technique, as this is a flexible method that fits a mixed method project such as the one presented in this thesis. The work process followed the criteria for thematic analysis by Braun & Clarke (2006). Using the coding software Invivo, the co-author and I did a first round of in vivo coding (Saldaña, 2016) where we coded the phrases and words that appeared relevant and interesting, in order to discover patterns and themes. After the first round, we compared our codes and discussed how they could be categorised. Based on this, we compiled a list of themes, categories and codes. We collated the relevant extracts for each theme, checked the coherence between the themes and made sure that themes did not overlap. We then tested this adjusted list of codes, categories and themes in a second round of coding on a selection of transcriptions. This process allowed us to clarify the focus of the research further and reorder and reformulate the themes, categories and codes. Finally, with the resulting list of codes, we performed a third round of coding.

4. Papers summaries

This chapter presents the main findings of the four papers that were produced in the course of research for this thesis, places these in relation to the overall aim of the thesis, and points to relationships between the papers.

4.1 Paper I – Disentangling barrier effects of transport infrastructure: synthesising research for the practice of impact assessment

The literature review presented in Paper I forms a response to the observed scarcity of transparent and fact-based assessments of barrier effects of transport infrastructure and its traffic in practice (Anciaes, Jones, et al., 2016). This could be related to the limited dissemination of literature on the assessment of barrier effects, to the complexity of these effects, and to the difficulty in isolating barrier effects from other externalities. The intention of the review was to increase the knowledge base concerning barrier effects of transport infrastructure by formulating a model that gives a quick overview of which elements need to be taken into consideration when assessing barrier effects, and how these elements relate to each other.

The literature describes barrier effects as externalities of transport systems similar to noise, pollution or vibrations. However, an important difference is that the latter are emitted by the traffic in the transport system regardless of its context, while barrier effects arise in the meeting of several elements. Transport infrastructure like motorways or railways are not barriers in themselves, but become barriers when they are in the way of someone on their way to somewhere. It could be argued that the term "barrier effect" is a tautology, as a barrier can already be considered to be an effect, an effect of the feature on those individuals that want to pass it. For the understanding of barrier effects, and for the development of methods for their quantification, it is important to unravel the process of a transport feature becoming a barrier. If the definition of a barrier would be limited to the characteristics of the transport feature alone, there is a risk that significant effects can be missed. This unravelling involves, firstly, the distinguishing of the determinants of barrier effects and their relations, and secondly, the describing of the different hierarchical levels of barrier effects.

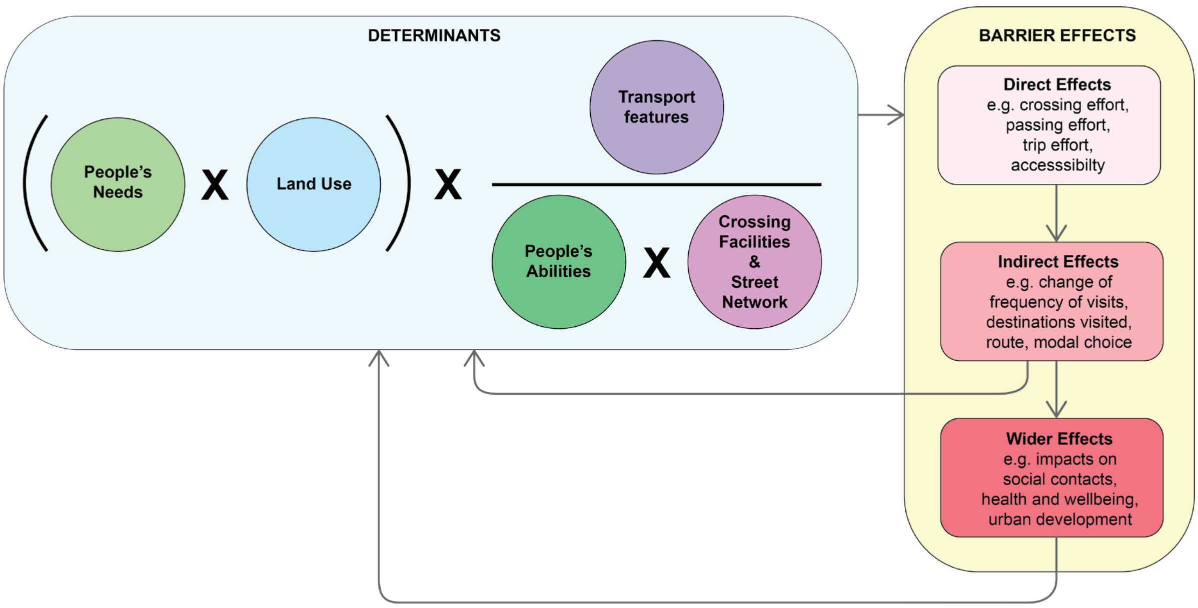
Based on Anciaes, Jones, et al. (2016), Boon et al. (2003), CROW (2011) and Korner (1979), a model for barrier effects was formulated that identifies the five determinants of barrier effects: 1) Transport features; 2) Crossing facilities & street network; 3) People's abilities; 4) Land use; 5) People's needs (see Fig. 2). Subsequent to the experiences of applying the model in practice (Paper IV), the determinant 'Crossing facilities & Routes' is renamed in this thesis as 'Crossing facilities & street network', as it became clear that the street network as a whole plays a role. On a theoretical level, the model aligns with the elements of accessibility, where People's abilities and People's needs correspond with the agents, Land use corresponds with the attractions and the Transport features and Crossing facilities & street network correspond with the impedances that agents need to overcome to reach attractions.

The five determinants do not all play the same role in the process of how barrier effects come about. In the model, Transport features are elements that can become a barrier, while the other four determinants define the significance of the hindering effect of those features. Traffic networks are split into two determinants, the hindering Transport features and the Crossing facilities & street network that cross those features, as these determinants have opposing influences on barrier effects. An increase in the separating characteristics of Transport features leads to an increase in barrier effects, whereas an increase in the number of crossing facilities and the density of the street network decreases barrier effects. Similarly, the component People is separated into two determinants: People's needs and People's abilities, as these also have opposing influences on barrier effects; an increase in needs increases barrier effects, whereas an increase in abilities decreases barrier effects. The determinant Transport features has a specific role as it clarifies what type of assessment is relevant. In the case of dynamic barriers, such as busy roads, the crossability of the Transport feature is variable and indicators for measuring how crossability is affected must be used. In the case of static barriers such as motorways and railways, the crossability is zero and therefore it is not relevant to include it in the assessment. More details about the determinants can be found in paper I.

In the model, the components of barrier effects are described as 'determinants', to clarify that all components in the model determine the level and distribution of barrier effects, but that not all components cause barrier effects. For instance, the need of a person to reach a destination on the other side of a road determines the extent to which this person is affected by the road as barrier. Here, it is the road that creates the barrier. In Paper II, an example is given of the active role that land use can play in barrier effects. In the model, mathematical operators are used to describe how changes in the determinants interact with each other and lead to barrier effects. Writing the model as an equation suggests the possibility that the model could be used to calculate levels of barrier effects numerically. But as the five determinants are related to widely different aspects, this would require further investigation to establish.

Different ways to differentiate between levels of barrier effects have been suggested. The model is based on Korner (1979) and Mouette & Waisman (2004) and differentiates three levels of barrier effects, using travel behaviour as a distinguishing factor: 1) Direct barrier effects; 2) Indirect barrier effects; 3) Wider barrier effects. This categorisation creates further opportunities for collaboration by separating areas of responsibility for different stakeholders in an infrastructure project.

Figure 2 Conceptual model of the barrier effects of transport infrastructure and traffic.



The model also describes the role of time in the processes concerning barrier effects and their determinants. For example, when a busy road forces people to travel by car, which increases traffic flow (characteristic of the Transport feature determinant), which in turn affects the crossability of the road (direct barrier effect) and which can make even more people chose the car for their trips (indirect barrier effect). These changes can lead to a number of wider barrier effects, for example a reduction in consumer base for services, which can lead to closure or relocation. And these changes in Land use can lead to feedback loops that in turn change the levels of direct barrier effects. Reactions of individuals to the conditions created by barriers change over time, and consequently, also indirect barrier effects can change over time.

Another contribution of the review is the list of the indicators and methods that were developed for the assessment of barrier effects, categorised according to the three levels of barrier effects. This list offers the possibility to quickly find the most relevant tool for a given impact assessment. We found 42 direct barrier effect indicators that are related to various properties of the built environment, and seven indirect barrier effect indicators that are predominantly concerned with travel behaviour and therefore require qualitative assessment methods. The wider effects of barriers are generally complex, multi-factor phenomena that develop over time. Assessment of these effects requires more extensive analyses that are part of SIA and longitudinal studies of urban development.

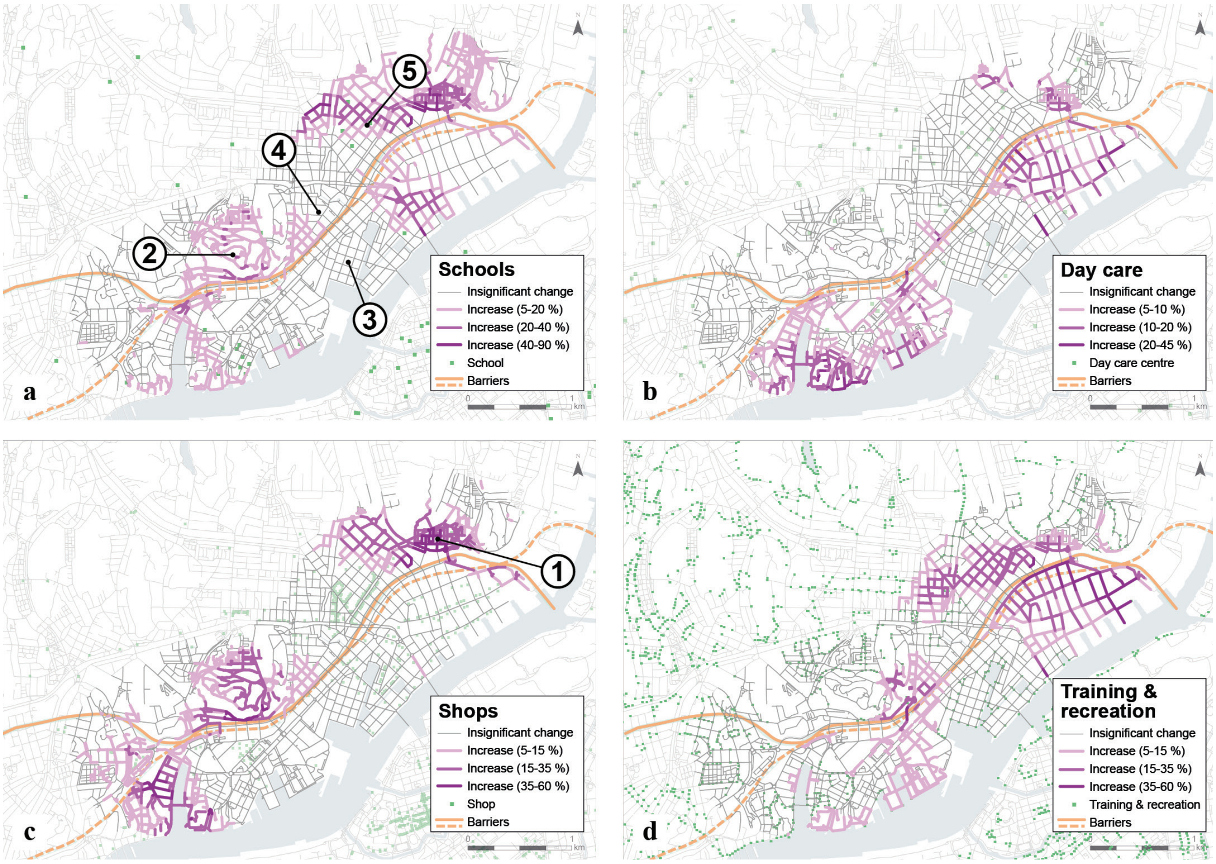
4.2 Paper II – Missing links: quantifying barrier effects of transport infrastructure on local accessibility

Of the 70 infrastructure projects in Sweden that we reviewed, none used a method for quantifying barrier effects. In response, this paper presents four local accessibility indicators that allow for the quantification of direct barrier effects. The indicators are focused on direct barrier effects, as these effects are related to the elements in the built environment that are the subject of planning processes of infrastructure projects. The barrier effects that were identified in the literature were: increase in travel time/distance/effort, decrease in choice of facilities available to people, decrease in catchment areas around facilities, and reduced travel efficiency for services vehicles such as mail, freight and emergency services. Based on Anciaes (2013), Cline (1963), Forkenbrock & Weisbrod (2001) and Korner (1979), this paper proposes four indicators to measure the majority of these direct barrier effects: Travel time; Choice; Catchment; Service efficiency. A case study was selected to test and demonstrate how the indicators can be operationalised in an infrastructure project. From a methodological point of view it is of interest to observe that the analyses that were done concern the reduction of existing barrier effects, not the level of effects of existing or new barriers. The case study concerns a motorway and railway in Gothenburg, Sweden, that conflict with ongoing urban development in the vicinity. The STA presented several alternatives for adapting the infrastructure to these developments (Trafikverket, 2008). In the case study, we compared the tunnel alternative with the present-day situation. The input for the assessment is the municipal plans for urban development in the area, and road centre line networks (RCL) for cycle and pedestrian traffic and for car traffic. These networks were adapted in the tunnel alternative by increasing the present eight connections across the infrastructure to 36. For destinations and residential addresses, we used datasets from Open Street Map and from Gothenburg municipality.

The results show the potential of the indicators to quantify the levels of direct barrier effects and map the spatial distribution of these effects. The effects were distributed in complex patterns over the area surrounding the infrastructure, rather than in a linear way, from the infrastructure outward. This is information that could not have been obtained through aggregated analyses of travel times between origins and destinations in the area. The indicators are simple and easy to implement and have the potential to provide support for impact assessments, such as traffic assessments and social impact assessments. In the analyses, the differences between the current situation and the tunnel alternative were presented, either in relative change (percentage) or in absolute change (travel time in minutes). In the presentations of the case study to officers at the STA, the municipality and other colleagues, this way of presenting the results made them accessible and easy to present and discuss.

An area for further research that can be pointed out, is how the indicators can be adapted to the needs and abilities of specific social groups, which was the topic of Paper III. Additionally, the indicators need to be tested in real-life projects to identify the advantages and drawbacks of the metrics, and also how the indicators can best contribute to impact assessments, as in Paper IV. Another area for further development of the methods is the adjustment of the street network in the alternatives that are assessed. The pre-study by the STA (Trafikverket, 2008)

Figure 3 Change in Choice of the number of destinations within a fixed travel time of 10 min by bicycle around each street segment. Purple to grey indicate increase in Choice in percent; for grey segments there is only minor change. (1) Backa, (2) Ramberget, (3) Frihamnen; (4) Kvillestaden; (5) Backaplan



did not include any proposals for how the existing street network could be complemented or adjusted in the different planning alternatives. This made it necessary to make assumptions about new connections across the vacant strip that was left when the motorway and railway were placed in a tunnel. From a methodological perspective, this is a crucial point, because all analyses compared the impacts of these 28 new connections, while the other determinants, including Land use, were left unchanged (as this case involved a static barrier, the determinant Transport feature was not a variable). This process of creating alternative versions of the street network became the central theme of Paper IV.

4.3 Paper III – The social dimension of barrier effects of transport infrastructure

Paper III highlights several issues regarding the determinants 'People's abilities' and 'People's needs'. In the study, the indicator 'Choice', presented in Paper II, was adapted to assess children's accessibility to parks, waterside, and leisure facilities. The indicator was applied to the case study described in Paper II, illustrating how the indicator can be adapted to the needs and abilities of a specific social group to make it relevant for social impact assessments of infrastructure projects. The indicator Choice can offer support for estimating trips-not-made that were described as important for the assessments of barrier effects (Hine, 1994) but that are hard to evaluate, as people can adjust their expectations, and therewith their needs, to the opportunities that are offered by their neighbourhood.

A central issue for the adaptation of the indicators is how to categorise social groups in a way that is relevant for the assessment of barrier effects. In the barrier effect literature this issue has received a great deal of attention, and Paper I presents a list of factors that define people's abilities to overcome barriers. For the process of categorisation it is important to be aware of what Rajé (2007) describes as an experience and communication gap that exists between users, planners and policy makers in transport. Rajé argues for basing categorisation for transport studies on the lived experience of transport rather than on given socio-economic groups (ibid.). An example of this is how gender is often pointed out as a factor, which describes women as sensitive to barriers. This hides the fact that also men can have reduced access to cars for transport, due to household responsibilities or unemployment.

Another issue is the level of detail of the categorisation, an issue that can be related to the dilemma between rigour and relevance that applies to planning support systems (PSS) in general (Silva & Larsson, 2018). The assessment of barrier effects aims to give decision support for interventions that take many years to construct and that define conditions for people for many decades. During that time the composition of the affected population can change considerably. This characteristic of transport projects makes it less appropriate to base assessments on the needs of specific groups. However, basing the assessments on 'general needs' of a population can hide a preference for a certain social group.

4.4 Paper IV – From trench war to dialogue: studying the assessment of barrier effects in a transport infrastructure project

The observation presented in Paper I was the starting point for Paper IV, namely that barrier effects are a multi-factor problem, and that their assessment requires close collaboration between stakeholders with different perspectives and responsibilities within an infrastructure project. An increased need for collaboration in transport projects in general can be observed as a result of the present transition to governance-based decision processes in transport planning (Pettersson & Hrelja, 2020). Paper IV presents an action research-based case study in a high-speed railway project, involving interviews with practitioners about their experiences of the use of and work process with a set of barrier effect analyses (BEA). For these BEA, a selection of the barrier effect indicators that are presented in Paper I was used. The case study concerns a railway project in the Swedish city of Linköping that was the subject of a twenty year conflict between the STA and the municipality of Linköping (ML). In the project, the assignment for the STA was to build a high-speed railway connection between Stockholm and Gothenburg at as low a cost as possible. The location of the station in Linköping was not yet fixed. It was even thinkable to not have a station in the city at all. The LM had a different perspective on the project, preferring a fixed location for the station, where it could contribute in an optimal way to urban development, as well as a tunnel for the railway, to minimise the barrier effects in the city. The tunnel was deemed too expensive by the STA. After a failed attempt to arrive at an agreement, a new route study for the railway was initiated, this time with particular focus on creating conditions for collaboration between the two stakeholders. In the common goals as formulated by the STA, their consultants, and by LM, the central role played by the barrier effects of the railway became apparent. The purpose of the BEA was to provide quantitative support for the impact assessments used to assess goal compliance.

In the interviews, the practitioners expressed their view that the main contribution of the BEA was the precise, impartial support that was offered by the analyses. This support created a common language and contributed to the establishing of trust between stakeholders, which made it possible to reach consensus on a planning alternative. Fig. 4 presents an example of one of the results of the BEA that was used for the traffic impact assessment. Through the experiences of the work process with the BEA, it becomes clear how the analyses are closely related to the questions of the impact assessments, which requires a close interaction throughout the work process between the analyst and the practitioner who uses the BEA as support in the impact assessment (hereafter called end-user). This interaction starts with the phase of definition of the analyses, where the model of barrier effects worked as a checklist and as a platform for discussion. The participants expressed the need for an iterative process where different input material and techniques could be tested. One consultant suggested that a workshop could be organized in the definition phase, in which prototypes of the maps could be developed, and where the end-user could formulate what information an ideal map for their impact assessment would offer, without being restricted by knowledge of the technical possibilities of the BEA.

Figure 4 Example of the results of one of the BEA: Analysis for the Steninge corridor of the average detour factor for cycle and pedestrian trips within a radius of 1 200 m from each street segment. Range detour factors between ≤ 1,2 and ≥ 1,5.

The selection and creation of input material for the BEA involved several challenges to the collaboration between the stakeholders, as well as between the urban planners and the traffic planners in the consultant group. This became evident with the determinant Street network, for which different alternatives of the street network had to be produced. This was challenging due to the different perspectives of the STA and the ML on the relevant time scale and geographic scale for the impact assessments. These differences in perspectives are related to the different areas of responsibility of the STA and the ML. The STA needs to avoid paying for costs related to consequences outside their responsibility in the project. This was expressed in the scepticism of the officers about the urban development scenarios, which were not seen by the STA as part of their assignment. The more the consequences for the local street network and the crossings with the infrastructure are assessed, the more the municipality can argue that the STA needs to pay for mitigation of these consequences. This reluctance to engage by the STA was a hindrance for the assessment of barrier effects, as the street network was the main variable for the BEA. The street network had the same role and function in the impact assessments as the railway centre lines had for, for instance, noise assessment and calculation of contraction costs. For successful collaboration between stakeholders, the important role of the street network needs to be acknowledged.

The difference in the stakeholders' perspectives on the project was also apparent with the determinant Land use. It was decided not to consider the impacts of the new station and railway on Land use in the BEA as it would make it difficult to distinguish the role of the individual variables in the results: are the changes in barrier effects due to the changes in the network, or due to changes in land use? Moreover, changes in land use require changes in land use plans, which lies outside the STA's responsibilities. Another aspect related to land use that was mentioned was that the selection of destinations in the BEA, apart from destinations for children, was based on expert judgements instead of dialogue with citizens. People's abilities and People's needs were also based on expert judgements. This can be seen as a missed opportunity of good governance (Rye and Isaksson, 2018). Also for these last two determinants the geographical and time scale is a challenge, as pointed out in section 4.3.

The final phase of the BEA, communication of the results, also requires interaction between analysts and end-users about how the results of the analyses can be presented in such a way that they address the issues that are of interest for these users.

There are diverse groups of end-users: practitioners, politicians, journalists, and the general public. A successful example of this translation was how some of the descriptions from the BEA made it all the way to an interview with the mayor of Linköping in the local newspaper.

5. Conclusion

The problem addressed in this thesis is that, although several methods for the assessment of the barrier effects of transport infrastructure have been developed, their use in practice is limited. The reasons for this are: limited dissemination of information about the methods, difficulty in distinguishing the assessment of barrier effects from the assessment of accessibility, difficulty in separating barrier effects from other externalities, the challenges generated by a multi-factor phenomenon like barrier effects and the difference in terminology used by scientific disciplines for defining the problem. In response, the overall aim of this thesis is to make existing academic knowledge and instruments more applicable in practice.

This chapter presents the main results and findings of the thesis, highlights how they address the research questions, and reflects on how the results contribute to the wider theoretical discussions presented in chapter 2. Further, I will describe the contributions to practice and point out directions for further research.

5.1 Discussion of results and findings

The thesis presents four results: 1) a conceptual model that identifies the five determinants of barrier effects and the three consecutive levels of these effects (RQ 1); 2) a list of barrier effect indicators that are categorised according to the barrier effect levels that they relate to (RQ 2); 3) a demonstration of how four of the indicators can be operationalised in a transport infrastructure project using conventional GIS techniques and how one of these indicators can be adapted to the needs and abilities of a particular social group (RQ 3); 4) a description of a collaboration between stakeholders and professional disciplines in the assessments of barrier effects in a transport infrastructure project (RQ 4). Based on these results, the main finding of this thesis is that knowledge of the social process as well as the technical process of the assessment of barrier effects is required for making existing academic knowledge and instruments related to barrier effects more applicable in practice. In the following sections, I will elaborate on these results and on this finding.

Conceptual model

In the literature review presented in Paper I, it becomes clear that barrier effects are a multi-factor phenomenon that cannot be isolated from its context, and that the assessment of those effects requires a multi-disciplinary approach. In order to manage this multi-factor character, the findings of the literature search were synthesised into a simplified conceptual model of barrier effects, in which barrier effects are defined as a particular type of impedance within the framework of accessibility. The model lists the five determinants of barrier effects – Transport infrastructure; Crossing facilities and street network; People's abilities; Land use; People's needs – and describes how these determinants influence barrier effects. Further, the model describes the levels of barrier effects, defined as: Direct effects; Indirect effects; Wider effects.

The intention for the model is not to describe the complexity of barrier effects (cf. Marsh & Watts, 2012), but rather the opposite, to formulate a simple yet complete model that can function both as a checklist and a framework for collaboration between stakeholders and different professional disciplines in infrastructure projects. In transport infrastructure projects there are usually a number of perspectives involved. In the European context, this is often a national transport administration on the one side, and a municipality on the other. As the case study described in Paper IV illustrates, these stakeholders have different mandates and geographical and temporal perspectives on transport infrastructure projects. The model makes it possible to show how the different perspectives and responsibilities of stakeholders in an infrastructure project relate to the different determinants. Further, the assessments of the barrier effects of transport infrastructure involve practitioners from a wide range of disciplines, such as traffic planners, land use planners, landscape architects, human geographers, spatial analysts, economists and health experts. The model facilitates collaboration between these practitioners, by pointing out causal pathways between effects, and by providing a set of terms to describe these effects. An example of this is how the locations and design of the tunnels under the railway in the case study presented in Paper IV could not be simply left to the railway engineers only, but required taking the whole street network into consideration.

List of indicators

Paper II deals with RQ 2 and lists the indicators and assessment methods for the barrier effects of transport infrastructure that have been formulated in the literature. In the list, the descriptions of the indicators are specified by pointing out the unit of the indicator and the technique of their measurement. The indicators and methods are categorised according to the different levels of barrier effects that they address. This specification and categorisation facilitates the application of the tools in practice by allowing a quick decision about which project scale and phase and for which assessment question the different tools are most relevant. Other than an overview of the available tools, the list can function as a checklist in transport projects and offer a vocabulary for discussing barrier effects.

Operationalising of indicators

Some of the barrier effect indicators that were presented in Paper I involve concrete measurements such as road width and traffic flow. Others are formulated more as concepts, such as 'Catchment area for facilities' and 'Choice of destinations'. In order to study how the indicators can be operationalised in a infrastructure project with the GIS tools that are used in practice in urban planning and transport (RQ 3), four indicators were applied in a practice-based case study, described in Paper II. The focus was on the direct barrier effect indicators related to the static barrier properties of large-scale transport infrastructure, as these indicators have received less attention in the literature, Anciaes' study (2015a) being one of few examples. In contrast, methods for the assessment of indirect barrier effects have been studied by, amongst others, Mindell, Vaughan et al., (2017), Nimegeer et al. (2018), and Russell & Hine (1996). For the discussion of the applicability of the indicators, I will make use of the four criteria that were formulated by Geurs & van Wee (2004) for accessibility measures in general - these criteria appear to be relevant also for the indicators of barrier effects.

To be theoretically sound, the indicators ideally need to involve the four components of accessibility that Geurs and Van Wee (ibid.) list: Land use, Transport, Temporal component, and Individual component. The case study presented in Paper II describes how the indicators involve two of four components: Land use and Transport. The temporal component is related to opening hours of services, but these were not included in the case study. Otherwise, the temporal and individual components are included through adapting the indicators to the wishes, needs and abilities of people. As it would take too much time and resources to adapt the barrier effect indicators to each individual who lives in or visits a study area, some form of categorisation in social groups must be done. As described in section 4.3, this categorisation must be handled with care, as it is intimately related to the questions of the assessment. In fact, the identification of the groups whose perspective the indicators need to be based on is one of the central tasks in the start phase of the analyses of barrier effects, as described in Paper IV. As guidance for this categorisation, Paper I lists some of the factors that determine people's ability to overcome barriers.

The criteria regarding ease of use and ease of understanding are difficult to assess, using hypothetical studies as presented in Paper II and III. One observation related to ease of use is that in the case study relatively conventional GIS-techniques could be used for operationalisation, such as the calculation of shortest distance and of service areas. A challenge for use is that for the analyses different versions of the street network had to be created. As described in Paper IV, the challenge is not the practical drafting of these street network changes, but the collaboration that is required to reach consensus about changes between stakeholders. Paper IV highlights that the officers involved in the study experienced the analyses as easy to understand, that they create a common language, and enabled them to reach an agreement in the infrastructure project. More aspects related to the ease of use and the ease of understanding of the indicators can be found in Paper IV. Several interviewees who worked with social impact assessments (Trafikverket, 2021a, 2021b) in the project pointed out the value of the indicators in making issues that are hard to capture more precise. The use the indicators in economic valuations needs to be studied further.

Process of assessment

In order to study the process of assessment of barrier effects, the model and the indicators presented in Paper I were applied in practice in an action-based case study of a large-scale infrastructure project, and described in Paper IV. During the interviews, the participants remarked that the analyses clarified the effects of the different alternatives, and that they experienced these as relevant to their interests and responsibilities, and also as trustworthy, because they were specific and impartial. In this way the analyses solved the disentanglement of components which can be a hindrance in assessment (Atkins, 2009). The analyses became a ‘common language’ in discussing the planning alternatives, which is a prerequisite for collaboration in planning, as described by Gil Solá et al. (2018), and Rye & Isaksson (2018). This shared understanding created trust between the stakeholders, enabled collaboration, and made it possible to reach an agreement regarding the planning of the railway.

The practitioners’ experiences of the work process illustrate that barrier effect analyses are not independent investigations, like noise assessments, but are strongly connected to the impact assessments which they support. To ensure that the analyses are relevant to the process, close interaction between analyst and end-users and between end-user and stakeholders is necessary. One of the central topics for this interaction is the selection and creation of input material for the analyses, and the case study describes several challenges due to the stakeholders' different perspectives and responsibilities. An example of this is the difficulty in producing different alternatives of the street network for the analyses. The STA considered changes in the street network to be a municipal responsibility and had a different perspective on which time scale and geographic scale were relevant for these changes, and was therefore experienced by others as unwilling to engage in the assessment of these changes. The reason behind this could be that assessments of impacts create responsibility for mitigation, which often leads to higher costs, which the STA is keen to avoid. Also the accounts of the final phase of the work process with the analyses, the communication of the results, were found to require interaction between the analyst and the end-users.

The assessment of barrier effects as a social process

The four results presented here relate to various technical aspects of the process of assessing barrier effects, such as which elements in the built environment and which social aspects need to be considered, and how the indicators can be used in a GIS-model. Another theme emerges in the results, namely, that assessment of barrier effects involves the social process of interaction and collaboration between stakeholders and practitioners from different professional disciplines. The conceptual model and the descriptions of causal pathways define a vocabulary and help to distinguish the positions and responsibilities of stakeholders (Paper I). Awareness of the perspectives and responsibilities of stakeholders is also essential in the practical process of selecting and creating input material for the analyses, as the case of the street network demonstrates (Paper IV). The list of indicators is both a catalogue of tools and a system of concepts for communication (Paper I). The description of how the indicators can be adapted to the needs and abilities of social groups helps to make the analyses more relevant to the interests and responsibilities of stakeholders (section 4.2 & Paper III). Together, these aspects enable barrier effects analyses to become a 'common language' (Gil Solá et al. 2018, Rye & Isaksson, 2018) for assessing planning alternatives in transport infrastructure projects.

5.2 Contribution to theory

The thesis makes six contributions to theory. The main finding of the thesis, described in section 5.1, that the assessment of barrier effects of infrastructure requires knowledge of the social process as well of the technical process of the assessment of barrier effects, is a novel perspective within the literature on barrier effects. A further contribution to the barrier effect literature is the demonstration of how accessibility offers the theoretical framework for the understanding of the multi-factor character of barrier effects.

Further, the thesis contributes to theories of accessibility with a demonstration in two case studies of how a focus on mobility can lead to a reduction in accessibility in situations where there is a relatively high density of buildings and a geographically close proximity to destinations. Within the framework of accessibility, the case study presented in Paper II exemplifies how changes in one transport system can lead to a reduction in impedances (such as longer distances, or delay) in another transport system. Further, the thesis offers an overview of local accessibility indicators that were identified as a need (Silva & Larsson (2018).

Lastly, the thesis contributes to the literature on the SIA, by consolidating knowledge and methods for assessing barrier effects, which increases the usefulness of these tools in the planning context. The model of barrier effects enables the disentangling of the components and effects related to barriers, which makes it possible to assess when a barrier effect becomes an social impact (Geurs et al., 2009).

5.3 Contributions to, and from practice

The interaction with practice has been a recurring theme throughout the project and is fundamental to the aim of the thesis, which is to make existing academic knowledge and tools for the assessment of barrier effects more applicable in practice. I had the opportunity to test the relevance and validity of my assumptions, my methods, and the results of my studies in numerous meetings with practitioners. I have given over 60 presentations to officers and politicians at consultancies, municipalities, regional authorities, health organisations, and the Swedish Transport Administration. A special task during these presentations was to explain how barrier effects work. I tested different models, using the social reality of the interaction with the audience as an assessment tool. What is of relevance to practitioners, what prior knowledge do they have, which terms, which diagrams bring the story across? The contribution to practice during these presentations was the dissemination of information about academic knowledge and methods of assessing barrier effects. I also had the opportunity to present the results of the analyses in the case study described in Paper II to the officers of the STA and the municipality who were working on a new pre-study for the project. Although my analyses were not formally part of the project, my presentations of the analyses did confirm the conclusion of the project team that the benefits of putting the motorway and the railway in a tunnel did not justify the costs.

Besides verbal presentations, I was able to apply the model and the indicators in a series of practical assignments for Swedish municipalities and the STA; amongst others, an assessment of barrier effects with the municipality of Gothenburg, the planning of a new tram line in the Stockholm region, in the assessment of the barrier effects of a marshalling yard in Kristianstad, as well as the planning of the East Link through Linköping as described in Paper IV.

Finally, the thesis has potentially made a contribution to policy, as the conceptual model of barrier effects is now integrated in a new method for the analysis of impacts of transport infrastructure projects on urban environments that was developed for the STA by Berghauser Pont et al., (2022). However, thus far this method appears not to have been adopted as a requirement by the STA.

5.4 Further research

Several directions for further research can be pointed out:

Paper 1 lists the barrier effects that were identified in the literature. Some of these effects are supported by empirical evidence, though often they are related to single cases. More empirical studies on the barrier effects of infrastructure would strengthen and deepen the evidence base for barrier effects. The study of Lee and Tagg (1976) and Lassière (1976) who interviewed 960 residents about their experience of the barrier effects of motorways in their neighbourhoods is a strong example. As another topic within this research effort, following up on the studies of Anciaes & Jones (2018) and Grisolía et al. (2015), there is a need to study the impact of amenity levels in streets and other urban spaces of the experience of barrier effects.

To make the assessment of barrier effects more effective, and create possibilities to increase the quality of the analyses, standardisation of the methods and the indicators of barrier effects is needed. There is an intrinsic need to develop principles for determining the relevance of the different indicators for different types of project, for different project phases, and different scales. The scheme developed by Anciaes, Jones, et al. (2016) would make a good starting point. Further, there is a need for benchmarks or reference values for barrier effects to increase possibilities for comparing the barrier effects of different planning alternatives in a project.

A central challenge for the development of benchmarks is to determine with which situation barrier effects in an area need to be compared. An option could be to compare the effects in a situation before and after the barrier is removed, as with the scenario assessed in Paper II and II. This opens up possibilities for taking into account the trips-not-made due to a barrier. As seen in the case study in Paper IV, processes and methods are needed for taking into account the differences in the perspective of stakeholders about how these adjusted street networks can be created. To prioritise investments in mitigation measures, there is a potential to develop methods for comparing barrier effects of transport infrastructure features within a whole municipality or region. Such methods could also address the combined effects of infrastructural barriers. A research question for this study would be how the effects of other existing barriers could be discounted. As a consequence of the paradigm shift in academia and practice from mobility to accessibility, barrier effects move from the category of externalities to a central consideration of transport planning. Research is needed regarding the policy implications of this change in priorities. The experiences of the participants in the case study described in Paper IV highlight the importance of the process related aspects of the assessments of barrier effects. There is therefore a need for more case studies of these collaborative processes, to generalize the findings of the case study in Paper IV. Finally, in order to facilitate the inclusion of barrier effects of transport infrastructure in existing appraisal models of investments in transport systems, there is a need to develop a way to valuate barrier effects, not only through monetisation but also through a method of objective valuation.

5.5 Concluding personal reflection

The overarching subject of this thesis has been the study of the applicability of scientific knowledge and tools in practice. During the study, I experienced the potential of this exchange between science and practice. In the project, I had the opportunity to bring a question from practice to research: 'Why are the barrier effects of transport infrastructure not quantified?' The research process that evolved during the past seven years was partly a matter of joining up the dots. Through a review of the literature, I could list the barrier effects that were described, and identify the elements that determine these effects.

In this process, accessibility emerged as the theoretical framework. The literature review enabled me to compile a list of indicators and methods, and I found that there were good opportunities to apply these in a GIS model. It also enabled me to gather ideas on how to consider the needs and abilities of people in the assessment.

Then, an opportunity arose in the form of an existing infrastructure project, which allowed me to test the model and the indicators, and to describe the process of working with assessments of barrier effects in practice. This case introduced the gritty reality of practice that involves the perspective of stakeholders in infrastructure projects, the financial considerations, and responsibilities in planning projects. In this confrontation with practice, it became clear to me that the assessment of barrier effects of transport infrastructure is not only a technical process that needs fact-based tools, but that this assessment also involves a social process that is dependent on the collaboration between stakeholders and between different professional disciplines. This social process needs clear terms and descriptions of causal pathways, the translation of general principals into practical analytic tools and awareness of the diversity of people. This knowledge and these tools enable the interaction between analyst and end-user, and the collaboration between the different stakeholders in the project. Awareness of this social process is key to transforming the model and the indicators from a collection of potentially useful tools into relevant instruments that are used for the assessment of barrier effects of transport infrastructure in practice.

Returning to the start of this section and looking back at this project, I can conclude that the exchange between practice and theory has been incredibly inspiring and useful.

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Appendix A – Types of barriers

There are many types of barriers in cities. Besides the linear features in transport systems, movement can also be deterred by built structures in cities such as industrial plants, train stations, hospitals, etc. (Héran, 2011). Not only artificial elements but also natural elements can work as barriers, both linear features such as rivers (Forgaci, 2018) and surface features such as lakes, forests and mountain formations. Depending on their character, different types of natural features can have different effects as is shown by many urban waterfronts that concentrate and intensify city life (Jacobs, 1961).

The attention to barrier effects has grown parallel with the growth of car traffic in cities and the literature on barrier effects has mainly focused on this mode. Yet barriers can be defined as all things that reduce or make impossible opportunities for movement from one side to another. A barrier is something that prevents, hinders, or controls progress or movement. To position the barriers created by infrastructure in a broader field of elements that form barriers to the movement of people, I present here a broad categorisation of different types of barriers. Table 1 presents three main groups: physical, psychological and formal barriers. The system of categorisation is based on Anciaes et al (2016), Héran (2011, 1999) and Korner (1979).

Table 1 Types of barriers

<table>
<tr><th>ELEMENT</th><th colspan="3">FORM</th><th>TYPE</th><th>CHARACTERISTICS</th></tr>
<tr><td colspan="6">PHYSICAL</td></tr>
<tr><td rowspan="4">Artificial</td><td rowspan="3">Linear</td><td colspan="2">Static</td><td>Motorways and feeder roads, railways, waterways</td><td>Fences, railings, noise screens, height differences (embankment, ditches), road width, traffic isles, sight conditions</td></tr>
<tr><td rowspan="2">Dynamic</td><td>Transversal</td><td>Car traffic, trams</td><td>Traffic flow, bunching of vehicles, traffic direction, speed, proportion of heavy vehicles, parked vehicles, ice and slush removal, waiting time at controlled crossing</td></tr>
<tr><td>Longitudinal</td><td>Car traffic, trams</td><td>Traffic flow, speed, proportion of heavy vehicles, parked vehicles</td></tr>
<tr><td colspan="3">Surface</td><td>Industrial plants, airports, harbours, train stations, hospitals, military areas, power stations, shopping centres, closed housing, former quarries, marshalling yards, cemeteries, etc</td><td></td></tr>
<tr><td rowspan="2">Natural</td><td colspan="3">Linear</td><td>Rivers</td><td rowspan="2"></td></tr>
<tr><td colspan="3">Surface</td><td>Sea, lakes, forests and mountain formations</td></tr>
<tr><td colspan="6">PSYCHOLOGICAL</td></tr>
<tr><td></td><td colspan="3">Linear & Surface</td><td>Fear of crime, experienced risk for traffic accidents, discomfort, noise, pollution, smell, dust, less attractive route.</td><td>Psychological reactions on characteristics of the barrier that deter people fwrom crossing and that are not related to longer distances or extra physical efforts.</td></tr>
<tr><td colspan="6">FORMAL</td></tr>
<tr><td rowspan="2"></td><td colspan="3" rowspan="2">Linear</td><td>Traffic Rules</td><td>Traffic lights, possibility for manually controlled traffic lights, one-way direction streets</td></tr>
<tr><td>Planning infrastructure projects</td><td>Reserves in land use planning documents, uncertainty about the impacts of planned infrastructure</td></tr>
</table>

PAPER I

van Eldijk *et al.*
European Transport Research Review (2022) 14:1
https://doi.org/10.1186/s12544-021-00517-y

European Transport Research Review

ORIGINAL PAPER

Open Access

Disentangling barrier effects of transport infrastructure: synthesising research for the practice of impact assessment

Job van Eldijk[1*], Jorge Gil[2] and Lars Marcus[2]

Abstract

Transport infrastructure such as railways, motorways and arterial roads increases regional accessibility for motorised transport but simultaneously can create barriers in local street networks that can decrease accessibility for pedestrians and cyclists. Although several tools for an objective assessment of these barrier effects have been developed, their use in practice is limited; impact assessments are instead based on subjective descriptions. This article reviews the literature on barrier effects of the last 60 years and aims to offer guidance for the use of objective methods of assessment of barrier effects. The first contribution is a conceptual model for the barrier effects of transport infrastructure and their determinants. The second contribution is an overview of tools for the assessment of barrier effects. We conclude that a multi-disciplinary approach is required, supported by the conceptual model and the overview of assessment tools. Investments in transport infrastructure can then be based on broader decision support involving not only the benefits of increasing regional accessibility but also the cost of reducing local accessibility.

Keywords: Barrier effects, Severance, Transport infrastructure, Impact assessment, Accessibility

1 Introduction

Transport infrastructure such as motorways, railways and arterial roads can improve accessibility for motorised transport on a regional and inter-urban scale but can at the same time create barriers that reduce accessibility for pedestrians and cyclists on a local scale. These barriers can create detours, reduce opportunities for social contacts, reduce access to workplaces and services, and can make active modes less attractive. Although several indicators and methods have been developed for quantifying the effects of barriers in street networks [3, 40, 104], their application in practice remains limited [8]. Research on barrier effects is also limited compared to other externalities of transport, such as noise and pollution [8].

Instead of objective assessment methods, subjective descriptions are used for the assessment of barrier effects [8], making it difficult to include in the overall assessment of transport infrastructure projects, and risking inconsistent estimation of barrier effects. This in turn may negatively affect trust between stakeholders, create social and political controversy, and cause delays to infrastructure projects [46]. Further, it creates the risk of poor and incomplete decision support concerning project alternatives, route alignments and design, which can prevent barrier effects from being solved. Incomplete and subjective assessments of barrier effects can lead to a situation where the mitigation measures turn out to be ineffective in practice or even aggravate the barrier problem [67].

Several reasons have been suggested for the limited research attention to barrier effects of transport infrastructure and the limited use of methods for their assessment in practice. The problem is described as very complex [67, 129] as it is difficult to separate barrier effects from other impacts [14]. The dissemination of knowledge of barrier effects is limited because some of the work is hidden in technical reports commissioned by public administrations

*Correspondence: job.van.eldijk@ramboll.se
[1] Ramboll Sweden AB, Gothenburg, Sweden
Full list of author information is available at the end of the article

and not indexed in academic databases [8], and is published in other languages than English.

In response, this review aims to disentangle the many factors involved in barrier effects by (1) synthesising the existing research into a simplified conceptual model of barrier effects of transport infrastructure and (2) presenting an overview of the indicators and methods that have been developed for their assessment. Further, we propose that the objective assessment of barrier effects in all its forms require a wide range of methods, techniques and indicators, rather than a single assessment method as is suggested by the reviews of Marsh and Watts [97] and Quigley and Thornley [116] and Tate.

After this introduction follows the presentation of the review methodology in section "Review methodology", and section "A conceptual model of barrier effects of transport infrastructure" offers a conceptual model for disentangling and understanding the barrier effects of transport infrastructure. Section "What are the determinants of the barrier effects of transport infrastructure?" includes a description of their determinants and in section "What are the barrier effects of transport infrastructure?" a description of the different levels of barrier effects. Section "Which tools have been developed for assessing barrier effects of transport infrastructure?" provides an overview of the indicators that have been developed for the assessment of barrier effects. The conclusion presents a reflection on the conceptual model and the assessment tools presented in the article and their implications for practice and theory.

2 Review methodology

2.1 Search and selection process

The literature searches for the review were conducted in March 2019 and complemented with an additional search in September 2020. The databases that were searched were TRID, Scopus and Web of Science. TRID was chosen as it is the largest online database for transport literature. Scopus and Web of Science were added as resources because of their extensiveness.

The following search query was used: (severance OR "barrier effect*") AND (transport* OR traffic OR highway* OR motorway* OR freeway* OR rail*). No limit was set for the year of publication. The search included all kinds of publications, such as journals and conference proceedings, research reports, governmental guidelines and books. From the search results (n = 2 267), duplicate publications and publications not related to transport or to impacts on people were excluded by reading titles and abstracts, reducing the list to 142 publications. Through searches based on the reference lists of these publications, discussions with experts, and broad searches in Google Scholar an additional 169 relevant publications were found, resulting in a total of 311 publications. Of these, 35 publications could not be retrieved, and nine were written in languages not spoken by the authors. This resulted in a final list of 267 publications, the earliest from 1961 and the most recent from 2021.

The fact that more than half of the relevant literature was not indexed in some of the largest research databases, or could not be found using general search terms, demonstrates the difficulty of getting access to material related to barrier effects. The use of English search terms to some extent limited the coverage of the literature, as this excluded research published in other languages or publications without an English abstract. 75 percent of the publications are academic articles, theses and books, 25 percent are technical reports, guidelines, policy documents and newspaper articles.

2.2 Scope and terminology

In the literature, the term 'severance' is frequently used to describe barrier effects of traffic and infrastructure, often in combination with a specification: community severance, physical severance, social severance, secondary severance or psychological severance. There appears not to exist any consensus about the definition of the term, as a review of 60 different definitions shows [4]. Further, the term presupposes the existence of a community before the introduction of a barrier, and it is also used to denote the relocation of residents and businesses for an infrastructure project, but in that case without involving a barrier [61]. The general public has been found to often conflate severance with other nuisances such as noise, pollution and perceived danger [37, 67, 75]. In some studies the term 'encroachment' is used [56, 77], which is a broad concept, including land taken for transport, visual intrusion, reduction of the usability of areas near the infrastructure due to emissions and noise, risk of accidents, and negative impacts on wildlife, as well as barrier effects. To avoid confusion, and the risk that the use of specialised terms diverts attention from more important issues [5], the term 'barrier effects' is used in this article.

The concept of 'community cohesion' occupies a central position within the research on barrier effects, as illustrated by the long tradition of the term 'community severance' [8, 28, 37, 76, 116, 141]. Community cohesion is a very broad term also relating to e.g. the values that are shared by people, which creates difficulties in separating barrier effects from other impacts and dimensions of transport in a community. We will use instead the term 'social connectedness', which can be defined as a more precise marker of community coherence [116], and is specifically related to the linkages between people, and between people and places of interaction [46] which can be affected by transport infrastructure.

Barriers created by traffic and infrastructure affect opportunities for movement and contact for wildlife in nature [123]. The majority of publications found in the initial phase of the review are related to these impacts. In this article, however, the focus is on impacts on people. Most studies describe impacts on pedestrian and bicycle traffic, but a study by Rajé [117] shows that residential areas can also be isolated by infrastructural and traffic barriers blocking car traffic. Further, the planning and design of motorways can reduce access to adjacent land use for drivers [17]. Therefore, the review is not limited to impacts on pedestrian and bicycle traffic.

Different terms are used in the literature for different categories of modes of transport, such as 'motorised/non-motorised' and 'sedentary/active travel'. With the introduction of e-scooters, e-bikes and motorised wheelchairs the borders between these categorisations have become blurred. Since differences in speed between different modes can be considered a fundamental rationale underlying the design and planning of transport systems and a central reason why barrier effects arise [67], the categorisation proposed in CROW [40] in 'fast and slow modes' is used in the article, unless a specific mode is addressed. The word 'infrastructure' is not only used to denote motorways and railways but also all other constructions built for transport purposes, including roads and tramways.

Publications that refer to barrier effects as an impact of transport or simply include barrier effects in a collection of negative impacts of transport on health, social contacts, use of the street and the environment, without specifying the role of barrier effects, were not included in this article.

3 A conceptual model of barrier effects of transport infrastructure

Barrier effects are concomitant effects of transportation systems comparable to noise, pollution and vibration. However, an important difference is that the latter three are emitted from the traffic on the system regardless of its context. In contrast, barrier effects are described as an emerged phenomenon [91] that is determined by several factors; a transport feature becomes a barrier only when it is in the way of someone on their way to somewhere. As a consequence of this multi-factor character, barrier effects cannot be assessed as an isolated externality, but require the engagement of several stakeholders and competences. This creates a need to distinguish firstly, the barrier effects from their determinants, secondly, the relations between different determinants, and thirdly, the different levels of barrier effects. To disentangle these aspects, Fig. 1 presents a conceptual model for the barrier effects of transport infrastructure, describing the determinants and levels of these effects.

Concerning the determinants of barrier effects, following Korner [87], CROW [40], Boon et al. [26] and Anciaes et al. [8], five determinants can be distinguished: (1) transport features, (2) crossing facilities and routes, (3) people's abilities, (4) land use, (5) people's needs. In order to express how the interplay between the determinants results in changes in barrier effects, relations between determinants are here described using mathematical operators. The intention with this notation is to express these relations in a concise way that broadens the perspective on barrier effects from a focus on the transport feature to inclusion of the other four determinants in an equal way. It might be possible to develop the

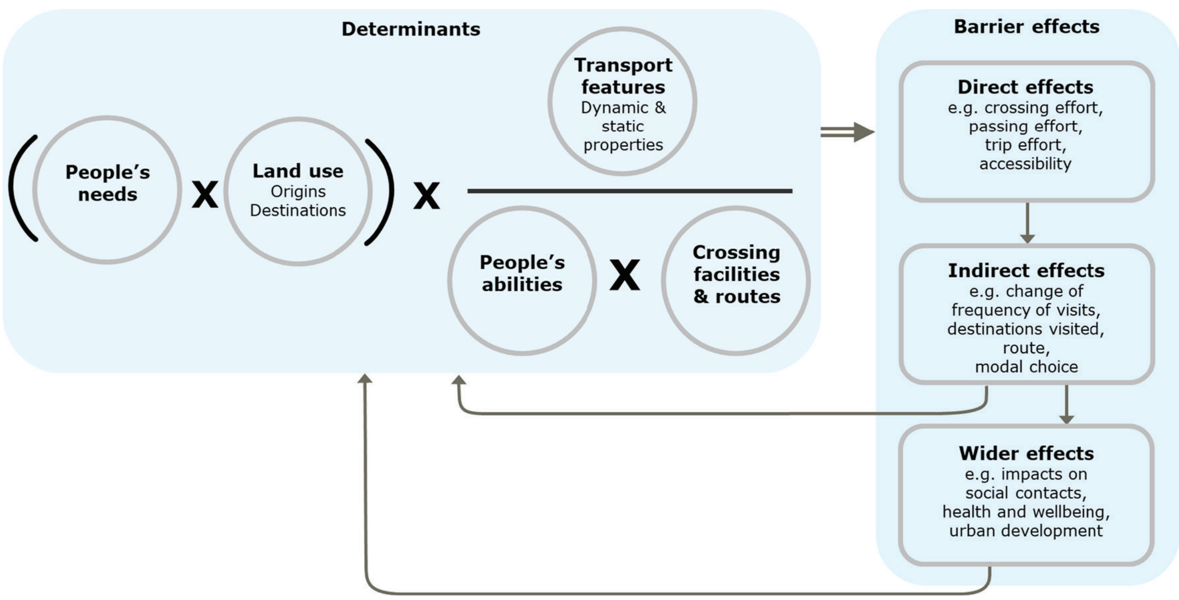

Fig. 1 Conceptual model of the barrier effects of transport infrastructure and traffic

model further into a mathematical equation, this however requires further investigation and lies outside of the scope of this review.

Some examples can demonstrate the rationale behind the relations between the determinants. Due to the intensity of traffic and the presence of physical barriers, such as fences and noise screens, a transport feature like a road can limit opportunities to cross. Therefore, in the model, an increase in the separation value of 'Transport features' leads to an increase in barrier effects. If a transport feature has no separating characteristics, for example, a footpath in a residential neighbourhood, its separation value is zero and there are no barrier effects, regardless of the values of other determinants. The impact of the separating characteristics of a transport feature can be reduced by the value of the determinant 'Crossing facilities and routes' (such as bridges, tunnels or pedestrian crossings), that create opportunities to cross. These opportunities are further determined through the position of the crossing facilities in the street network and their quality. However, if an individual's ability to cross is limited, due to age or ability, the value of 'People's abilities' is lower and barrier effects increase. For individuals who are unable to cross, the barrier effects of a transport feature become very high, no matter how few separating properties it might have. The determinant 'People's needs' defines the needs of people to reach certain destinations, whereas the determinant 'Land use' defines the need to cross due to the presence and location of destinations. These two determinants combined define the demand to cross the transport feature. For example, if children live on the same side of the railway as their school, they experience no barrier effects of the railway. If the school is relocated on the other side of the railway (a change to the determinant 'Land use'), barrier effects arise. If the number of children in the area decreases (a change to the determinant 'People's needs'), barrier effects are reduced again.

Regarding the levels of barrier effects, most authors make a distinction between direct and indirect effects. Like Mouette and Waisman [108] and Korner [87], we have chosen to further split the indirect effects into indirect and wider effects, as this allows the distinction of different areas of responsibility and competence involved in the assessment process. We therefore categorise barrier effects according to a three-level hierarchy (Fig. 1) where transport behaviour is the distinctive element: (1) direct effects: extra travel efforts that occur when a new transport feature is constructed or when the deterring characteristics of an existing transport feature changes, such as an increase in traffic; (2) Indirect effects: changes in travel behaviour when the extra efforts caused by the barrier pass the acceptance level of the individual; (3) Wider effects: impacts of the changes in travel behaviour on individuals and society at large. The model (Fig. 1) represents the role played by time, both on barrier effects and their relations with the determinants. Barrier effects can create positive and negative feedback loops in the system by impacting the determinants from which they originate [87]. An example of such a feedback loop occurs when a busy road motivates people to drive instead of walk or cycle (indirect effect). This leads to an increase in car traffic on the road (transport features determinant), affecting the crossability or passing effort (direct effect), and can lead to more people choosing to take the car and further increase of barrier effects [67].

4 What are the determinants of the barrier effects of transport infrastructure?

4.1 Transport features

Transport features are the central determinant in the process of how barrier effects arise. The attention on barrier effects has grown together with the growth in car traffic in cities, and the literature is mainly focused on the determinant role of this mode of transport. However, infrastructural barriers can be defined as all forms of transport infrastructure that reduce or remove opportunities for movement from one location to another, including railways and waterways. Based on Anciaes et al. [8], Héran [65, 67] and Korner [87], Table 1 presents the physical and psychological properties of transport features that determine their barrier effects. Also listed are separating aspects of transport features that depend on formal regulation rather than physical boundaries.

Table 1 follows the distinction between physical and psychological barriers often made in the literature. Sometimes these categories are described as "real" and "perceived" barriers [32, 58], terms that could be interpreted as a value statement. We define physical barriers as *objective* barriers, related to characteristics that exist without a person being present, and psychological barriers as *subjective* barriers, related to psychological reactions to the built environment that can vary from person to person and do not occur when no one is present. Psychological aspects of transport features are concerned with *conditions* that can lead to various psychological reactions (barrier effects of different levels, see section "What are the barrier effects of transport infrastructure?"). For example, the nuisances of traffic, such as risks of accidents, noise, pollution, dust and vibrations, can create a separating effect without physically hindering travel behaviour.

4.2 Crossing facilities and routes

The planning and quality of crossing facilities [95, 99] and of crossing routes [40, 67] further determine

Table 1 Properties of transport features that determine barrier effects

Properties	Type	Description
Physical		
Static	Motorways and feeder roads, railways, waterways	Fences, railings, noise screens, height differences (embankment, ditches), road width, traffic isles, visual conditions at crossing points [22]
Dynamic	Transversal, across a feature (car or tram traffic)	Traffic flow, traffic direction, speed, proportion of heavy vehicles, parked vehicles [8], bunching of vehicles [57], waiting time at controlled crossings [87], snow clearing
	Longitudinal, along a feature (car or tram traffic)	Traffic flow, speed, proportion of heavy vehicles, parked vehicles [67], affecting mostly bicycles [48, 67, 87]
Psychological		
Characteristics of transport features and their environment that have a deterring effect without creating a physical barrier	Conditions for fear of accidents	Experienced risk of traffic accidents occurring when crossing or travelling along a transport feature [70, 78]
	Conditions for fear of crime	Lighting, visibility, escape opportunities, social surveillance [6, 142]
	Conditions for discomfort	Noise, pollution [60, 92], dust [30], smell, vibrations, splashes, less attractive routes [40], amount of scrap on and around crossing facilities [88]
Formal		
Traffic rules		Traffic lights, possibility for manually controlled traffic lights, one-way streets [87], parental rule that a child is not allowed to cross a road [87, 130]
Planned infrastructure projects		Reserves in land use planning documents can create zones that form a barrier for transport [31, 43], uncertainty about the possible barrier effects of planned infrastructure can impact land prices and urban development [127]

opportunities to overcome barriers. Table 2 lists properties that have been identified as determining barrier effects.

The importance of the frequency and location of crossing facilities varies for different modes. For car traffic, travel time is the most defining factor. For slow modes, since they often involve muscle power, distance is a more sensitive parameter, as the numerous shortcuts and 'elephant paths' (informal footpaths trampled over time) in our cities demonstrate [40, 67]. These two principles, travel time and travel distance, combined with the need to create safe traffic environments, have led in many cities to the development of two separate traffic networks: one tree-like, hierarchical network for fast modes that allows

Table 2 Properties of crossing facilities and routes that determine barrier effects

Properties	Description
Crossing facilities	
Number of crossing points	Slow mobility modes require a higher number of crossing points than fast mobility modes [40, 67]
Height differences	Stairs and ramps leading to bridges and tunnels [6, 67]
Integration in the local street network	Connection to routes or central mobility strips [131]
Visual conditions	Lines of sight and overview at crossing points on roads [22, 87]
Conditions for fear of crime	Lighting, visibility, escape opportunities, social surveillance [6, 142]. For a further description, see section "Transport features"
Quality	Protection from weather, maintenance [6], design and cleanliness [88]
Formal regulation	Pedestrian crossings, traffic lights and possibility to manually control these [87]
Crossing routes	
Number of crossing routes	Utilitarian and recreational routes for slow mobility that cross the transport feature [40]
Connectivity of the street network	Mesh width [40]
Density of the street network	Network length per hectare or km^2 [67]
Attractivity	Planning, design, signage, cultural-historic value, level of traffic safety [6, 40]

for differentiation of speeds in connecting and distributing traffic, and one network for slow modes that is finely gridded and allows for shortcuts [67]. The superposition of these two networks in cities leads to many overlaps (longitudinal) and crossing (transversal) conflicts, the latter solved with different crossing facilities that often require extra effort, detours, or waiting for slow modes.

4.3 People's abilities

The actual impacts of the separating characteristics of a transport feature and the availability of crossing facilities and adequate routes are determined by people's abilities, related to both crossing and moving along the actual transport feature, as well as travelling across a larger area that is created for a transport feature and its safety zones. Table 3 lists some of the factors that define people's abilities to overcome barriers.

Age is identified in the literature as the dominant factor for dealing with barriers; besides being listed as a separate factor in Table 3, age is also linked to the other factors listed. Gender is another aspect often mentioned in the literature; related factors are: physical capabilities, limited or no access to a car due to the role in the household, responsibility for accompanying others, and pregnancy. A further example of how gender forms a factor is the way many parents in African cities are reluctant to let their daughters walk along major roads and unsafe paths [30].

Modes of transport determine the possibilities to move across the built environment as they give or restrict access to transport networks and spaces. The studied literature strongly focuses on barrier effects on cyclists and pedestrians, while Rajé [117] demonstrates that car traffic from residential neighbourhoods can also suffer from the barrier effects of busy roads.

4.4 Land use

Land use plays a passive role in the location and extent of barrier effects through the spatial distribution [93] and density of both residential addresses and facilities. But land use can also play an active role when the spatial distribution and density of land use changes, which can increase, decrease or relocate potential needs to cross [3, 17, 67], for example, the expansion of residential areas and the relocalisation of sports clubs or schools to the 'other side' of motorways and railways [40, 67]. Functional separation in cities also contributes to barrier effects by separating residential zones from retail, service and industry zones, which increases travel distances and creates the need to cross the transport infrastructure located between these zones [87] (Table 4).

Table 3 Factors that define people's ability to overcome barriers

Factor	Description
Age	Sensorial, cognitive and practical constraints of children and older people [35, 70, 103, 136]
Mobility restrictions	Physical and psychological capabilities [67]
	Pregnancy [67]
	Accompanying others (e.g. pram or wheelchair) [67, 108]
	Carrying luggage/shopping [67]
Mode of transport	Foot, bicycle, public transport, car [8, 117]
Limited or no access to a car	Role in the household [67]
	Environmental concern [18, 67]
	Financial restrictions [130]
Knowledge restrictions	Awareness of transport options [130]

Table 4 Aspects of land use that contribute to barrier effects

Aspect	Description
Distribution	Location of residential addresses and facilities within the area affected by a barrier [35, 67]
Density	Density of residential addresses and facilities within the area affected by a barrier [3, 42]
Quality	Differences in the quality of service or products offered on both sides of a barrier [26]
Temporal availability	Opening hours of facilities [26, 130]
Substitutability	Available choice of alternative facilities [17, 130]

Table 5 Factors that influence people's needs to visit destinations involving trips across or along a barrier

Factors	Description
Age	Averages of daily trips, e.g. to playgrounds, bus stops, services for different age groups, can be derived from travel surveys [48]
Socio-economic	Income, employment, role in the household, lifestyle orientation and preferences [83] leading to restrictions in choice of residential location, workplace, education, shopping [8, 67]
Social connectedness within the neighbourhood	The more a person is dependent on local social contacts, the stronger the need to cross a barrier if these local contacts are located on the other side [130]. In contrast, more mobile social groups are described as less sensitive to barrier effects [130]

4.5 People's needs

While the four determinants described so far all contribute to the *potential* barrier effects of a transport feature, it is through the needs of people that barrier effects are actualised [126] (Table 5). *Actual* barrier effects arise only when a person needs to visit a facility on the other side of a road that is too busy for crossing, or when a person is not able to take the stairs of a bridge over that road, or where no crossing facility is provided. The needs to visit social contacts, facilities, services and amenities vary for different groups and individuals. Boon et al. [26] distinguish three general groups of needs: self-fulfilment, social interaction and consumption. Different sets of destinations to fulfil the needs of people have been proposed, such as health, education, services, social, leisure, shops and transport [37, 46].

In impact assessments, the focus generally lies on people who are resident in the study area, but as many trips have other starting points than home, the perspective of workers and visitors in the area also needs to be considered [8, 130]. Barrier effects can also impact business and services in a different way than residents. Losing access to a supermarket will have less of a cost for a resident if a new supermarket is established within reach, however, for a supermarket the loss of customers can have significant consequences [46, 133].

As impacts cannot be assessed for each resident separately, some form of categorisation of groups must be made. Many general categorisations of people have been suggested for the assessment of effects of changes in transport systems [69, 81–83], and with a specific focus on groups that are vulnerable to barrier effects (see section "People's abilities") [37, 46, 67, 91, 119]. However, it is likely that different categorisations need to be established for the specific cultural context, type and scale of the project or situation that is being assessed.

5 What are the barrier effects of transport infrastructure?

5.1 Direct barrier effects

Direct barrier effects (Table 6) are the inconveniences that people experience and sacrifices they must make due to separating 'Transport Features'. The defining characteristic of direct barrier effects is that they occur when people keep their ordinary travel behaviour and accept the inconveniences and sacrifices, either because the level of the barrier effects does not exceed their acceptance level or because there is no alternative. Table 6 lists the direct barrier effects of traffic and transport infrastructure.

Extra effort to cross or pass along a transport feature is the primal direct effect of barriers. Fear of crime, like fear of traffic accidents, is an emotional reaction to the perceived physical and social environment [140] that can create psychological barriers (see section "Transport features"). It is therefore a type of crossing effort. Because of its complexity, it is presented here as an individual effect. Defined by a wide range of factors, on an individual, group as well as environmental level [142], it is typically related to the enclosed spaces of underpasses [6]. It involves both the direct fear of becoming a victim, which can affect travel behaviour during a trip, and anxiety about the risk of becoming a victim, which can lead to long-term changes in travel behaviour.

5.2 Indirect barrier effects

Indirect barrier effects comprise the various changes in travel behaviour that occur when direct barrier effects exceed the acceptance level of a person. These behaviour changes can relate to travel frequency, destination, route, time, or transport mode (Table 7). Acceptance levels of individuals are not fixed and can change; consequently, indirect effects can alter over time [91].

The indirect effect of mode of transport can cause a negative feedback loop where a modal shift from walking and cycling to car travel can increase car traffic on roads and increase direct barrier effects [40, 67].

5.3 Wider barrier effects

Wider barrier effects involve the impacts on individuals, groups and society at large of changed travel behaviour due a barrier. These effects involve many dimensions and aspects and are therefore hard to reduce to a concise list. Instead, we will describe some of the general groups of wider barrier effects found in the literature.

Table 6 Direct barrier effects of traffic and transport infrastructure

Effects on	Description
Crossing effort	Delays, physical effort, discomfort, stress, and fear of traffic accidents while crossing a transport feature, due to its static or dynamic barrier characteristics or the quality, design or planning of crossing routes and facilities (transversal barriers, see section "Transport features") [6]*,[18], [29], [71]*,[76]*
Passing effort	Physical effort, comfort, stress and traffic risks while passing along a traffic feature, affecting cyclists especially (longitudinal barriers, see section "Transport features"). [67, 87, 104]
Fear of crime	Fear and anxiety about becoming the victim of crime, typically related to crossing facilities [6]*
Trip effort	Extra travel time, physical effort, comfort, stress and cost for trips, e.g. to schools, workplace, facilities and social contacts. [29]*,[31]*,[39], [59]*,[76]*,[107]*,[108]*
	Detours and delays at level crossings that lead to increased travel time and reduce the reliability of service vehicles such as mail and waste collection [38, 67, 95, 111] and public transport [41]
	Change in the number of routes available to reach a destination [40, 97]
	Change of possibilities for drivers to access destinations located adjacent to a road [17], when the road is upgraded to motorway standard, possibilities to park at the roadside are removed and the number of exits are reduced
	Travel time between different parts of a farm [20]
Accessibility	Change in the available choice of opportunities within a given travel time or distance [31]*,[40], [50], [108]*
	Change of consumer base of facilities, measured as the change in the number of residents within a certain travel distance of time from a facility [17, 37, 91, 130]

* Empirically supported effect

Table 7 Indirect barrier effects of traffic and transport infrastructure

Effects on	Description
Frequency of visits	When trips take more effort due to a barrier, the frequency of visits can change or motivate people to suppress trips all together [9]*,[71]*,[96]*,[108]*
Visited destinations	Changes in accessibility can motivate people to reorient themselves regarding shops they usually visit, looking for opportunities that do not involve crossing [50, 62, 108]*
Routing of trips	Routing of trips can be changed to avoid barriers [40]
Organisation of trips	Timing and organisation of trips can be changed, with people combining different destinations in one trip [59]*, [71]*
Mode of transport	Increased distances or changed levels of traffic safety can make people change mode, typically choosing to drive instead of walk or cycle to everyday destinations [47]*,[76]*,[115]*

* Empirically supported effect

The most prominent wider barrier effect mentioned in nearly all studies and reports is the impact on social contacts and social connectedness. Important studies were carried out in the late 60 s, 70 s and 80 s by Appleyard and Lintell [12, 13], who demonstrated that people living in streets with high levels of traffic had fewer social contacts with their neighbours than people living in streets with less traffic. Also, people living on busy streets indicated that their neighbourhood was smaller than that of residents on lightly trafficked streets. The findings by Appleyard and Lintell had been previously demonstrated by Bryan [34] and have since been confirmed in several studies [27, 63, 86, 98, 125, 135, 143]. A limitation of these studies is that they analyse the combined impact of noise, pollution and traffic risks on social contacts which makes it difficult to isolate the specific impact of traffic as a barrier.

Lee and Tagg [93] studied the impacts of barriers on social contacts specifically, demonstrating that, despite what was expected and contrary to the results of Appleyard and Lintell [12, 13], the areas indicated by residents as their neighbourhood were larger in locations near a motorway than comparable locations without a motorway. Neighbourhoods near older motorways were even larger but were found to grow away from the barrier. Fewer trips across the motorway were recorded and residents also had fewer social contacts across the motorway. However, this last effect was found to diminish over time. Further, barriers can force people to choose cars rather than walking or cycling (an indirect effect, see section "People's abilities"), which reduces possibilities for social contacts and social connectedness [29, 76]. The discontinuities caused by barriers reduce the free flow of people on the street network, and can decrease diversity and mingling of people on the streets [73].

The second group of wider barrier effects that is often mentioned are impacts on health and wellbeing, even if a direct causal relationship is hard to establish [44, 102]. Negative impacts on health occur due to reduced opportunities for social contacts [25, 103, 126], for active travel [25, 80, 90, 102], and reduced accessibility to health services, to shops with healthier food products and to facilities for physical activity [25, 39, 102, 103]. Barriers can lead to feelings of being cut off, including missing the passive utility of knowing that the opportunity of access to facilities exists, for example, availability of a hospital, giving a feeling of security [130]. Busy streets can reduce possibilities for children's independent play which has been connected to reduced motor and social skills and independence of children [128], although it is unclear if the reduction in children's play is related to difficulties in crossing streets rather than to noise, pollution and traffic safety. For older people, barriers can lead to restricted freedom of movement, affecting their experience of independence and engagement in social networks, which affects physical and mental health [59, 80, 101, 126].

Barriers also have wider effects on urban development and economic activity that extend over larger temporal and geographical scales. An example are railways and stations, often playing a key role in the historic development process of cities, both attracting and generating movement as well as forming a hindrance to movement [19, 113]. Such infrastructures can disrupt the street network in the vicinity to the station, and lead to a process of degradation and concentration of poverty [23, 24]. This segregating effect of motorways and railways has also been used intentionally for the enforcement of socio-political agendas, as cases in South Africa [30] and in the US [100] demonstrate. Although no causal relations were established, different studies showed cases where barriers like motorways and major roads coincide with boundaries between ethnic groups in the US [110], between vulnerable social groups [85], and between income levels of neighbourhoods [105]. Additionally, the effect of large roads as barrier against crime has been studied, with apparent contradictory results. While some studies show no reduction in crime [114, 118], other studies show how roads and other types of barriers do contribute to reducing crime [16, 36, 144].

On a more local scale, reduced numbers of passers-by in the vicinity of transport infrastructure barriers can increase the fear of crime, and create a negative feedback loop in which more people avoid the area around infrastructure, turning it more desolate. Similarly, barriers can cause a decrease in economic activity [51, 72, 119] and a reduction in the customer base of commercial and public facilities, leading to negative impacts on their capacity and quality [46, 87, 133]. If traffic in a multi-functional street is prioritised over its function as a service centre for the surrounding area, its role as magnet for economic and social activity can disappear, leading to a decline in the number of businesses located there [38, 73, 95]. Outside of urban areas, barriers can fragment recreational areas and recreational road networks [64, 132].

6 Which tools have been developed for assessing barrier effects of transport infrastructure?

Several tools have been developed for the assessment of barrier effects of transport infrastructure, to be used individually and as part of an assessment method. The following overview is organised on the same three levels as barrier effects. Besides indicators and assessment methods, monetisation techniques have been proposed for the assessment of barrier effects. As these are not connected to a specific effect level, they are presented in a separate subsection.

6.1 Indicators of direct barrier effects

The majority of indicators that have been developed deal with direct effects. Table 8 lists the indicators of direct barrier effects found in the literature, categorised according to the effects they relate to.

A central aspect of the trip effort and accessibility indicators is the selection of destinations considered, and different sets of destinations have been proposed [37, 46]. Which destinations are of importance depends on the social and geographic context of the study area, the character and scale of the project, and the issues that are being assessed. It is important to consider that the indicators involving land use give no insight into the actual demands of people [126], that the accessibility needs of people vary, attitudes and reactions from residents can change over time [8], and that changes in transport systems can create conditions for the establishment of new services that replace old ones of lesser quality [46].

A different perspective can also be applied to the assessment, shifting focus from measuring barrier effects of a transport feature to measuring the potential improvements of alternative solutions of new crossing facilities to reduce barrier effects. An example of this can be found in Andersson et al. [11] who assessed locations for a bridge across a river by looking at increase in accessibility to workplaces and travel time savings offered by different alternatives.

6.2 Indicators of indirect barrier effects

Table 9 presents the indicators for indirect barrier effects found in the literature. Given that these effects relate to changes in travel behaviour, most indicators are based on surveys and interviews. Russell and Hine [122] emphasise that travel behaviour is based on subjective perception of

Table 8 Indicators of direct barrier effects

Effect on	Indicator	Description	Technique			
			Video observation and traffic counting	Site audits	Surveys and interviews	Geospatial analysis
Crossing effort (static characteristics)	Localisation of transport infra-structure	[21, 40, 87]				X
	Road width	Road width that needs to be crossed in meters [21, 40, 87]		X		X
	Number of lanes	[21, 40, 87]		X		X
	Hindrances along infrastructure	Fences, noise screens, etc. [21, 40, 87]		X		X
	Width of central reservation	[21, 40, 87]		X		X
	Visual conditions at crossing facility	Lines of sight at the crossing facility [21, 40, 87]		X		X
	Height differences	Bank on which the transport feature is located or if the feature is placed in a trench [21, 40, 87]		X		X
Crossing effort (dynamic characteristics)	Speed	km per hour [40, 99, 122]	X			
	Volume	Vehicles per hour [40, 99, 122]	X			
	Vehicle composition	Proportion of heavy vehicles (trucks, busses) in the total traffic flow [40, 99, 122]	X			
	Direction of traffic	Left/right [40, 99, 122]		X		X
	Distribution of acceptance gaps	Related to the grouping of passing vehicles, measured by adding reaction time, crossing time and a safety margin. It must be considered that different social groups (e.g. age groups) have different reaction times, crossing times and safety margins. [57, 58, 122]	X		X	
	Parked vehicles	Number of parked cars along a street [67, 122]		X		
	Risk of traffic accidents while crossing	Number of traffic accidents on a given stretch or point [99]	X			
Crossing effort (facilities)	Distance to a crossing facility	Distance between a street connection with the barrier and the nearest crossing facility [99]			X	
	Delay at crossing facility	Waiting time for the next opening of a railway or road crossing facility or next ferry crossing. Possibility to control traffic lights manually [40]	X		X	X
	Effort required for use of crossing facilities	Height difference to be overcome at bridges over and tunnels under the transport feature [67]		X		
	Protection from weather conditions at the crossing facility	Roofs and screens at bridges for shelter from rain and wind [6, 67, 95]		X		
Passing effort	Volume	Vehicles per hour [48, 67, 130]	X			
	Vehicles composition	Proportion of heavy vehicles (trucks, busses) in the total traffic flow [48, 67, 130]	X			
	Frequency of overtaking	Number of vehicles that overtake a cyclist [48, 67, 130]	X			
	Speed	km per hour [48, 67, 130]	X			
Fear of crime	Social surveillance	Presence of "social eyes" from entrances, windows, passers-by and surveillance cameras [142]		X		
	Escape options	Number of alternatives for exiting the crossing facility [142]		X		
	Visual conditions	Level of lighting in and around the crossing facility and area around the transport feature. Possibilities for an overview [142]		X		
Trip effort						
	Distance between crossing facilities	Distance between crossing points; benchmarks: within urban environment max 300-500 m, outside urban environments max 1,000–1,500 m [6, 9, 40, 67]				X
	Distribution of crossing facilities	Number of crossing facilities per km along the barrier [40]				X
	Number of barriers along routes	Number of barriers along existing slow mobility routes (utilitarian and recreational) weighted by e.g. attractiveness, presence of signage and its cultural heritage value [40, 64, 67, 132]				X
	Number of disconnected streets	Number of streets that are not connected due to the presence of a railway station and railway [120]				X

Table 8 (continued)

Effect on	Indicator	Description	Technique			
			Video observation and traffic counting	Site audits	Surveys and interviews	Geospatial analysis
	Detour factor	Ratio of network distance and straight-line distance between given origins and destinations [40, 66, 67]. Benchmarks for average detour ratio: 1,15–1,25 in urban areas, 1,3 in regular grids [67]				X
	Closeness	Proximity of single street segment to all other street segments within a given travel distance [23, 42]				X
	Betweenness	Frequency of street segments being part of paths with least impedance between one street segment and all other street segments [42]				X
	Isodistance	Ratio of area reachable with a given street network distance and area within the same distance measured as straight line [67]				X
	Proximity to destinations	Network distance/travel time/travel cost from each address point to the nearest facility within a given group of facilities. Also, the number of households affected by longer travel distances to a given selection of facilities can be calculated [14, 15, 138]				X
	Travel time for service vehicles	Travel time for service vehicles such as ambulances, public transport and waste collection [41, 67, 95, 138]				X
Accessibility	Catchment areas for facilities	Number of residents or households within the catchment area of each facility within a given category of facilities. Catchment areas are measured using network distances and are defined as overlapping or exclusive areas [37, 138]				X
	Choice/substitutability of destinations	Number of destinations within a given group of destination that are accessible from each address point within a given travel time. The effect of the barrier will be lower if more than one destination is accessible [50, 130, 133, 138]				X
	Accessibility to employment	Accessibility to job opportunities, measured by number of jobs or revenue of the workplace, inversely weighted by travel time [2, 76]				X
	Degree of separation	"Physical severance index" [35]. Distribution of built area (in sq.m.) and distribution of destinations on both sides of a barrier, expressed as index values. The barrier effect is highest when the built areas and destinations are equally divided on both sides, as this implies the highest level of communications that can be affected. When the built-up area and activities are on one side only, the barrier effect is lowest [35]				X
	Lost population-interaction potential	Number of potential meetings between residents from different neighbourhoods at a common facility that are affected by a barrier [3]				X
	Land use connectivity	Number of barriers that are crossed by straight lines drawn between neighbourhoods and neighbourhoods or between neighbourhoods and given destinations [2, 40, 46]				X
	Access from roads	Number of exits from a road and travel time for drivers to reach destinations directly adjacent to the road [17]				X

the physical environment, and argue, like many others [8, 26, 109, 127], for the importance of combining qualitative methods such as surveys and interviews with quantitative methods. Interviews especially are described as an important tool as some responses to barriers, such as avoiding road crossings, are impossible to observe [68].

The measurement of suppressed trips offers a challenge, as these trips do not involve behaviour that can be observed directly [68]. The demands that exist within a population can sometimes be revealed only when new services are established [126]. Tirachini [134] used general statistics of travel behaviour to estimate the probability of trips-not-made. If in a specific geographical

Table 9 Indicators of indirect barrier effects

Effect on	Indicator	Description
Frequency of visits	Ratio of changes in number of visits	Percentage of interviewees who indicate they changed the number of visits they make to destinations and social contacts or decided not to make some of these trips to avoid a barrier [9, 10, 71, 108]
	Suppressed pedestrian trips	Number of trips missing in travel behaviour statistics, relative to averages for comparable places. Missing trips can be assumed to be suppressed or that a different mode was chosen [134]
Visited destinations	Ratio of changes in destination of trips	Percentage of interviewees indicating that they changed the range of destinations they visit [108]
Routing of trips	Crossing ratio	"[N]umber of pedestrians who cross a road as a proportion of the pedestrian flow, over a given section or at a specific point" [122]. Registration through video observation
	Ratio of changed routes	Percentage of interviewees indicating that they changed their route planning [59, 71]
Organisation of trips	Ratio of changes in timing and organisation of trips	Percentage of interviewees indicating that they changed their trip timing and organisation [68]
Mode of transport	Modal share	Number of trips that, due to barriers, are made with another than the preferred mode, typically foot and bicycle [29, 47, 71]

area a certain range of short trips is missing compared to general travel behaviour statistics, it may be assumed that these trips are either suppressed or that a different mode was chosen. The study also estimates the probability of people travelling certain distances, defining a threshold after which the probability that people travel by bicycle or on foot drops. The crossing ratio suggested by Russell and Hine [122] allows for the measurement of effects of changes in dynamic and static characteristics of a road, for example when due to a change in the road network the traffic intensity increases. If fewer people cross a street than in comparable situations, there is a possibility that trips are being rerouted or suppressed. The large variations that exist between the character of different streets presents another challenge for this indicator.

Traffic counting at crossing facilities is a conventional approach for estimating indirect barrier effects and making prognoses regarding changes in crossing behaviour due to changes in transport features. But this approach only considers the characteristics of a transport feature and crossing facilities, and disregards the role that routes, people's abilities, land use and people's needs have in the level of barrier effects, and where they can arise. This can lead to misestimations of barrier effects and incorrect decision support regarding planning and design on new crossing facilities [31]. Another misconception is to compare the number of people using a certain crossing facility with the number of people using the transport feature [67]. As described in section "Crossing facilities and routes", slow mobility networks commonly have a spread-out distribution compared with the concentrated flow of fast mobility networks. For a fair comparison, the flows at crossing facilities should be recorded over a longer stretch of the transport feature and compared with the flow on the transport feature itself [67].

6.3 Assessment of wider effects

As described in 5.3, wider effects are generally complex, involve many factors and are often characterised by a development over time. In contrast to direct and indirect effects, few explicit indicators or methods for measuring wider effects have been described in the literature. Their assessment is instead part of broader social impact assessments of transport systems that also include the consequences of other impacts of transport, such as noise and pollution. A central challenge for the assessment of wider barrier effects is that little has been done to translate the concepts from social theory to which they relate, to practical tools for assessment [50, 52]. An example of this is the concept of 'social community', central to much of the research on barrier effects, yet one that is difficult to define objectively. This can be seen as an instance of the hindrances for including barrier effects in the objective assessment of transport infrastructure projects. Furthermore, it is difficult to aggregate the conclusions from the assessment of different types of wider barrier effects into cohesive decision support, given that these assessments often involve different types of valuation, or different scales and units.

Some approaches and methods for assessing the impacts on social contacts were found in the reviewed literature. Hine and Russell [71] and Ogilvie et al. [112] describe their approaches to performing interviews with residents regarding the social impacts of barriers for example. Similar surveys and interviews, comparing neighbourhoods with and without a motorway as a barrier were undertaken by Lee and Tagg [93]. Risks in these assessment methods are reverse causation (such as, low wellbeing causing people to experience traffic as a barrier instead of the other way round) and residual confounding (such as, poor people with low wellbeing can only afford cheaper apartments that may be located near busy roads) [9].

Changes over time in the land use and street networks around station areas have been studied using different techniques for longitudinal morphological analyses [23, 24, 113]. A method for studying correlations between residential locations of different socio-economic groups and barriers in cities is presented by King [84]. Similar studies concerning the correlation between socio-demographic characteristics of residents and the quality of the nearest railway crossing (measured as traffic volume, lighting conditions, width walkway, height differences etc.) were presented by Lara and Rodrigues da Silva [88], who repeated their study in a case of crossings over an urban motorway [89].

6.4 Monetisation

A generally accepted way of dealing with the challenges of aggregating the results of different impact assessments into decision support is monetisation, that is, representing all impacts with a unified monetary value. Table 10 lists a range of techniques for the monetisation of barrier effects that have been developed.

These monetisation methods are well established within transport investment appraisals and offer the benefit of making it possible to compare externalities of transport systems that are otherwise impossible to compare. The monetisation techniques, except for those based on estimated values and objective valuations, allow for the judgements of the general public to be included in the decision process instead of being based on expert judgements only.

Some challenges in the application of these methods can be mentioned. Estimated monetary values suffer from the problem of subjectivity [121], which goes against the very motivation for attempts at quantification and monetisation. Hedonic modelling typically does not offer understanding of the motivations behind WTP for housing or real estate. Further, it is difficult to isolate barrier effects from other factors that correlate with it, such as noise. An example is the hedonic study by Kang and Cervero [79], often cited as an example of monetisation of barrier effects. It is not clear if the increases in real estate prices presented in the study are due to the introduction of a park, or the removal of noise and other externalities, or if they are due to the removal of a motorway as a barrier. Depending on the design of the choice modelling or contingent valuation surveys, participants can find it difficult to understand the alternatives offered with regards to distance, time, speed and non-visual stimuli [119]. A more general critique of monetisation techniques is that they can lead to a focus on cost-efficiency of the project, and not on general equity for society, and that there is often a disregard of the link between ability to pay and willingness to pay [137]. However, many of these challenges are not limitations inherent to the monetisation methods but result from the way that they are applied, and different approaches have been proposed for addressing the above challenges e.g. handling equity in monetisation [1].

7 Conclusion and directions for further research

The background of this review is the trade-off that typically occurs when the increase in accessibility for motorised modes on a regional and inter-urban scale leads to a decrease in accessibility for pedestrians and cyclists on a local scale. The assessment of these barrier effects of transport infrastructure is rarely based on objective methods even though these methods do exist. The possible reasons that are mentioned for this lack is that the problem of barrier effects is complex, it is difficult to separate barrier effects from other impacts and, the dissemination of the literature on barrier effects is limited. In response to these problems, the goal of this article is to increase the knowledge base concerning barrier effects, which can offer support for practice and research for objective assessments of barrier effects.

7.1 Contributions to practice and theory

Based on a broad literature review, we have proposed a conceptual model for barrier effects of transport infrastructure and traffic (Fig. 1) that defines the relationships between the determinants of barrier effects and distinguishes different levels of barrier effects. The determinants of barrier effects are identified as 'Transport features', 'Crossing facilities and routes', 'People's abilities', 'Land use' and 'People's needs'; the effects of barriers are categorised in three levels as 'Direct effects', 'Indirect effects', and 'Wider effects'. Importantly, since effects can influence the determinants, which in turn may create new barrier effects, the two parts of the model may interact in a feedback loop. The model offers the possibility of quickly obtaining an overview of which elements in a given situation need to be taken into consideration when assessing barrier effects.

The review highlights how barrier effects are the result of a chain of events involving characteristics of transport systems, of the built environment, and of people. As a consequence, we conclude that barrier effects cannot be treated as a singular externality of transport but instead require a multidisciplinary approach. A central condition for the collaboration in this multidisciplinary approach is consensus about how different elements and aspects of barrier effects are to be named, and how they relate to each other. The proposed conceptual model can contribute to this collaboration by identifying and relating the different determinants of

Table 10 Techniques for monetisation of barrier effects

Technique	Examples	References
Estimated values	Using general estimates to assign a monetary value to a barrier effect	Flowerdew and Hammond [49], Monzon et al. [106]
Contingent valuation method (measuring Willingness To Pay (WTP) for non-market goods using bidding techniques)	Measuring WTP for avoiding a motorway	Grudemo [55], Soguel [128]
	Measuring WTP for avoiding a barrier to a recreation area	Grudemo et al. [56]
Choice modelling (measuring preferences or WTP based on choice experiments involving different combinations of characteristics of a barrier)	Measuring WTP for reducing barrier effects of different types of roads, involving characteristics related to road design, traffic intensity and crossing facilities	Anciaes and Jones [10]
	Measuring WTP for reducing barrier effects of roads	Anciaes et al. [6]
	Measuring WTP for removing a barrier between two neighbourhoods, taking into consideration amenity characteristics	Grisolía et al. [54]
	Measuring Willingness To Accept a new road that reduces access to a recreational area, using increased leisure time as a result of decreased travel time as a payment vehicle	Ivehammar [72]
Hedonic modelling (measuring WTP for different attributes of housing (e.g. view, distance to station) based on analysis of house sales)	The impacts on WTP for housing related to reductions in accessibility caused by a motorway	Broach et al. [33], Eliasson et al. [45], Ellis [46]
Objective valuations (using the value of related market goods as proxy for the cost of barrier effects)	Socio-economic costs (increase in traffic accidents, travel time, school transport, sick leave, parking costs etc.) when potential bicycle links are not realised due to barriers	Sælensminde [124]
	Time spent accompanying children to school	Tate and Mara [129]
	Monetisation of delay	Baart and Molenkamp [15], Jarlebring et al. [74]
	Multiplying the total population by the number of seconds of delay that roads and motorways imply. The resulting time is multiplied by a monetary value	van Essen et al. [139]
	Demand for crossing facilities as a decreasing function of the generalised cost of crossing (such as time to reach the crossing facility, effort of crossing)	Héran [67]

barrier effects in a non-hierarchical way. The model describes how barrier effects can be created by a transport feature and can be multiplied by both the distribution of land use over both sides of the feature as well as by the needs of people to access these land uses. The categorisation of barrier effects in direct, indirect and wider effects can further facilitate this collaboration by highlighting the different roles of different actors in the assessment process.

Further, the literature review has found a number of tools for the assessment of barrier effects, and using the conceptual model these tools were categorised and linked to the different levels of barrier effects that they address. This makes it possible to decide more quickly for which project scale and phase and for which assessment question the different indicators are most relevant. Indicators in the categories Crossing effort (dynamic characteristics) and Passing effort (Table 8) for instance, are not relevant to the assessment of a railway project.

The conceptual model and the listed indicators and methods can facilitate objective assessment of barrier effects, which in turn can enable the engagement of stakeholders such as local communities, who often lack access to the technical competence required to interpret indirect and wider barrier effects. Additionally, a multi-disciplinary and more inclusive approach increases the likeliness that measurements to mitigate barrier effects fulfil their purpose.

7.2 Further research

The article opens up several directions for potential further research. First, there is a need to extend the evidence base for barrier effects, as only seven of the twelve direct and indirect barrier effects identified in this review are supported with empirical evidence, and the majority of these studies relates to single cases. Second, further work remains regarding the development of indicators in order to cover all types of barrier effects and allow the assessment of not only the magnitude but also of the significance of barrier effects, which is the point when an effect turns into an impact.

Thirdly, in this article, we have limited the description of wider barrier effects to what has been presented in the reviewed literature. But many of these effects relate to topics, such as segregation and urban development, that have been studied extensively by other sciences, for example social sciences. A third direction of research is then, on the one hand, to relate the insights offered in those fields of research to the theories and tools of barrier effects, and on the other, to introduce the case of infrastructural barriers into these fields. The conceptual model offers a framework for enabling these inter-disciplinary research exchanges.

The fourth direction concerns the application of the indicators in practice. Transport infrastructure involves a wide range of construction types, project phases and geographical scales, from national high-speed railways to a pedestrian bridge across a road. Anciaes et al. [8] proposed a scheme how to relate these to different types of techniques and methods for the assessment of barrier effects. Further research is needed to establish how the indicators presented in the current review can be categorised in this or another suitable scheme, which can offer explicit guidance for their use in practice.

Fifthly, due to its multi-faceted character, the assessment of barrier effects can involve a multitude of analyses, which can lead to problems of readability, interpretation fatigue, and loss of overview. Further research is needed to establish how the diversity of analyses can be aggregated into comprehensible and concise decision support.

Sixthly, in the introduction we argue that the current practice of basing assessment of barrier effects on subjective descriptions can have a negative impact on the levels of trust between stakeholders. It would be valuable to study what the model and the indicators can contribute to these collaboration processes, specifically if the objective decision support that they offer can increase levels of trust between stakeholders.

Finally, we also see some theoretical implications emerging from the relation between accessibility and the conceptual model of barrier effects, which cannot be fully developed here. The five determinants of barrier effects in the conceptual model developed in this study can be aligned with the three main elements of accessibility [53]: first, 'People's abilities' and 'Peoples needs' concern the individuals that are 'Agents 'in the model of accessibility; second, 'Land use' relates to the different kinds of 'Attractions' that agents want or need to access; third, 'Transport features' and 'Crossing facilities and routes' represent the 'Impedances' that agents need to overcome to access those attractions. Framed this way, the concept of barrier effects can to some extent be said to describe the inverse of accessibility, in dealing with the *effort* of reaching, rather than the *ease* of reaching, as accessibility is described (Cervero 1996, in: [94]). In these terms, the improvement of car infrastructure can be described as commonly being aimed at decreasing the impedance (travel time) for the agents (car drivers) to access certain attractions, and increasing car accessibility. This infrastructure often introduces a barrier in accessibility systems on a local scale, increasing impedance for other modes, for instance walking, to access attractions. Since the general aim for national transport administrations concerns the optimalisation of accessibility for all members in society, it is essential to understand the way accessibility works as an inter-scalar system, where the optimisation of accessibility on one scale can lead to a sub-optimal outcome for another. There is a need for research to capture this interaction, which we hope to have contributed to. With adequate theoretical support, investments in transport infrastructure can be based on broader decision support involving not only the benefits of increasing remote accessibility but also the costs of reducing local accessibility.

Authors' contributions
JE has preformed the literature review on which the manuscript is based and has written the larger part of the text. JG and LM have supervised the research, contributed to the structure, conceptualization, and reviewed the text. All authors have read and approved the final manuscript.

Funding
Open access funding provided by Chalmers University of Technology. This work was supported by the Ramboll Foundation (Grant dated 23-12-2015), Ramboll Sweden Ltd (Grant dated 16-05-2016), InfraSweden (Grant number 2019-01150), Trafikverket (Grant Number TRV 2016/10608), and Trafikverket's Skyltfond (Grant Number 2015/84777). The funding organisations have had no involvement in the design of the study or the interpretation of the results.

Declarations

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Ramboll Sweden AB, Gothenburg, Sweden. [2]Department of Architecture and Civil Engineering, Chalmers University of Technology, Gothenburg, Sweden.

Received: 19 April 2021 Accepted: 2 November 2021
Published online: 18 January 2022

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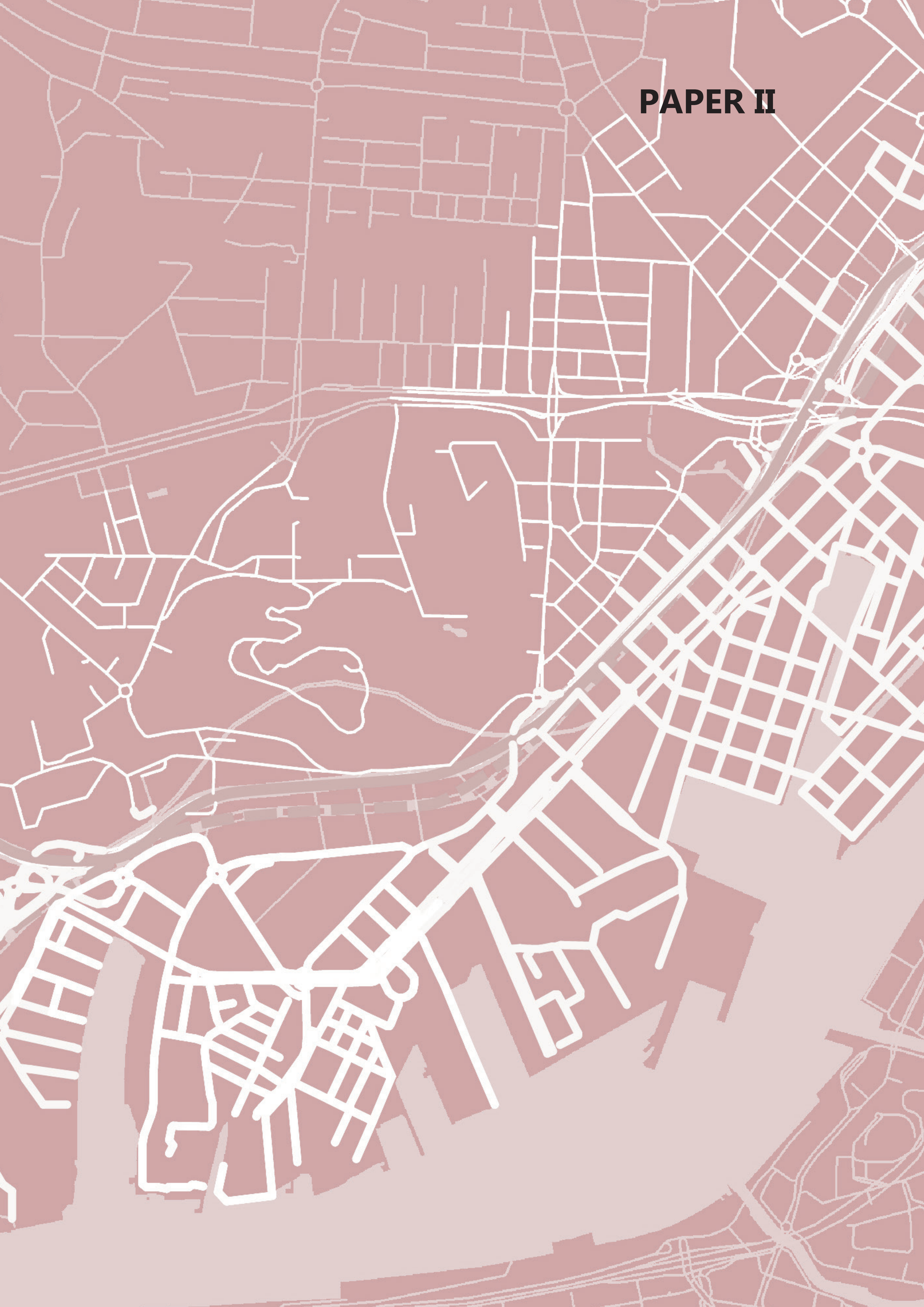
Publisher's Note

PAPER II



Transportation Research Part D 85 (2020) 102410

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Missing links – Quantifying barrier effects of transport infrastructure on local accessibility

Job van Eldijk[a,b,*], Jorge Gil[b], Natalia Kuska[a,1], Rashmita Sisinty Patro[a]

[a] *Ramboll Sweden, Vädursgatan 6, 412 50 Gothenburg, Sweden*
[b] *Chalmers University of Technology, Department of Architecture and Civil Engineering, Sven Hultins gata 6, 412 96 Gothenburg, Sweden*

ARTICLE INFO

Keywords:
Barrier effects
Transportation infrastructure
GIS
Accessibility
Indicators
Assessment methods

ABSTRACT

Transport infrastructure can create efficient connections in traffic systems, yet it can also create barriers to movement on a local scale. In transport infrastructure projects there is a need for methods to quantify these barrier effects – also called severance – to assess their impacts on social inclusion, health and viability of businesses.

This paper proposes four local accessibility indicators to measure direct barrier effects: Travel time, Choice, Catchment and Service efficiency. The indicators are tested in a case study where the consequences of placing a motorway and a railway in tunnels are assessed. The results show how local accessibility is affected in non-linear patterns.

The paper contributes to accessibility literature by introducing direct barrier effects as an applied case of local accessibility, and demonstrates the potential of those indicators to quantify barrier effects. Finally, it offers accessibility as a theoretical framework for further developing theories on barrier effects.

1. Introduction

Cities can be understood as distributions of accessibility. One of the elements that have a fundamental influence on this distribution is transport infrastructure, which can create efficient, conflict-free connections between city districts, regions and countries, but it can also create barriers to movement on a local scale. Through an intricate process of cause and effect, these barriers can have a series of negative consequences on the potential for social contacts within neighbourhoods (Bradbury et al., 2007), between neighbourhoods (Anciães, 2013), on access to facilities (Clark et al., 1991) and to workplaces (Anciães, 2011), on the conditions for economic viability of businesses (Forkenbrock and Weisbrod, 2001; Jacobs, 1961), on health (Mindell and Karlsen, 2012), and on possibilities for urban expansion (Korner, 1979). Thus, an overall increase in regional accessibility is often achieved at the expense of a drop in local accessibility for specific population groups and to specific services.

Decisions concerning investment in infrastructure projects are usually based on extensive assessments of their effects. For many of these effects, such as noise and pollution, quantitative and objective ways of measuring have been developed. As a result, specific regulations with thresholds are put in place, which create restrictions for projects, with economic and legal sanctions if not complied with. However, assessments of barrier effects are usually based on qualitative and subjective estimations (Anciães et al., 2016) in the form of "a few well-chosen words" (Tate and Mara, 1997, p227). This limits the possibility of including barrier effects in the overall

* Corresponding author at: Ramboll Sweden, Vädursgatan 6, 412 50 Gothenburg, Sweden.
E-mail addresses: job.van.eldijk@ramboll.se (J. van Eldijk), jorge.gil@chalmers.se (J. Gil), natalia.kuska@tyrens.se (N. Kuska), srap@ramboll.com (R. Sisinty Patro).
[1] Now works at Tyréns AB, Lilla Badhusgatan 2, 411 21 Gothenburg, Sweden.

https://doi.org/10.1016/j.trd.2020.102410
Received 16 October 2019; Received in revised form 26 May 2020; Accepted 26 May 2020

evaluation of effects, and creates the risk that these important negative impacts of investments in transport infrastructure are undervalued or disregarded.

By bridging the field of research on barrier effects and of accessibility, the present research aims to develop a simple method for the quantification of barrier effects of motorways and railways that can be used in the planning processes of transport infrastructure projects. Barrier effects can be conceptualised as the interplay between transport, land use and people (Korner, 1979). Direct barrier effects are the impacts created by transport infrastructure on physical access to activities for people, and opportunities for business. The concept of accessibility and its measurement seems to offer a unifying framework to both conceptualise and quantify direct barrier effects. In this article, a case study is presented, in which four local accessibility indicators are tested that have been developed to quantify direct barrier effects of transport infrastructure.

The article has the following structure. First, the theoretical background is presented, summarising a survey of technical reports, handbooks, academic studies concerning barrier effects and the current methods of measuring these, and second, how accessibility literature offers a platform for quantifying direct barrier effects. Next, four local accessibility indicators of direct barrier effects are introduced and defined. The next section describes the case study, the datasets, and the methods used for testing the proposed indicators. This is followed by a presentation of the results of the analyses. In the discussion section we reflect on the results and the potential use of the indicators in practice, and identify some limitations of the present study. In the concluding section, the findings are summarised.

2. Theoretical background

In this section, the relevant literature relating to barrier effects and their measurement, and their relation to accessibility measures is presented, which forms the theoretical background of this research.

In the literature, barrier effects of motorised traffic and transport infrastructure are often referred to as ‘severance’. The concept of severance presupposes the presence of a built environment or social community prior to the process in which the construction of infrastructure or the increase in traffic levels creates a barrier (Handy, 2003). However, in many transport infrastructure projects, there is no pre-existing urban area or community to sever. Additionally, urban redevelopment projects address situations where an existing infrastructure such as a motorway or railway already forms a barrier. Taking this into account, the term ‘barrier effects’ appears to be more suitable for the type of assessment method that we present in this study, and is the term used henceforth.

2.1. Barrier effects of transport infrastructure projects

A central starting point for the study is that barrier effects do not originate as an autonomous externality of a system, with a unit of measure of itself, like noise and pollution. Korner (1979) describes three situations in which barrier effects can arise: 1) changes in crossability, due to the construction of new infrastructure or to changes in design, or in traffic flow within the existing infrastructure; 2) changes in the ability to cross - this relates to demographic changes, such as an increase in the number of older people or children; 3) changes in the need to cross, due to the establishment of new destinations, the removal of existing destinations, or a change in the attractiveness of existing destinations.

Based on this description, barrier effects can be characterised as the result of the meeting of the properties of the transport system, the capabilities and preferences of people, and the properties of the land use system (Anciães et al., 2014; Geurs et al., 2009; Korner, 1979). The transport system includes features that form a barrier, namely, static properties such as walls and fences along motorways and railways, and dynamic properties like the flow and speed of traffic, but also the properties of the local street network in which the barrier is located. A motorway is not a barrier if there are sufficient cross-connections in the local network.

Another characteristic of barrier effects is that they can be conceived of as a chain of effects. Many descriptions of the complex causal pathway between barriers and their wider consequences for individuals and groups have been proposed (Anciães et al., 2016; Geurs et al., 2009; Korner, 1979; Marsh and Watts, 2012; Mouette and Waisman, 2004). As the present research aims to develop a method for the assessment of barrier effects for use in infrastructure planning processes, the scheme by Korner (1979) is particularly suitable. Korner arranges barrier effects into three hierarchical, consecutive levels: 1) primary effects: the direct effects of the barrier, such as loss of time and detours; 2) secondary effects: changes in travel behaviour which are caused by those primary barrier effects, such as frequency of visits, choice of destinations, mode of transport or route; 3) tertiary effects: the further consequences for society as a result of the changes in travel behaviour, for instance, liveability of streets, social interactions, commuting patterns and health. In this article, we will refer to these three levels as direct, indirect and wider effects, terms that are more commonly used within the field of transportation.

In the present study, the focus is on direct effects only, as these generally are directly related to investments in transportation infrastructure and can be more easily understood and isolated. Indirect and wider barrier effects are the subjects of other assessments in the transportation planning process, such as child impact assessments, social impact assessment and traffic assessments, and are, as such, not covered in this paper.

At the core of direct barrier effects are the increase in travel time, distance, cost and effort that a barrier can cause, along with reduced access to facilities such as education, health care, services, public transport stops, and leisure (Korner, 1979; Clark et al., 1991; Bradbury et al., 2007). Further, both choice of facilities available to people and catchment areas of facilities can be reduced (Bradbury et al., 2007; Clark et al., 1991; Korner, 1979). Accessibility to workplaces can be affected when the infrastructure, as barrier, limits communication (Anciães, 2011), but can also, as improved connection, increase access (Nimegeer et al., 2018). A further direct effect is the reduction in service efficiency of services such as freight, mail, waste collection, public transport, and emergency services (Cline, 1963; Héran, 2011).

In order for these direct barrier effects of transport infrastructure projects to be taken into account in practice, methods to quantify them are required.

2.2. Methods for quantification of barrier effects

Most of the literature on barrier effects proposes, alongside a definition and description, a method for their quantification. One of the earliest methods for assessing barrier effects was presented by the Swedish Transport Administration, Trafikverket, (introduced by Reyier, 1987 and revisited by Jarlebring et al., 2002). The method begins with calculating the magnitude of a barrier based on traffic flow, speed, and the number of trucks. Anciães et al. (2014) state that some consensus appears to exist concerning these parameters of how to define a barrier. The Trafikverket method then continues with measuring how local trips by residents are affected by a barrier, using statistics on the local travel behaviour of residents of different age groups. The extra travel time imposed by the barrier on these local trips is monetized.

One limitation of this method is that it does not consider the role of the spatial distribution of destinations, i.e. land use, and of the local street network (transport) in the extent and spatial distribution of barrier effects. Another limitation is that the consequences of barrier effects are too complex to be measured by the sole indicator of extra travel time (Quigley and Thornley, 2011). Hine remarks that a “key weakness of delay measures, treated in isolation, is that they do not refer to the deterrence of road crossings, that is, to those pedestrians who do not cross” (Hine, 1994, p. 14). A further limitation of the method is that it can only measure the delays involving crossing streets and roads at level crossings, which renders the method not applicable to motorways and railways where crossing is only possible by separating traffic flows. Indeed, the method was not used in any of the 70 assessments of infrastructure planning projects in Sweden that were reviewed for the present research. After interviews with experts at Trafikverket, the only projects that could be found where the method was tested, were two road projects, Väg 19 Förbi Degeberga (2002) and E22 Förbi Linderöd (2002). However, in the final assessments of these two projects, the results of the barrier assessments were not used (Trafikverket, 2016, 2007).

A quantification method taking spatial structure and distribution of land use into consideration was by developed by Clark et al (1991) for the British Department for Transport. This method quantifies barrier effects by estimating the number of residents for whom access to facilities is affected. Here, facilities are identified, the catchment areas for these facilities are drawn up, and the number of residents is estimated - both the total number of residents and separately the number of persons who may be considered especially vulnerable to barriers, such as older people, children, people with a disability, and people who are highly dependent on their community ties. A limitation of this method is that it describes barrier effects from the perspective of facilities only.

Forkenbrock and Weisbrod (2001) suggest that besides changes in travel time and travel costs, effects on accessibility could be measured by changes in the number of choices of destinations that are available to residents within a given travel time. Furthermore, the reduction in service efficiency for service transports has been pointed out as a barrier effect by Cline (1963).

Mindell et al. (2017) developed a set of tools for the quantification of barrier effects of busy roads. The tools measure the monetary cost of the barrier, based on Stated Preference (SP) methods. For barriers created by transportation infrastructure such as motorways and railways, being static and absolute, these tools cannot be applied. Grisolía et al. (2015) do deal with absolute barriers in a SP study in which they measure the Willingness To Pay of residents for placing a motorway in a tunnel. This study, like Mindell et al. (2017), focuses on the role of the infrastructure, but does not address the role of land use nor of the local street network in to what extent, and where, barrier effects arise.

Anciães and Jones (2020) have developed a method for valuing barrier effects in which they combine SP as well as Revealed Preference methods. This method takes aspects of the local street network and distribution of destinations into consideration, but only in regard to individual trips as reported by those responding to the survey. Further, the method appears to relate to dynamic barriers, where the possibilities to cross vary over time, rather than absolute barriers that permanently hinder cross connections.

In his study of the barrier effects of motorways, Anciães (2013) proposes ‘walking distance to facilities’ as an indicator for what he defines as ‘population-interaction potential’ between neighbourhoods on either side of the motorway. With this indicator, Anciães shows how a newly constructed motorway reduces the potential for residents from different neighbourhoods to meet, compared to the situation ten years before the motorway was built. This method does consider parts of the local street network and the distribution of destinations, and forms a central reference for the present study.

2.3. Accessibility and its measurement

The above overview of methods for quantifying direct barrier effects reveals a variety of measures proposed by different authors. Each one takes a different perspective on the concept, and has certain strengths but also leaves a number of gaps. This range of perspectives reveals the scope and diversity the problem of direct barrier effects, and calls for an integrative approach in order to combine these perspectives, and to create quantification methods that are consistent and useful for practice. A well-established unifying framework that is able to conceptualise and operationalize barrier effects can be found in accessibility and its measurement.

According to Handy and Niemeier (1997), accessibility to jobs, services and friends is the reason why people live in cities – despite congestion, high housing costs and crime. Barrier effects, by definition, can negatively affect all these qualities; hence the two concepts of accessibility and barrier effects are intrinsically linked. The three elements of barrier effects (namely, transport and traffic, land use, and people) are components of accessibility, and are mentioned by a number of authors. For example, Geurs and van Wee (2004) identify four components of accessibility: land use; transport; temporal; individual. Ferreira and Batey (2007) identify five layers of accessibility: transport networks; supply and demand; temporal; perception; institutions and culture. Beyond this conceptual alignment, accessibility can offer an operational framework for the quantitative measurement of these effects in transportation infrastructure planning projects.

Over the past two decades, a shift in transportation infrastructure planning has taken place, from a focus on mobility, i.e. the efficient movement of people and goods as a dominant performance metric and supporting motorways that promise high capacity and high speeds, to an increasing concern about accessibility (Levine et al., 2019; Straatemeier, 2008). This shift from mobility to accessibility involves adding land use in the assessments of transport projects similar to what Korner (1979) proposes in order to assess the barrier effects of those projects. As Levine et al (2012) have shown, the focus on mobility in transportation projects can lead to a reduction in accessibility as it fosters dispersed, low density land use. In recent years, national and regional transportation agencies, such as Trafikverket in Sweden, have regarded accessibility as a central policy goal (Trafikanalys, 2012). Likewise, Transport for London has developed accessibility instruments to assess the performance of the public transport system (Inayathusein and Cooper, 2018).

According to Papa et al. (2015, p57) “Accessibility instruments are a type of planning support system (PSS) designed to support integrated land use transport analysis and planning through providing explicit knowledge of the accessibility of land uses by different modes of transport at various geographical scales.” There are numerous examples of the application of accessibility instruments in transportation planning projects, but it is beyond the scope of this article to offer a comprehensive review. These are frequently used to assess and compare the accessibility of public transport projects against dominant car travel (Benenson et al., 2017, 2011; Karou and Hull, 2014) at metropolitan and regional scales.

While these types of studies support important strategic urban development goals, it is recognised that accessibility instruments need a stronger focus on local accessibility indicators (Silva and Larsson, 2018), especially in relation to transport infrastructure projects designed to improve regional accessibility. It is also necessary to provide support in the decision processes at the local scale, so as to avoid a situation where an increase in regional accessibility to jobs leads to a decrease in local accessibility. McCahill (2018) offers an example of local accessibility analysis with a focus on a diverse range of trip purposes beyond travel to work. In this respect, the assessment of direct barrier effects of transportation infrastructure projects can offer a practical context for the application of local accessibility instruments.

To summarise, accessibility instruments have a conceptual foundation that is compatible with the definitions of barrier effects, and they are well established in the quantitative measurement of transportation and land use planning projects. Local accessibility indicators can therefore offer a basis for developing an integrated set of direct barrier effect indicators, while the assessment of barrier effects offers a practical opportunity of further establishing local accessibility instruments in the transport infrastructure planning processes.

3. Local accessibility indicators of direct barrier effects

Drawing from the theoretical background, four local accessibility indicators were developed to quantify direct barrier effects: Travel time, Choice, Catchment, and Service efficiency. The indicators and their general definitions are presented in Table 1.

From an accessibility perspective (Papa et al., 2015), the indicators can be classified as spatial separation measures (Travel time and Service efficiency) and cumulative measures (Choice and Catchment). Further, the indicators consider three of the four components of accessibility as defined by Geurs and van Wee (2004): land use, transportation and the individual.

The indicators measure the local impacts of infrastructure on some of the conditions for the daily lives of the people living in the vicinity of the infrastructure. Although the focus in the present study is on pedestrian and bicycle travel, the indicators are based on general accessibility measures and are not to be considered as specific pedestrian and cyclist indicators. Rather, the parameters for each indicator (i.e. travel time budget, speed, network and facilities) can be adapted for each social group, their travel mode, and for the particular infrastructure project that is assessed. In the proposed indicators, travel time and distance are measured along the street networks, to capture small variations in local effects. Time can, in its simplest form, be calculated as a factor of distance and the average speed pertaining to a mode of travel. However, in direct barrier effects travel time can also include more detailed, non-distance-based delays, such as crossings, stairs, or traffic lights.

Table 1
Proposed direct barrier effects indicators and the measurements for their quantification.

Direct barrier effect	Indicator	Measurement	Accessibility measure
Increased travel time and distance	Travel time	Travel time from each location to the closest destination in a category.	Spatial separation
Reduction in available choices of destinations	Choice	Number of destinations in a category within a fixed travel time from each location.	Cumulative opportunities
Reduction in catchment areas for facilities	Catchment	Number of households within a fixed travel time from each facility.	Cumulative opportunities
Reduction in service efficiency	Service efficiency	Duration of public service vehicles trips (e.g. ambulances, public transport, waste collection, etc.) between public facilities and each location.	Spatial separation

3.1. Travel time

The travel time indicator refers to the effect of barriers on people's access to destinations (Clark et al., 1991; Korner, 1979; Vigar, 1999). The indicator measures the travel time $T(i)$in minutes between a location i and the closest point j in a given category of destinations using (1)

$$T(i) = \min_{j \in A} N(i, j) \tag{1}$$

where

A = a set of destinations in a category
$N(i, j)$ = shortest travel time from origin i to destination j.
i = origin location
j = point in a set of destinations

In order to capture the effect of a barrier, the situation before and after the realisation of the proposed infrastructure needs to be compared. Or, if the project involves an alteration in infrastructure, the modified and existing situations need to be compared. For Travel time, the percentage change of Travel time between the two situations is calculated.

3.2. Choice

Choice measures the number of destinations that are accessible from a location (Forkenbrock and Weisbrod, 2001; Wachs and Kumagai, 1973). Choice of destinations Chavailable to a location i within a given fixed travel time in minutes t is calculated using (2)

$$Ch(i) = \sum_{j \in A} N(i, j) \tag{2}$$

where

t = a given fixed travel time
A = the set of destinations in a category, reachable within a fixed travel time from i
$N(i, j)$ = shortest travel time from origin i to destination j
i = origin location
j = point in a set of destinations

The percentage change of Choice between the before and after situations is calculated.

3.3. Catchment

The indicator Catchment, based on the method proposed by Clark et al. (1991), measures the number of households accessible within a given travel time. It describes barrier effects in the same way as Choice but here from the perspective of each facility. Typically, categories of facilities are selected that compete in a common market, and for which travel time constitutes a factor that determines people's choices. Catchment Ca for a facility i is calculated using (3)

$$Ca(i) = \sum_{j \in A} N(i, j) \tag{3}$$

where

A = the set of households, reachable within a fixed travel time from facility i
$N(i,j)$ = shortest travel time from facility i to household j
i = origin facility
j = point in a set of households

The percentage change of Catchment between the before and after situations is calculated.

3.4. Service efficiency

The indicator Service efficiency refers to the reduction in efficiency of public services as described by Cline (1963) and Héran (2011). This indicator measures the effects of a barrier on accessibility to transportation-based public services (such as ambulances, public transport, waste collection) for residents and visitors in the vicinity of the barrier. For this indicator to capture the level of service provided at specific locations on the street network, the total travel time is calculated for journeys between the public service facilities from which the different vehicles depart (such as the ambulance central) and the facilities where they eventually arrive (the hospital emergency department) via the target locations on the street network. For the analysis, the shortest travel time in minutes S_f

(i) between location *i* and the public facility *j* of a specific type *f* (closest to *i*) is calculated using (4). The sum of $S_f(i)$ for all facility types of a given service is calculated as total travel time *SE(i)* for each target location *i* using (5).

$$S_f(i) = \min_{a \in A_f} N(i, j) \tag{4}$$

where

A = the set of public facilities (of a given type f)
f = the type of public facility (point of departure or arrival of a given service)
N(i, j) = shortest travel time from location i to public facility j
i = origin location
j = point in a set of public facilities

$$SE(i) = \sum_{f=1}^{n} S_f(i) \tag{5}$$

where

$SE(i)$ = travel time between i and closest public facility of type f
i = origin location
f = the type of public facility (departure or arrival of a given service)

The absolute change of Service efficiency between the before and after situations is calculated.

4. Case study and methods

In this section the case study is introduced, that was selected to test and demonstrate how the direct barrier effect indicators can be applied to a transport infrastructure project. Additionally, it presents a description of the Geographic Information System (GIS) models, including the data sets and tools for calculating the direct barrier effect indicators.

In the analyses, the focus is on pedestrian and bicycle traffic as these modes are affected the most by barriers. Furthermore, the political goals that have been formulated for Trafikverket (Trafikanalys, 2012) mention explicitly that infrastructure projects need to improve conditions for these modes, that the contribution to climate change by the traffic system should be reduced, and that the traffic system should contribute to improved health.

4.1. Case study

The case study is located in the north of Gothenburg, Sweden, where a four-lane motorway, Lundbyleden, and a railway track, Hamnbanan, impose substantial restrictions on the urban redevelopment of a former harbour area in the centre of the city and the surrounding areas in general. The case illustrates how developments of land use can play a role in transforming an existing infrastructure into a barrier. When Lundbyleden and Hamnbanan were constructed in 1958 and 1914 respectively, they purposefully separated an area with shipyards and other industry from the rest of the city. But over the last decades, this area has been redeveloped into a mixed-use residential area, and the existing infrastructures have become barriers to the potential benefits of these new developments to the population at large.

The city council formulated a number of policy documents expressing the ambition to unite the city as a whole and to improve its contact with Göta Älv, the river that runs through the city (Göteborgs Stad, 2012, 2009). In 2008 Trafikverket issued a pre-study (Trafikverket, 2008) in which different planning alternatives for Lundbyleden and Hamnbanan are presented that could reduce negative effects like noise, pollution, and barriers, in the surrounding areas.

The alternative assessed in this research is to place the motorway and the railway in tunnels, because this solution offers greater potential to demonstrate the barrier effect and its reduction. The reduction in barrier effects is measured by comparing this tunnel alternative with the present situation. The analyses are performed with networks on a city-scale; however, the results presented are limited to a study area of an 800-m buffer around the location of the tunnels as proposed in the pre-study by Trafikverket (2008). The choice of the study area is based on an assumption of the size of the local neighbourhood around the barrier, and it coincides with a number of existing borders in the area around Lundyleden and Hamnbanan. Within the study area, an inventory was made of all current urban and traffic projects (see Fig. 1). Some of these projects are in the early planning stages, while others are under construction. The main developments in the study area involve Backaplan (1), Frihamnen (2), Ringön (3), Karlavagnsplatsen (4) and Volvo (5). These comprise various initiatives to densify the city with housing, retail, services and offices. North of Ringön, a tram depot (6) is currently under construction. The depot is a clear example of what Anciães describes as another element besides infrastructure, that can create strong barriers in cities (Anciães, 2011). Since the site will become just as effective a barrier as the motorway and railway already are, the project is left out of the study.

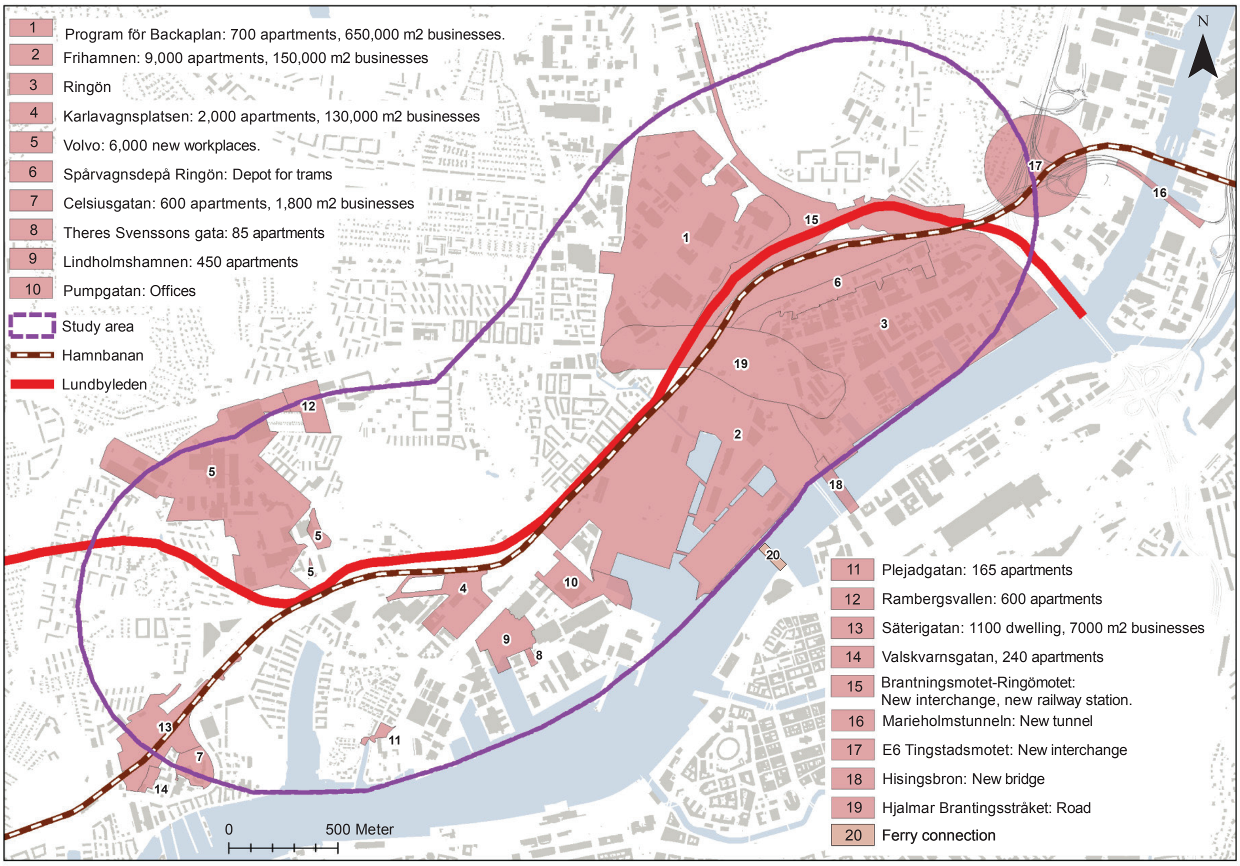


Fig. 1. Overview of study area, location of Lundbyleden and Hamnbanan, and current urban and traffic planning projects in the study area.

4.2. GIS models and datasets

In the study, two road centre line (RCL) networks of Gothenburg were used, which were developed by the Spatial Morphology Group at Chalmers (Berghauser Pont et al., 2017): one network for pedestrians and cyclists, and one for cars and heavy goods vehicles. Data sets provided by Open Street Map (OSM) and the municipality were used for data on address points and on commercial, residential and public facilities. A limitation of using OSM data is that the coverage and quality depends on the accuracy and engagement of the volunteers who create and update the data. However, the material used in the study was deemed to be of good enough quality for the purpose of demonstration. As the indicators deal with a rather uncertain situation, based on assumptions of future land use and networks, the OSM data are suitable for representing a distribution of facilities.

Facilities and other destinations were categorised in two stages. First, in 39 groups, using the Swedish Standard for Industrial Classification (SNI) (Statistics Sweden, 2007). These groups, plus destinations that fell outside of the SNI classification (such as parks and playgrounds), were then ordered according to the categories used in a travel survey by the traffic department of Gothenburg municipality (Göteborgs Stad, 2015): Work and study; Schools; Day care; Shopping; Training and recreation; Other (Table 2).

In addition to existing data, all the proposed new street and bridge/ferry connections were added to the two RCL networks of Gothenburg (Fig. 2). Further, all proposed new housing and commercial and public service projects inside the case study area (Fig. 1) were added to the GIS model. These projects encompass a total of 14,340 apartments and approximately 938,800 square m of floor space for retail, offices and services. Adding these future connections, residences and destinations allows for a more accurate assessment of the long-term barrier effects of the two scenarios.

Table 2
Categorisation of destinations based on RVU 2014 (Göteborg Stad, 2015).

RVU Category	Type of destination
Work and study	Workplaces, higher education (universities, professional)
Schools	Primary and secondary education
Day care	Pre-primary education
Shopping	Retail
Training and recreation	Sport centres, swimming pools, parks, nature areas, quays
Other	Health care, public services, commercial services, culture, restaurants, bars, leisure, religion

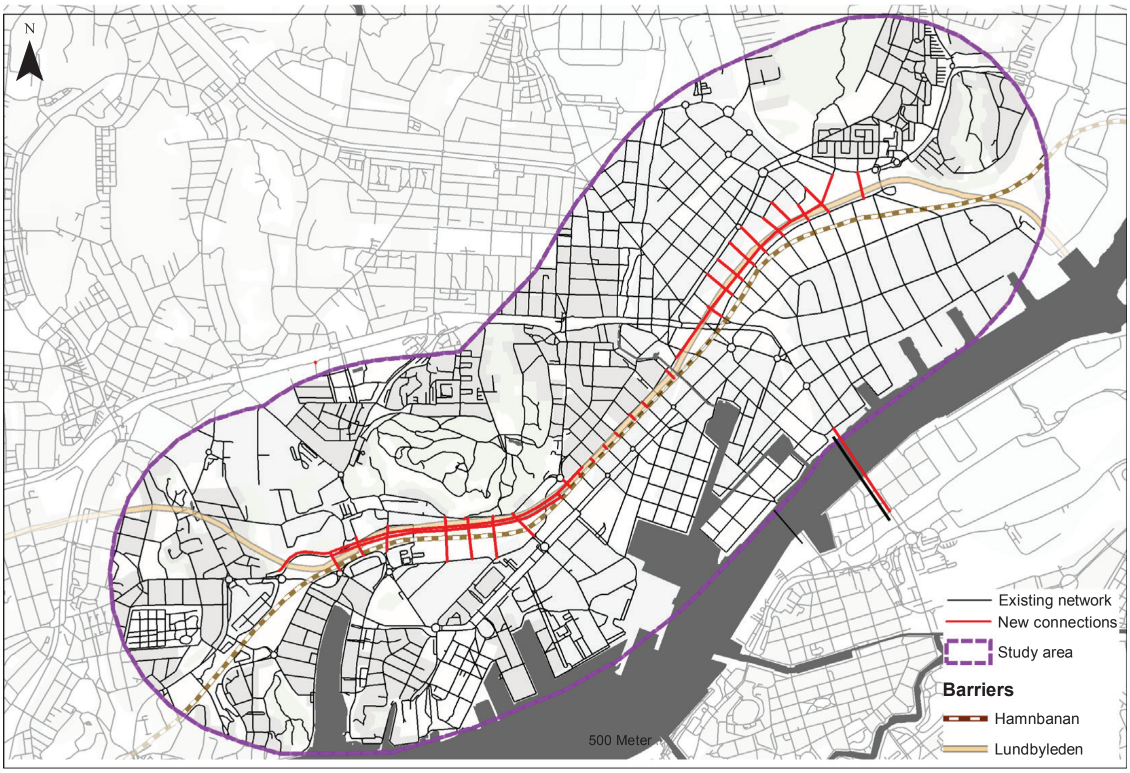


Fig. 2. The new connections in the tunnel alternative (red) in the road centre line network for pedestrian and bicycle traffic (Berghauser Pont et al., 2017).

Two versions were made of each of the two street network models, one of before, and one of after the transport infrastructure change. To model the tunnel scenario, the RCL networks were adapted: new connections were added to the existing urban structure and proposed urban development project, across the site of the motorway and railway, increasing the number of cross-connections from 8 to 36 (Fig. 2). Further, two longitudinal connections were added, representing a street located on the site of a former motorway and railway. The same datasets of locations of residences and locations of facilities and services were added to all four models. The GIS model data preparation was carried out in QGIS 2.18[2].

4.3. Indicator calculations

The four local accessibility indicators of direct barrier effects were calculated using the GIS model described above and a combination of different GIS tools, applied to two scenarios in the study area, namely the present situation and the tunnel alternative (Fig. 2). As the focus of this study is on demonstrating their potential, the indicators have not been adapted for any specific social groups, but are instead based on general assumptions of the needs, wishes and capabilities of people. While the results are reported only for the study area, that is, the 800 m buffer around the infrastructure project, the calculations take into account the complete GIS model of the city of Gothenburg. In all indicators (Sections 3.1 to 3.4), the midpoints of the street segments of the RCL network are used as locations. By using street segments instead of residential addresses, the analyses present the potential of different urban spaces, regardless of their present use. Another argument in favour of using street segments as locations, is that it includes all trips, not only those that start from home.

For the calculation of Travel time (Section 3.1), the tool Attraction Distance from the Place Syntax Tool[3]-plugin (PST) for QGIS version 2.18 was used (Marcus et al., 2019; Ståhle et al., 2005). Travel time was calculated separately for the destinations in RVU categories Schools, Day care, Shopping, and Training and recreation, using the pedestrian and cyclist RCL network.

For the calculations of Choice (Section 3.2), Attraction Reach from PST was used, taking into account the destinations within a 10-minute travel time frame by bicycle from each origin, which is considered to be a typical cycling time. Choice was calculated separately for the destinations in RVU categories Schools, Day care, Shopping, and Training and recreation, using the pedestrian and cyclist RCL network.

For the calculations of Catchment (Section 3.3), Attraction Reach was used, taking into account households within a 10-minute travel time by bicycle from each facility. Catchment was calculated for the facilities of type Day care centres, fast food restaurants,

[2] https://www.qgis.org/en/site/.
[3] https://www.smog.chalmers.se/pst.

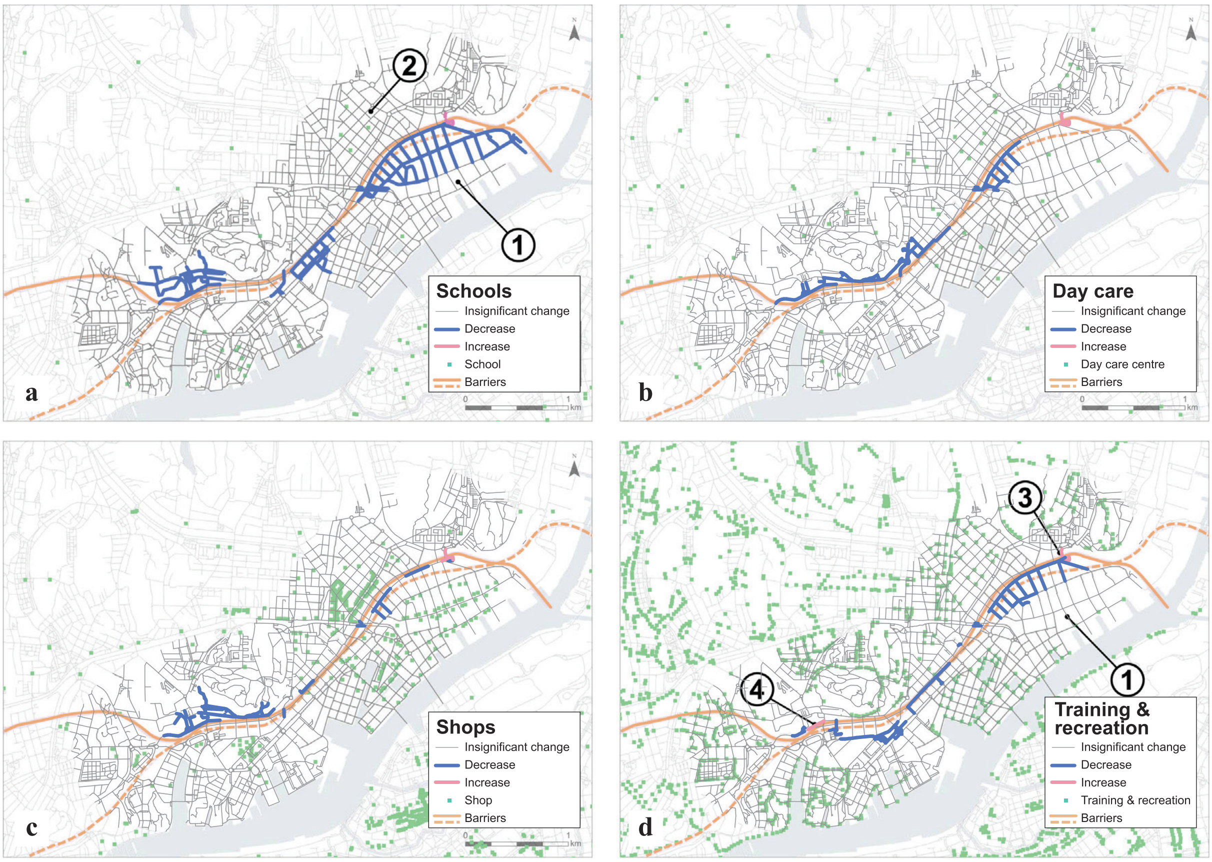


Fig. 3. Change in travel time between street segments and destinations in the tunnel alternative. For blue segments the travel time decreases, for pink segments it increases, and for grey segments there is no significant change. (1) Ringön; (2) Backaplan; (3) & (4) street segments where travel time to destinations increases due to changes in street layout following the tunnel construction.

sport centres and playgrounds, using the pedestrian and cyclist RCL network.

In the calculation of Service efficiency (Section 3.4) the RCL network for cars and trucks is used, instead of the pedestrian and cyclist network. In this indicator, the travel time of health emergency services is calculated as an example, using the ambulance stations as departure facilities and the hospital emergency departments as arrival facilities. Also, for the calculation of Service efficiency, Attraction Reach was used.

5. Results

In this section, the results of applying the four indicators described in Section 3 to the tunnel scenario (Fig. 2) are presented in a series of maps.

5.1. Change in travel time

Travel time to Shops (Fig. 3c) and to Day care (Fig. 3b) destinations are the least affected by the barriers as there are many such destinations spread relatively evenly across the whole city. Therefore, effects on travel time to these destinations are concentrated in areas in the direct vicinity of the barriers. Schools (Fig. 3a) are an exception, as there are fewer schools overall and none are planned for Ringön (1). Therefore, travel time to these destinations increases significantly when new streets connect the north of Ringön to Backaplan (2) where four new schools are planned. Also, there are few Training and recreation destinations (Fig. 3d) in Ringön (1), which leads to an increase in travel time in a greater number of segments.

Some street segments have longer travel times to destinations in the tunnel alternative due to the fact that these segments disappear in the tunnel alternative. Connection 3 (in Fig. 3d) would be removed in the reconstruction of an interchange when the tunnels are constructed, and connection 4 in Fig. 3d) would disappear when the motorway is replaced by a street grid.

5.2. Change in Choice

The analyses of Choice show substantial differences between different destination categories and, further, that the increase in Choice does not necessarily only occur close to the barrier. Some results can be highlighted. In Backa (1), tunnels would increase

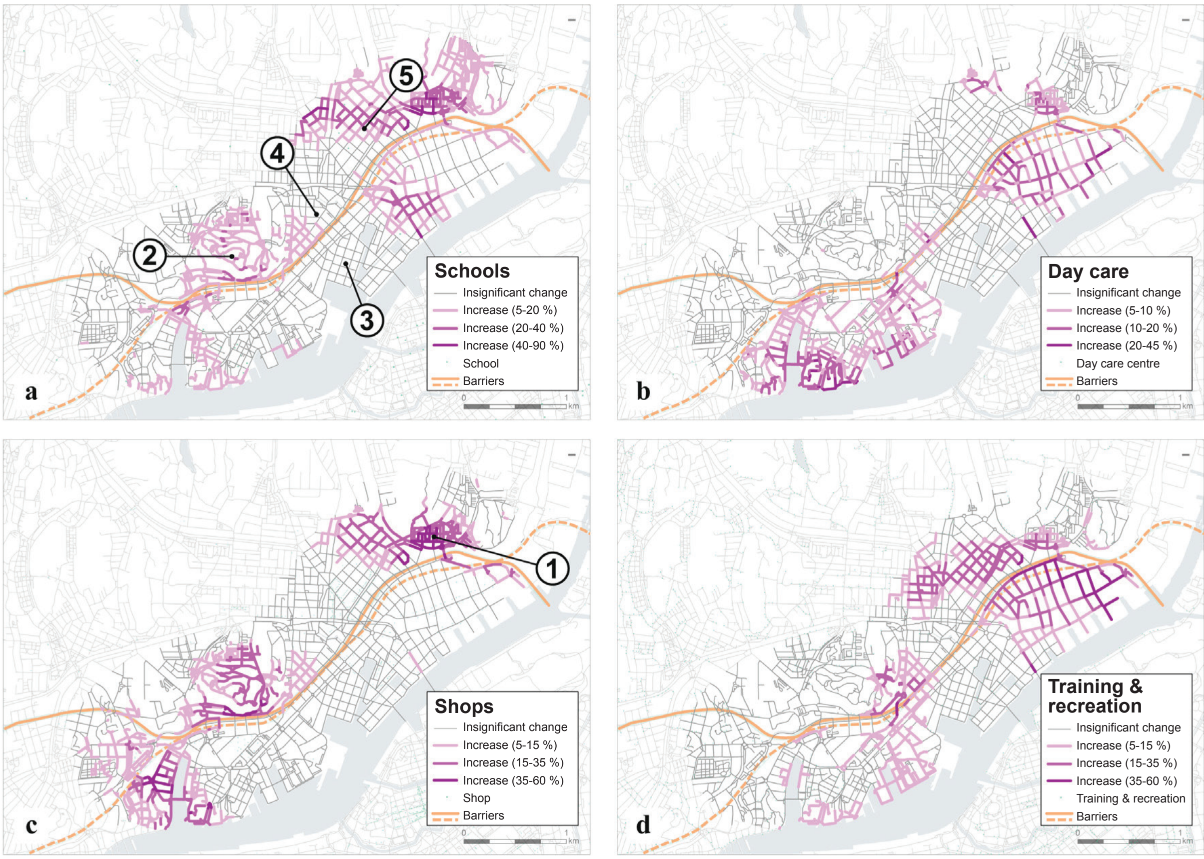


Fig. 4. Change in Choice of the number of destinations within a fixed travel time of 10 min by bicycle around each street segment. Purple to grey indicate increase in Choice in percent; for grey segments there is only minor change. (1) Backa; (2) Ramberget; (3) Frihamnen; (4) Kvillestaden; (5) Backaplan.

Choice of shops within a fixed travel time of 10 min by bicycle by as much as 60% (Fig. 4c). Backa has a high increase of Choice for all destination categories except Day care (Fig. 4b) and Training and recreation (Fig. 4d). Choice of Schools (Fig. 4a) and Shops (Fig. 4c) increases for Ramberget (2) too. It is important to know that this area is a park located on a hill with few destinations other than Training and recreation.

Another interesting result is that Frihamnen (3), Kvillestaden (4) and the southern part of Backaplan (5) show only insignificant changes in Choice for all destination categories. Although the impact that Lundbyleden and Hamnbanan have on these areas is the subject of much attention in the current planning process, it appears that this does not affect the Choice of the categories of destinations that are studied here.

5.3. Change in Catchment

The catchment area indicator describes changes in conditions for commercial and public facilities regarding, for example, economic feasibility. The analyses demonstrate that the removal of the barriers would greatly affect the catchment areas of the selected facility types, especially in Lindholmen (1) where the number of households that fall within a catchment area of a fixed travel time of 10 min by bicycle increases by 10–15% for all four categories of facilities (Fig. 5) Lindholmen is quite isolated from the rest of the city, with the river Göta to the south, harbours to the west and east, and parallel to this there are at present only six connections with the surrounding area. Again, the catchment areas of facilities located in Backaplan (2) and Frihamnen (3) show only minor increases due to the removal of the barriers.

5.4. Change in service efficiency

The Service efficiency analyses show that removing the barriers leads to a decrease in trip times for ambulances for the whole of the western part of the study area (Fig. 6). Based on an average speed of 50 km/h, this decrease can be as much as 1.92 min in Lindholmen (1). This could imply a considerable time reduction, since a reduction of 1.92 min in travelling through the city also reduces the risk of delays due to traffic congestion. Even a reduction in response time of ambulances of only a few minutes can have considerable impact on the chance of surviving a cardiac arrest, as a German study shows (Bürger et al., 2018).

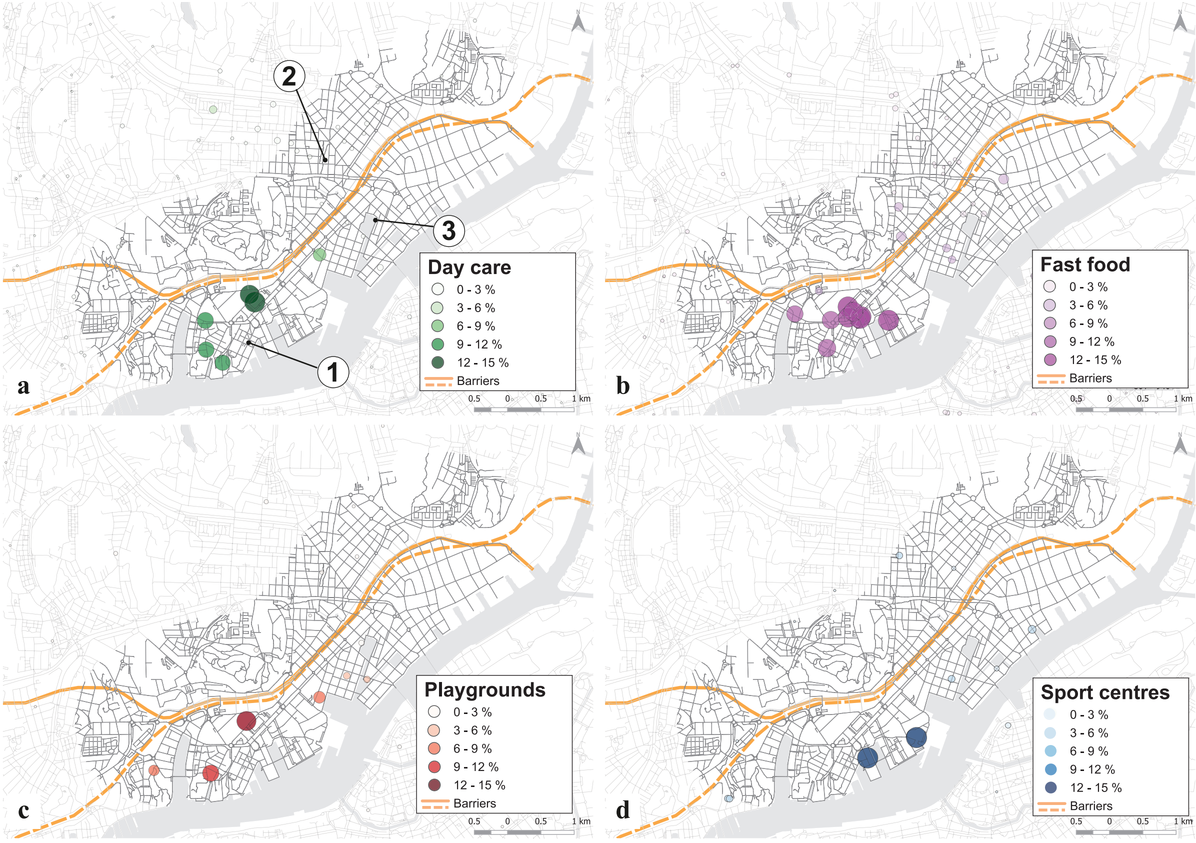


Fig. 5. Change in Catchment, showing the increase of households that fall within the catchment area around each facility (fixed travel time 10 min by bicycle).

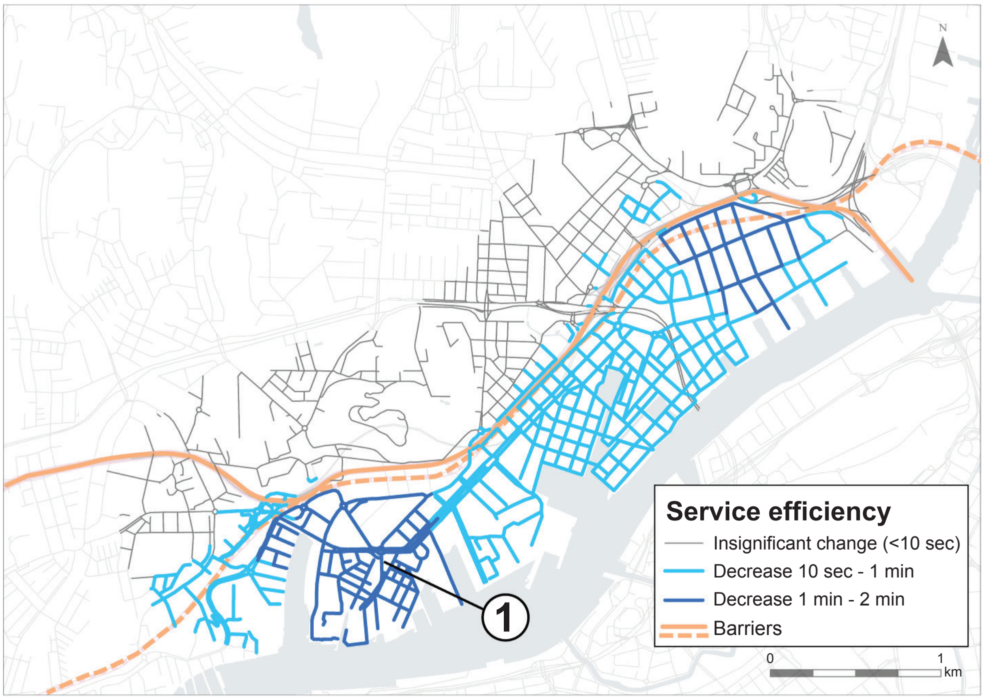


Fig. 6. Change in Service efficiency for ambulance transports. Decrease in blue, insignificant changes (< 10 sec) in grey.

6. Discussion

The results presented in this paper demonstrate the potential of the proposed local accessibility indicators to quantify the levels of direct barrier effects and their spatial distribution. The results show how these effects can be unevenly distributed rather than spread in a linear way along and from the barriers outward. This demonstrates that the indicators have the potential to offer useful information concerning the mapping of the distribution of direct barrier effects – information that cannot be obtained through aggregate calculations of average travel times between the origins and destinations of a study area. This uneven spatial distribution of barrier effects can be observed, for instance, in the central urban area around Backaplan and Frihamnen (for instance, see Fig. 4a at (3) and (4)), where barrier effects do not appear to be as extensive as expected. These results can offer useful information for the planning process of an urban area, and allow an objective assessment of the types of, and exact locations of, the different barrier effects of the transportation infrastructure.

The proposed barrier effect indicators aim to meet the criteria defined by Geurs and Van Wee (2004) for accessibility measures, stating that they should consider four components: land use, transportation, temporal, individual; should be easy to use; should be easy to understand; should show social and economic opportunities for individuals; and should show economic effects. Looking at the proposed indicators, we can observe that they take three of the four components into consideration (see Section 3). The temporal and individual component will be the subject of further research within this project. Analysis of the social and economic opportunities for individuals will require tailoring the indicators to different social groups, while further valuation of the social and economic impacts of these opportunities for individuals will require further research. The ease of use and of understanding of the indicators will require further assessment, but some first considerations on their usage are pointed out below.

In the development of the indicators, the aim has been to cover all the direct barrier effects identified in the literature: increased travel time (Section 3.1), reduction in available choice of destinations (Section 3.2); reduction in catchment areas for facilities (Section 3.3); reduction in service efficiency (Section 3.4). The indicators can also be used as input for a range of assessments of indirect and wider barrier effects, such as child impact assessments, social impact assessments and traffic assessments, offering the quantification of relevant aspects that at present are difficult to measure in a precise way (Forkenbrock et al., 2001). The indicator Travel time, for instance, measures one of the basic factors of accessibility that is fundamental for modal choice, an indirect barrier effect. Modal choice in turn is a key metric for a range of wider effects of barriers such as emission levels and health (Mindell and Karlsen, 2012). The indicator Choice can be used to assess 'trips-not-made', an important indirect barrier effect that is generally not included or undervalued in assessments of transport projects (Rajé, 2007).

Which indicators and which categories of destinations are most relevant for a specific assessment, needs to be determined in relation to the social groups, the research question, and the policy goals that are the focus of that assessment. This can yield a smaller or larger number of maps and results than presented here. Accessibility literature acknowledges the need for simplification if accessibility instruments are to be successfully applied to practice (Papa et al., 2015; Te Brömmelstroet and Bertolini, 2010). Despite the obvious potential for accessibility measures in spatial planning, many accessibility instruments suffer from a dilemma between rigour, i.e. the assessments are exact and complete, and relevance, i.e. the process and results are easy to understand and have meaning for planning decisions. For the general usability of direct barrier effect indicators in practice, which is an important aspect but outside the scope of this study, the indicators can be aggregated with each other into indices, or spatially, for example by using averages, to reduce the complexity of the output. This aggregation may lead to the disappearance of detail, eventually masking extreme cases, which might not be ethically acceptable. Such a complex and principal problem affects any set of indicators and is not specific to the indicator framework here developed.

6.1. Limitations

The limitations of the proposed indicators should be mentioned. A first limitation is that changes in Travel time, Choice and Catchment are measured in percentages, to make it possible to compare the results for different locations. This allows for an indication of the significance of the changes: for example, a 2-minute reduction on a 4-minute trip has more impact than a 2-minute reduction on a 20-minute trip. However, for short travel times, using percentage change can give misleading results; for example, a 100% increase on 2 min travel time is a very large increase in percentage, but only a small increase of 2 min in absolute terms. Further, describing change in percentages ignores the fact that certain benefits do not increase in a linear way. To illustrate: it is not immediately obvious that having access to eight schools is two times better than having access to four schools, and four times better than having access to two schools. It is therefore important to interpret the results as indications of the changes in conditions in the city as implied by the removal of the barriers.

A second limitation is that the indicators disregard the important role of the amenity value of mitigation measures, a subject studied by Grisolía et al. (2015), that is, the quality and comfort of the connections. In this case study, that is best noted in Frihamnen where the results for all indicators are rather low. This could be partly due to the high number of facilities planned for the area and the proposed ferry connection to the inner city, which would make connections across the motorway and railway less important. But the high accessibility results in the existing situation, without tunnels, is presumably due to the existence of a footbridge across the transport infrastructure. This footbridge is not accessible for bicycles and its comfort of use for pedestrians may be questioned. The amenity value of the connections could be dealt with in the analyses by using different networks for pedestrians and for bicycles, or by introducing a system of penalties in the model related to their quality, comfort or safety.

It should be mentioned that the tunnel scenario was chosen for this study as it is the clearest in terms of showing the effects of the barriers. However, there are other, less expensive alternatives to reduce barrier effects, such as constructing bridges that enable cross connections. The extent to which these measures can mitigate barrier effects can then also be assessed with the proposed indicators.

6.2. Next steps

As the case study focused on demonstrating the potential of the indicators, the parameters used in the analyses were based on general assumptions about the wishes, needs, and capabilities of the general population of the area, rather than those of specific social groups. This aspect needs to be further developed because barriers affect individuals in different ways, as several authors point out (Clark et al., 1991; Mindell et al., 2011; Nimegeer et al., 2018). Further research is still needed regarding adapting the indicators to specific social groups, and to explicitly address their needs, wishes and capabilities. The focus should be on adapting the parameters of the proposed indicators to analyse the effects of barriers, taking into account the different conditions such as destinations, travel times, and modes, pertinent to different social groups. At the same time, it is important to take into account possible future demographic changes, since the aim is to have a method for decision support of transport infrastructure interventions to be executed in ten or twenty years' time, when the composition of the population may have changed considerably.

Based on Papa's classification (Papa et al., 2015), the proposed set of local accessibility indicators for direct barrier effects can be defined as a multiple planning orientated instrument, relating to both transport and land use, and a passive decision support (PDS), in the sense that it "aids the process of decision making but cannot identify explicit decisions, suggestions, or solutions (Papa et al., 2015, p.62). For the application of this instrument in practice, it will be important to test the indicators in real-life projects to determine the advantages and drawbacks of the metrics, and in which phase of the evaluation and process of developing alternatives they are of most use. In dialogue with practitioners, it can then be determined how best these analyses of direct barrier effects can contribute quantitative support for assessments related to indirect and wider barrier effects, such as child impact assessments and traffic assessments.

Another essential step towards a method for the assessment of barrier effects, which is the final goal of the research project, is the formulation of principles for the valuation of barrier effects. One option for this valuation is monetization; Anciães and Jones (2020) have developed new tools for the monetization of the barrier effects of dynamic barriers based on stated preference and revealed preference techniques). Another possible option for valuation is to measure the extent to which an investment in transportation infrastructure increases or reduces conditions for reaching given political goals.

7. Conclusions

The purpose of this paper was to introduce direct barrier effects of transportation infrastructure as a theoretical and practical case within the research field of accessibility, and to demonstrate how these barrier effects can be quantified with simple local accessibility indicators, which addresses a current need from practice. The literature on barrier effects points to the need for taking the transport system, people's abilities and needs, and the land use system into consideration, three aspects that are conceptually aligned with the components of accessibility. From the literature, barrier effects are categorised into direct, indirect and wider effects, where direct effects are detours and time loss. Based on the direct barrier effects identified in the literature, four local accessibility indicators were proposed: Travel time, Choice, Catchment and Service efficiency. As the research project is focused on applicability to the assessment of transport infrastructure projects, the indicators are based on relatively simple measures that should be easy to implement and understand. In the case study, the indicators have demonstrated their potential to quantify direct barrier effects and to capture the spatial distribution of these effects. As a result, the indicators can give valuable input for assessments of indirect and wider barrier effects. For example, the indicator Choice allows for the estimation of trips-not-made, which can provide quantitative support for social impact assessments of transportation investments.

The existing accessibility literature explains how the present-day focus on optimising mobility can lead to low density sprawl which can reduce accessibility. This study complements this literature by demonstrating how the focus on mobility can even lead to a reduction of accessibility in situations where there is a relatively high density of buildings and a geographically close proximity to destinations. Further, it shows how the concept of accessibility can provide a suitable theoretical framework to the existing theories of barrier effects, and how these effects can be quantified with simple accessibility indicators.

The proposed indicators represent the beginning of the development of a quantification method for assessing direct barrier effects of transport infrastructure projects that can give objective information about the effects of barriers, allowing for better informed decision-making processes concerning investments in infrastructure. In consequence, measures to reduce barrier effects could be prioritised. Such reductions in barrier effects can have far-reaching societal impacts, from an increase in accessibility to destinations and a reduction in social segregation, to an increase in the potential for active travel such as walking and cycling, thereby improving health. Furthermore, a quantification method can improve equity and efficiency in negotiations about infrastructure projects, by providing local stakeholders such as municipalities and local communities with objective data to underpin their arguments.

CRediT authorship contribution statement

Job van Eldijk: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration, Funding acquisition. **Jorge Gil:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing, Supervision, Project administration. **Natalia Kuska:** Formal analysis, Investigation, Data curation, Visualization. **Rashmita Sisinty Patro:** Formal analysis, Visualization.

Acknowledgements

Funding: This work was supported by the Ramboll Foundation (grant dated 23-12-2015), Ramboll Sweden Ltd (grant dated 16-05-2016), InfraSweden (grant number 2019-01150), Trafikverket (grant number TRV 2016/10608), and Trafikverket's Skyltfond (grant number 2015/84777). The funding organisations have had no involvement in the design of the study or the interpretation of the results. The authors would like to thank Lars Nilsson and Lars Marcus for their guidance during the study, Karin Wogelius for creating the base maps of the study area, Oskar Sköld for assessing 70 Swedish infrastructure plans and Elien Groot for copy editing. Lastly, the authors would like to thank the two anonymous reviewers for their valuable comments on the early versions of this article.

Declaration of Competing Interest

None.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trd.2020.102410.

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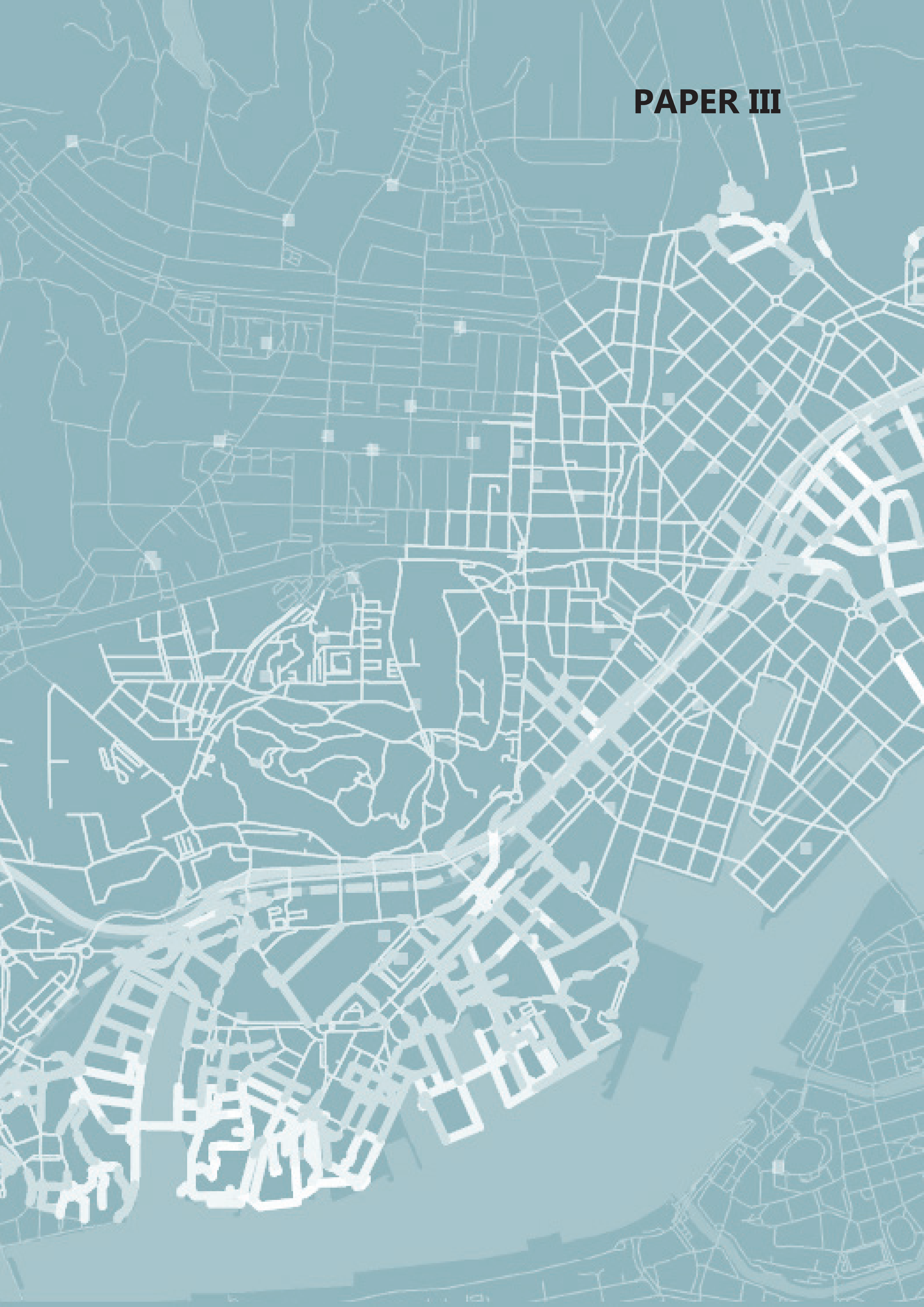
PAPER III



IOP Conf. Series: Earth and Environmental Science **588** (2020) 022071 doi:10.1088/1755-1315/588/2/022071

The social dimension of barrier effects of transport infrastructure

J van Eldijk [1] and J Gil [2]

[1] Ramboll Sweden, Vädursgatan 6, 402027 Göteborg, Sweden
[2] Chalmers University of Technology, Sven Hultins gata 6, 412 96 Göteborg, Sweden

job.van.eldijk@ramboll.se

Abstract. Motorways and railways increase regional accessibility but can at the same time reduce local accessibility by creating barriers in pedestrian and bicycle networks. This can influence several SDGs, such as SDG 5 (gender equality), 10 (reduced inequalities), and 11 (sustainable cities and communities). This paper presents some first principles of how quantitative indicators of direct barrier effects can be adapted in order to address specific social groups. To demonstrate this, the indicator 'Choice', from a set of four indicators previously developed, was adapted to assess accessibility by children to parks, and waterside and leisure facilities. The indicator was applied to a case in Gothenburg, Sweden, where a GIS-based analysis measured changes in barrier effects brought about by hypothetically placing an existing motorway and railway in tunnels. The results demonstrate how such local accessibility indicators can be adapted to make them relevant for impact assessments of infrastructure projects, and thus enable the measurement of compliance with social sustainability targets in transportation infrastructure planning.

1. Introduction

Transport infrastructure such as motorways and railways are built to create effective connections on a metropolitan and regional scale but can at the same time create barriers in local pedestrian and bicycle networks (severance) and reduce local accessibility. These barriers affect three SDGs in particular. Conditions for gender equality (SDG 5) are reduced as women in many countries, including Sweden [1], have less access to a private car, which allows an individual to have access to the car road network and overcome the barriers. The impact of this condition is aggravated by the fact that women bare a larger part of the responsibility for household and childcare then men. These responsibilities typically require accesses to local services. Infrastructural barriers divide cities into spatially segregated neighbourhoods and districts and can lead to social segregation that impacts possibilities to reduce inequalities (SDG 10). The spatial fragmentation caused by infrastructure has been shown to correlate with ethnic segregation on the level of residential areas [2] and can negatively affect the conditions for different societal groups to meet in public space [3,4]. Further, barriers can reduce access to jobs for poorer communities in a process referred to as spatial mismatch [5]. Barriers hinder the creation of sustainable cities and communities (SDG 11) as they limit the possibilities to build networks for bicycle and pedestrian traffic, and in turn limit possibilities to achieve a reduction of CO2 emissions through a modal shift [6].

Despite conflicting with these development goals, barrier effects of infrastructure receive little attention when impact assessments of transport investments are undertaken, and are commonly described only in broad, qualitative terms [7], which creates the risk of being undervalued or even ignored.

The quantification of barrier effects is challenging due their complex and multifaceted nature. Korner [8] describes how barrier effects arise from the meeting of the transport system; the land use system; and the wishes, needs and capabilities of people. The effects of a barrier develop in a sequential process, originating in direct effects (for example, longer travel times, or a reduction in catchment area for businesses); to indirect effects, such as change of mode of transport, of destination, of trip frequency; and to wider effects (for example, reduction in social contacts within and between neighbourhoods, or deterioration in health).

In an earlier phase of the present research, four indicators were developed, covering the four direct effects identified in the literature [9].. The parameter values used in the indicators, such as the selection of destinations and the maximum distance that people are willing to walk or cycle to reach these destinations, were chosen based on general assumptions. The aim of this paper is to present some principles for how the parameters used in the indicators can be adapted to the wishes, needs and capabilities of people.

2. Theoretical background

In addressing this issue, the question arises: What categorisation of social groups is relevant for the assessment of the interaction between people and transport in general? As assessments of the social impacts of transport are mostly focused on the distribution of the costs and benefits of the car-based traffic system, the most relevant categorisation for these assessments is to divide a population in groups of those who have access to a car and those who do not [10]. People can have no or limited access to a car due to age (too young or too old), gender, disabilities, income, or because of ethical considerations or personal preferences.

Geurs et al. [11] describe a conceptual chain for social impacts, consisting of the sequence: source – effect – impact – receptor. The focus in the first part, source – effect, is on the source, and in the second part, impact – receptor, the focus is on the receptor. An effect becomes an impact when it exceeds a defined sensitivity level of the receptor. This distinction between effect and impact is valuable for determining which types of technique are relevant for the assessment.

Relatively little has been done to develop tools to estimate social impacts [13], and it has proven especially difficult to define conceptual models and indicators to quantify theoretical concepts derived from social sciences [11]. Rajé [10] points out the experience and communication gap between users and planners and policy makers, and argues for an exploration of the "lived experience of transport structure and transport organisation." These observations indicate the importance of being aware of the limitations of categorising people in standard socio-demographic groups and ensuring that the categorisation and aggregation of the categories used are defined in relation to the impacts that are being assessed.

Another challenge for the assessment of social impacts is the complexity in the way people appropriate the spaces surrounding infrastructure. On the one hand there are clear cases like the removal of a freeway in Seoul, which unsurfaced an existing river and where a highly appreciated park was created and which has led to a clear increase of real estate prices in the surrounding area [14]. On the other hand, there are cases where, despite the problems of noise and pollution, local residents appropriate the spaces around and underneath exiting infrastructure. Lou and Ferretto [15] describe how the freedom and accessibility of these spaces allow them to function as stage for a diversity of social activities that are either not tolerated in other public spaces or that impossible due to the scarcity of space due to high density. An example of this is the Mei Foo housing district in Hong Kong, where residents have created a local market and places to meet and gather underneath the fly-over that crosses the district [15].

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For the quantification of the direct effects of barriers, four indicators have been developed by the authors [9]. Those indicators cover the four direct barrier effects that were identified in the literature: Travel time to destinations ('Travel time'); number of destinations accessible within a given distance from an origin ('Choice'); number of households within a given distance from a facility ('Catchment'); and transport efficiency of public services, such as ambulances and public transport ('Service efficiency'). The indicators are based on a Geographic Information System (GIS) model, consisting of the street network and destinations points.

3. Method

Taking into consideration the need to account for the social impacts of barrier effects on local residents, and the difficulty in quantifying them, an approach was developed to adapt the more general direct indicators of static barriers [3], to give them a social dimension that can be used to measure social impacts. This method is here demonstrated in a case study in the north of Gothenburg, where a railway track and a motorway are increasingly turning into barriers as the surrounding area is being redeveloped. 'Children' was selected as an illustrative group, and the indicator 'Choice' [9] as an example, in order to make the social dimension explicit.

Choice measures for every segment in a street network how many points from a given category of destinations can be reached within a given distance. The parameters of this indicator, which can be modified in order to address a specific social group, are: the choice of networks associated with a given travel mode; the category of destinations relevant to that particular social group; and the distance or time threshold within which destinations can be reached.

The Swedish Transport Administration, Trafikverket, is currently planning the construction of a tunnel for part of the railway in the study area; in connection with this project an assessment of the impact on children was made [17]. In the assessment, schools, playgrounds and leisure facilities were identified as important destinations for the children living in the vicinity. For the purpose of testing Choice, the selected parameters are: the street network for pedestrian and bicycle traffic; parks, places near the waterside and leisure facilities as the destination category; a travel time of 0-10 minute, which can be considered a reasonable range for children to cycle to a park or leisure facility, either independently or accompanied by an adult.

Two versions of the street network were analysed, one with infrastructural barriers and one without. The difference between these two street networks versions is that there are eight connections (bridges and tunnels) across the barriers in the network with barriers, and 36 connections in the network without them. The extra connections were added to the network based on assumptions of logical continuations of the existing street network. The dataset concerning the destinations (parks, waterside, leisure facilities) was the same in both versions. Using the analysis results of the two networks, the percent increase of accessibility to parks, waterside and leisure facilities that removing the barriers would imply, was calculated.

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4. Results

Figure 1 shows the results of the analysis of the increase in Choice of parks, waterside and leisure facilities. In large parts of the study area there is no or an insignificant increase, however in the northern part of the area (1) Choice increases up to 35 %. In Frihamnen (2), placing the road and railway in tunnels would result in insignificant changes, which is in stark contrast to the current planning debate where consensus appears to exist about the importance of removing the barriers in that area. The results show that barrier effects are distributed in an irregular way over the study area; this emphasises the complex nature of these effects, which makes them hard to predict, and important to analyse systematically and quantitatively.

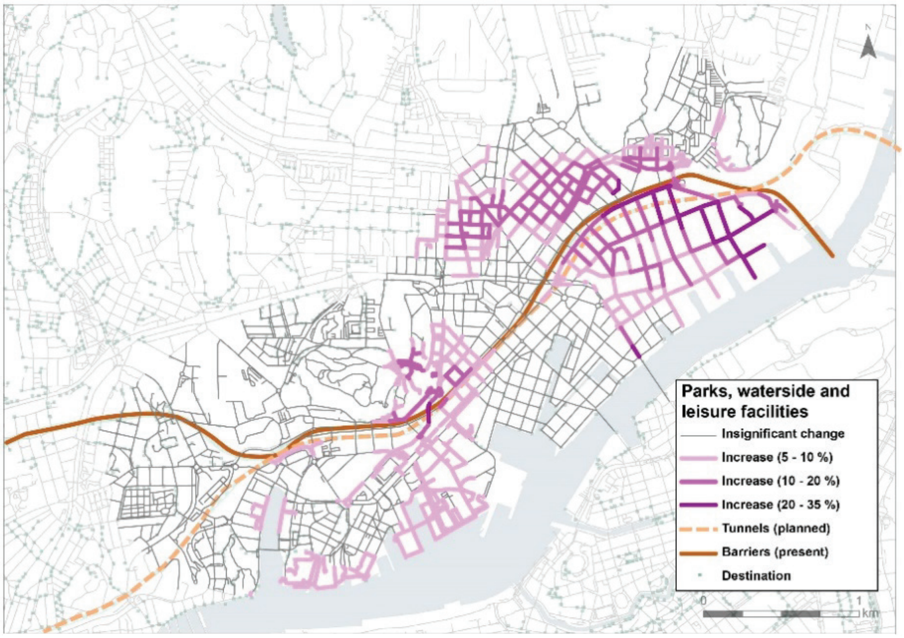

Figure 1. Increase in available choice of parks, and waterside and leisure facilities within a 10-minute travel time (bicycle) from every street segment, consequent to the removal of the barriers.

5. Discussion and conclusion

Returning to the research question – how we can make the quantitative indicators specific to different social groups – the above case illustrates that by selectively setting the three parameters (i.e. network, destinations and distance threshold) of an indicator, in this case Choice, can be adapted to address a specific social group. This makes the indicators more relevant for impact assessment of infrastructure projects and enables the measurement of compliance with social sustainability targets in transportation infrastructure planning. Also, the analysis of Choice can, for instance, be used to assess 'trips-not-made', an important social effect of transport that is not usually included in assessments, or undervalued [10]. An important aspect when setting the parameters of the indicators is choosing a relevant principle for social categorisation for each assessment, as there are no universal social categories that fit all situations and research questions. Further, it is important to use supporting evidence for choosing the parameter values (the values used here are just an example).

With the support offered by quantitative indicators, impact assessments could make it possible for different stakeholders to participate on equal terms in the planning process of infrastructure projects. Additionally, through clearer impact assessment, efforts to mitigate barrier effects can be prioritized.

Considering the groups most sensitive to barriers (children, women, older persons, people without access to a car), the networks for pedestrian and bicycle traffic are important, but also those of public transport.

One limitation of the current method is that it only considers street networks; further research is needed to incorporate public transport in the indicators. Another area that requires further exploration is the effect of the quality of connections on people's willingness to use them.

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PAPER IV


Gärstadverken
Småbåtshamn
Västergården
E4
Tornby
Mörtlö
Småbåtshamn
Kallerstad
Gravfält
Nykvarn
Fotb stadion
44
Vasastaden
Stångebro
Råberga
Tannefors
SAAB
Ramshäll
Jonsbo
Vimanshäll
Garnisonen
Johannelund

From trench war to dialogue: An action-research study of the assessment of barrier effects in a transport infrastructure project

Job van Eldijk, Ramboll Sweden AB
Anna Lundberg, Ramboll Sweden AB

Abstract

Transport infrastructure such as railways and motorways create barriers in local street networks, reducing social contacts between people and limiting their access to shops and services. To handle these barriers, a fact-based assessment of their effects is required. However, in current planning practice, the assessment of barrier effects is mostly done through general descriptions and rough estimations. This paper presents an action research based case study involving interviews with practitioners (n=22) about their experiences of the use of, and work process with, a set of barrier effect analyses in a high-speed railway project. The interviews show that the analyses created a common language and offered concrete support, which increased trust between stakeholders and made it possible to reach a consensus about a planning alternative. The use of the analyses requires interaction between practitioners and analysts throughout the work process, as the analyses and the impact assessments they provide support for are closely related. Among other findings, the importance of the street network emerged as the main variable in the analyses. There is a need to acknowledge this role and to create methods for adapting it to different planning alternatives of the infrastructure. Finally, there is a need for more case studies on the collaborative processes of barrier effect assessments, as these processes are important for enabling the transition to more socially and ecologically sustainable transport systems.

Keywords: Barrier effects, severance, transport infrastructure, collaboration, governance, impact assessment.

1 Introduction

Transport infrastructure increases accessibility on a regional scale but can also create barriers for local traffic, predominantly for pedestrians and bicyclists. These barriers can lead to reduced social contacts and decreased access to services, shops, and leisure (van Eldijk et al., 2022). Active modes such as pedestrian and bicycle transport can become less attractive, which can have a detrimental impact on health (Higgsmith et al., 2022). It can also lead to an increase in car traffic and emissions, air pollution, and noise. As the rate of urbanisation in the world accelerates and cities continue to densify, the negative effects of infrastructural barriers increase.

Although tools for quantification of these effects do exist (Anciaes et al., 2016b), in current planning practice the assessment of the effects of barriers is mostly composed of general descriptions and rough estimations. One of the reasons for their restricted use in practice is the limited dissemination of those tools (Anciaes et al., 2016b). A further challenge is that the complex, multi-faceted character of barrier effects requires collaboration between organisations and practitioners with different responsibilities and perspectives in the project (Anciaes et al., 2016a; van Eldijk et al., 2022). Additionally, the research on barrier effects is hindered by the fact that different scientific fields, such as traffic planning, public health, and urban planning, use different concepts and methods to study the problem (Anciaes et al., 2016a). In contrast, the assessments of other transport externalities such as traffic noise and air pollution, can be performed without direct engagement of the involved organisations since these assessments are based on standardised methods and on regulations concerning maximum values.

In this paper, we present an action-based case study of the assessment of barrier effects of the new high-speed railway (HSR) through the town of Linköping in Sweden, in which a new set of barrier effects analyses (BEA) were applied (van Eldijk et al., 2022). Through a series of semi-structured interviews, we studied what the practitioners from the Swedish Transport Administration (STA), their consultants, and the municipality of Linköping (ML) found that the BEA contributed to the project, and how they experienced the work process related to the BEA. The aim is to offer a deeper understanding of the process of assessing barrier effects of transport infrastructure in practice, and create conditions for improved communication and collaboration between national and local authorities and other stakeholders.

Following this introduction, we present the theoretical background of the study, with a description of the HSR project in Linköping and the research design of the study. We synthesise the results of the interviews in the discussion section. In the conclusion, we summarise the main findings, indicate the policy implications of the study and point out directions for further research.

2 Theory: Barrier effects, collaboration and governance

In this section we introduce the main theoretical perspectives of the paper, starting with a description of what barrier effects are. Then we present a conceptual model of their determinants and describe some theoretical underpinnings of the process of assessing barrier effects, followed by key points from theories on inter-organisational collaboration and governance.

2.1 Barrier effects

Rather than being emitted from transport infrastructure, such as noise and air pollution, barrier effects arise in the meeting of several components (Korner, 1979). Transport infrastructure only becomes a barrier when it is in the way of someone on their way to somewhere. Figure 1 presents the conceptual model by van Eldijk et al. (2022) of the barrier effects of transport infrastructure and its traffic, that defines five determinants of barrier effects. Transport features can create physical barriers through traffic flow and fences, as well as psychological barriers, such as fear of traffic accidents or fear of crime. Crossing facilities and street network define the physical conditions for movement across the barrier, such as the number and location of crossing facilities, height differences at the crossing and connectivity of the street network. People's abilities refers to mobility restrictions and the modes of transport that are available for a person. Land use describes how the location and quality of origins and destinations determine when the need to cross arises. Lastly, people's needs determine which destinations people want to reach, and depends on aspects such as age and socio-economic characteristics.

The model (fig. 1) distinguishes three levels of barrier effects (van Eldijk et al., 2022). Direct effects consist of the extra effort required for travel, such as detours, waiting time caused by the construction of new infrastructure, changes to existing infrastructure, and increased levels of traffic. Indirect

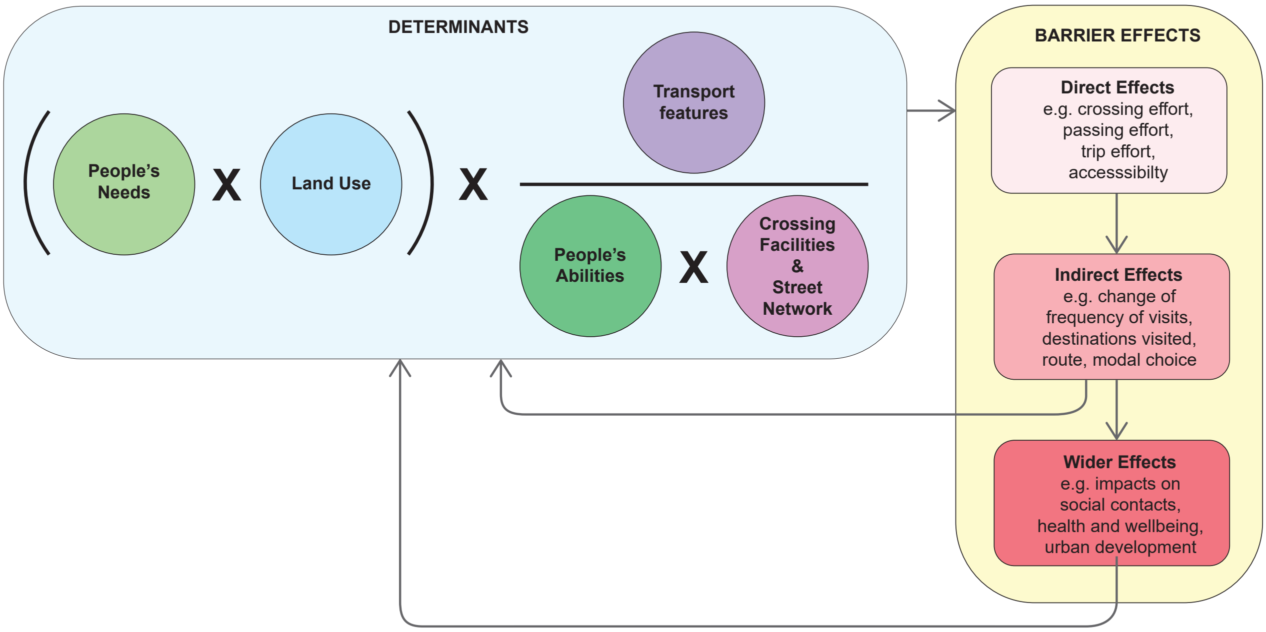

Figure 1 Conceptual model of the barrier effects of transport infrastructure and traffic.

effects occur when direct effects lead to changes in travel behaviour, such as choosing an alternative destination or mode of transport. Finally, wider effects are the societal consequences of the indirect effects, for instance reduced social contacts, a decreased consumer or user base for commerce and service, and detrimental health impacts. The model also describes feedback loops that can occur when, for instance, high traffic flows force people to drive a car instead of walking or cycling to their destinations, which in turn adds to the existing traffic flow and increases barrier effects. The model gives names to the determinants of barrier effects and to the levels of these effects.

The process of assessment of barrier effects

Little research has been done on the process of assessing barrier effects. In their report on the social impacts of traffic barriers, based on interviews with officers at local authorities in England, James et al. (2005) describe that many participants found it difficult to describe the assessment of barrier effects in practice, "as there was little knowledge amongst most of the practitioners about the process" (James et al., 2005, p. 10). Moreover, participants were reported not to see barrier effects as a standalone issue but rather as intertwined with accessibility planning. In a comparative study, Enel (1998) noted an increased awareness of barrier effects and in general a more "urban approach to road planning" (ibid., p. 42). This increased awareness resulted in changes such as the area that is assessed being larger, that a longer period is considered, and that more parameters are included in assessments. The drivers behind these changes are increased interaction between the state and municipalities, more attention to the pedestrian perspective, and the development of methods for participation and of computer tools for visualisation. Despite these improvements, the interaction between the state and the affected municipalities was still experienced as a power struggle rather than collaboration. Participants described how information about the projects was withheld or shared too late, which reduced the collaboration to unilateral information about facts and decisions. Often there was no coordination between urban development projects and road planning. This appeared to be related to different perspectives on, and responsibilities for, the project: the transport administration is focused on the project until completion, the municipality from completion onwards.

The description of the hindrances to the collaboration between land use planners and transport planners by Te Brömmelstroet and Bertolini (2010) offers insights that are also relevant for the process of assessing barrier effects. These hindrances relate, amongst others, to the tools that are used by the respective disciplines, their operational modes ("holistic visioning versus optimizing problem solving") and their professional language (Te Brömmelstroet and Bertolini, 2010, p. 86). Planning support systems (PSS) have been developed to accommodate this collaboration; however, they are not widely used in practice, due to the difficulties in adapting them to the dynamic needs of the planning practice, as well as insufficient transparency, flexibility, and user-friendliness. To overcome these hindrances, PSS and its output need to be developed in dialogue with the practitioners using them.

2.2 Inter-organisational collaboration and governance

As stated above, barrier effects are multifactor phenomena that require collaboration between different organisations. Research on collaboration in planning practices stresses the importance of creating a collective understanding of the planning project in question, as well as common visions and goals (Huxham & Vangen 2005). Huxham and Vangen stress the complex nature of inter-organisational collaboration with a recommendation, put in simple terms: "don't do it unless you have to" (2005, p. 80). Agreeing to aims and visions is a challenge, not only on a general level but also in detail, which can be difficult when there are clashing interests (Gil Solá et al., 2018; Pettersson and Hrelja, 2020). When the outcomes are predicted to exceed the effort of (successful) collaboration, there is a need to create an understanding of the different organisations' perspectives, guided by aims that can be connected to the collaboration and the organisations themselves. The aims can be both explicit and implicit, as well as hidden (Huxham and Vangen, 2005). As put by Paulsson et al., (2018, p. 378): "successful collaboration manages to develop and host both common shared goals and individual actors' objectives". Where a new collaboration is established, building trust between the organisations is of prime importance, so that people are willing to share information and take risks. Moreover, it is important to reflect on pre-existing power relations and how they are likely to develop. Who is included in the collaboration, as well as how and by whom critical decisions are taken, are decisive questions (Huxham and Vangen, 2005).

A reason for the growing interest in collaboration is the ongoing shift toward planning based on governance, or the 'governance of place' as described by Healey (2003, p. 116). This process can be seen as part of the politicisation of planning (Schmitt and Wiechmann, 2018), where single-focus actors and responsibilities are replaced by networks of stakeholders striving towards common goals. Governance is often discussed in relation to participation of the private sector and civil society, but it can also apply to collaboration between actors within the public sector (Mäntysalo and Bäcklund, 2017). The transition to governance is in its essence an increased need for collaboration between different organisations. And since planning is a value-based practice (Grange, 2017; Healey, 2003), this collaboration is challenged by conflicts that can arise both inter- and intra-organisationally (Pettersson and Hrelja, 2020). The challenge here is to understand what roles different stakeholders occupy in the new networks of steering, and how power imbalances should be handled.

3 Case study: The East Link through Linköping

The East Link (Ostlänken) is a national project that will increase connections between the three largest cities in Sweden: Stockholm, Malmö and Gothenburg, and will pass several cities along its way. The Swedish Transport Administration (STA) is responsible for the railway, and the main aim is to reduce the travel time between Stockholm and Gothenburg from around three to two hours (Banverket, 2009). The project is estimated to be finished in 2035.The process of defining a suitable location has been going on for several decades. One of the cities the railway will pass through is Linköping, the site of this study. Whereas the assignment of the STA is to build the railway at the lowest possible cost, what is important to the ML is that the railway creates as few barriers as possible and that the station will be in a central location (Norrköpings kommun and Linköpings kommun, 2010; Linköpings kommun, 2016).

In the first route study, out of four locations the STA elected for further analysis a corridor east of the Stångå river on elevated tracks and platforms (Banverket, 2009). The station was planned for the east bank of the river Stångå, which corresponded with the municipal plans. However, the ML wished to place the railway underground (Linköpings kommun, 2016). In response, a complementary investigation by the STA also included tunnel alternatives. Even though some positive aspects of an underground railway were shown, there were negative implications in terms of environmental effects and uncertain construction costs (Trafikverket, 2014). The tunnel alternative was therefore ruled out by the STA, even though it was seen as more or less essential by the ML (Hermelin and Gustafsson, 2021). In this conflict, the STA occupied a powerful position with a mandate from the national government allowing them to decide to locate the station outside of the city centre or to not construct a station in Linköping at all. However, as Swedish legislation prohibits the construction of transport infrastructure in conflict with municipal land use plans, the STA was at the same time dependent on the approval of ML for adopting the railway plan.

Figure 2: The work process in the route study of the East Link through Linköping (Trafikverket, 2022a).

After a few years of unsuccessfully attempting to reach an agreement, in 2019 the STA initiated a new route study, involving a work process in which a strong focus was placed on enabling collaboration (see Fig. 2). The project started with a series of workshops and meetings with the ML where 19 common goals were formulated for the project, split into four themes: (1) Function and economy, (2) Environment and health, (3) People and society and (4) Mobility and accessibility. In the next stage, the goals were translated into indicators and methods of measuring these. Thirdly, broad corridors were defined wherein the railway and station could be located (see Fig. 3). The consequences of each corridor in relation to the indicators were assessed in the fourth stage. Lastly, the assessments were summarized in a multi-criteria analysis to give an overview of how each corridor complied with the common goals defined in phase 1. The process concluded in a public hearing of the railway project, which constitutes a base for choosing one of the corridors (Trafikverket, 2022a). In the next stage of the project, the chosen corridor will be elaborated further in a railway plan.

During the route study, the Steninge corridor (orange in Fig. 3) emerged as an alternative possibility to tackle barrier effects other than constructing a tunnel. Even though it was a compromise – for the STA as it involves a slight detour for the railway, and a greater expense than placing the railway in the outskirts of Linköping, and for the ML as it does not involve a tunnel – the two parties managed to reach consensus about this alternative. On the 17th of May 2022, Steninge was formally chosen as the corridor to go forward with in the railway plan (Sadeghi, 2022).

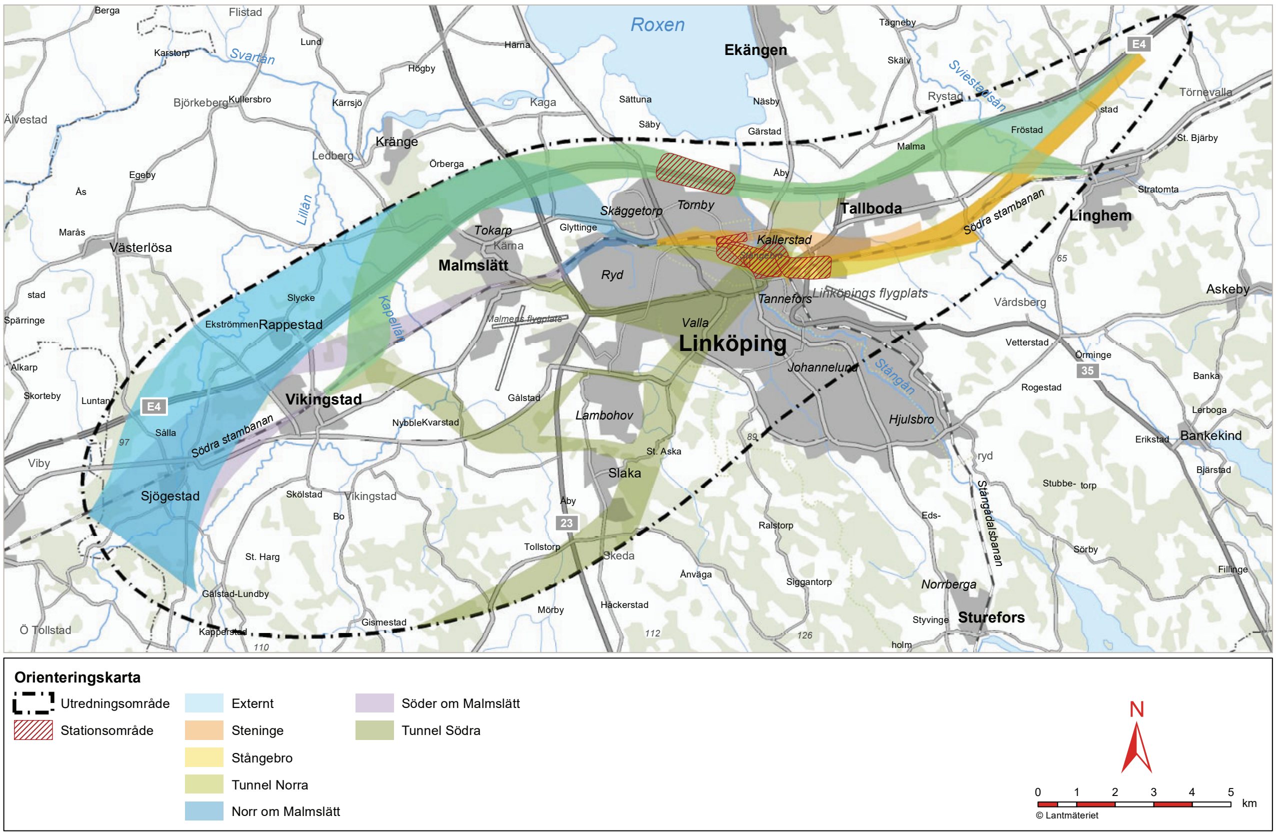

Figure 3: An overview of the corridors for the East Link through Linköping (Trafikverket, 2022b)

3.1 Barrier effect analyses

In several of the common goals and indicators identified by the STA and the ML, barrier effects were considered to be of central importance. Therefore, barrier effect analyses (BEA) were done using indicators defined by van Eldijk et al. (2022). The quantitative measurements of barrier effects were requested by and used in five of the impact assessments: Traffic Impact Assessment (Trafikverket, 2022b), Architectural Program (Trafikverket, 2022c), Child Impact Assessment (Trafikverket, 2021a), Segregation/Social Impact Assessment (Trafikverket, 2021b) and Recreation Impact Assessment (Trafikverket, 2022d). The barrier effects introduced by the railway, as well as possible reductions of these barrier effects, were assessed through GIS-analyses (a reduction occurs in those corridors where the existing railway is combined with the HSR in a tunnel). Place Syntax Tool (a plug-in for QGIS) was the main tool used. Table 1 presents a summary of the BEA. In addition to the quantitative analyses, qualitative BEA were made through design sketches and 3D-visualisations of the railway and the station. For more detailed definitions and examples of the analyses, design sketches and 3D-visualisations, see the Accessibility Impact Assessment (Trafikverket, 2021c) and the Architectural Program (Trafikverket, 2022c).

4 Research design

A methodological ground pillar for this study is how knowledge is co-created, involving both academics and practitioners (Straatemeier et al., 2010). More specifically, following Dewey's observation that practical knowledge can only be generated within actual experience (Straatemeier et al., 2010), the focus lay on the personal experiences of practitioners in the studied transport infrastructure project. From these starting points, we have chosen the following research methods.

Table 1: Analyses used for the barrier effect analyses (Trafikverket, 2021c).

Analysis	**Description**
Attraction Distance	Calculates the shortest distance from each segment to the closest origin or destination within a set. Distance is measured in metres through the network.
Attraction Reach	Summarizes the number of origins or destinations it is possible to reach from each segment within a radius. Distance is measured in metres through the network.
Angular Integration	Calculates closeness through the shortest path, from each segment to every other segment within a radius. Distance is based on accumulated angular turns.
Angular Choice	Calculates the number of times a segment is part of the shortest path between segments within a radius. Distance is based on accumulated angular turns.
Isochrones	Analysis of a service area. Distance is measured in metres through the network.
Average Detour Factor	Calculates the relation between the Euclidean distance and the relative distance through the network.

4.1 Action research

The study for this paper was done as action research (Herr and Anderson, 2015), meaning that the researchers are insiders and play an active role in the practice that they are researching. Further, since that practice is strongly influenced by its context, a case study approach was considered suitable (Yin, 2018) to create a broad understanding of the processes (Flyvbjerg, 2004). Both the action research and the case study approach offer the opportunity of deepened insights in the study object, although they also bring limitations regarding possibilities for generalising the findings (Hammersley, 2012). However, the knowledge produced in an action research project can be transferable through offering a documentation of a successful collaboration and its product. Another challenge with action research is the risk of self-promotion of the researcher (Herr and Anderson, 2015). To deal with these aspects, the research team for this paper consisted of one person who was responsible for the BEA that are studied and one person who was involved in the project, but not with the development of the BEA and did not participate in the interviewing. To validate the findings of the study, both persons coded the transcripts and were involved in analysing the transcriptions and writing the paper.

The STA partly financed the development of the methods used for the BEA and the study presented here. This background, combined with the facts that the analyses were done as an assignment of the STA and that the authors are employees at a consultancy, defined the approach to the project. The assumption was that the objective for the knowledge created is to contribute to the reaching of consensus in conflicts related to transport infrastructure. This aim can be contrasted with the more critical approach where the objective of knowledge is to clarify how conflicts about investments in transport infrastructure result from wider conflicts related to the distribution of resources in society, conflicts for which there is no given amelioration (King, 1982).

4.2 Interviewing method

The study is based on a series of semi-structured interviews. To capture a variety of perspectives on barrier effects, different groups of people were interviewed: officers from the ML, from the STA and from the consultancies appointed by the STA. Of the 24 individuals who were involved with different types of impact assessments in which barrier effects played a role, 22 persons were willing to participate. The participants were asked to describe the work process with the BEA and what the participants considered to be the contribution of the BEA to the five impact assessments. For the interviews a guide was used (see Appendix A), which was adjusted after the first few interviews. The participants were given pseudonyms as follows: officers from the Municipality of Linköping: ML1 to ML7; officers from the Swedish Transport Authority: ST1 to ST4; the officer from the regional authority: RE1, and the consultants: CO1 to CO10.

Interviews were conducted via video call. The interviews were between one and two hours long, and were transcribed using an online automated service and thereafter corrected by one of the authors. The interviews were done in Swedish; quotes were translated only at the moment when they were added to the article. The resulting transcriptions were read and analysed using a coding program (NVivo). As the aim of the study is to develop existing theory about and methods for the analysis of barrier effects, we have done a thematic analysis of the transcriptions, adhering to the 15 criteria defined by Braun and Clarke (2006). In the analysis, we have used descriptive codes (ibid.) in the 1st round of coding, and an elaborative coding technique in the 2nd round of coding (Saldaña, 2016). In Appendix B we present the list of themes and codes that we have used in the analysis. In the 2nd round, we looked at the participants' descriptions through the lens of the barrier effects model in which five determinants of barrier effects are defined (see section 2.1). Indirectly, this is also a way of verifying the relevance of the model. In addition to the BEA, the accessibility of the station was analysed in the different corridors (see PM Tillgänglighet (Trafikverket, 2021c) for a description of these analyses). These analyses are closely related to the BEA and were made by the same team, therefore both types of analyses were discussed by the interviewees. However, in the coding of the transcriptions, we excluded all comments and descriptions that were related to analyses of the accessibility of the station.

5 Results

In this section, we describe the participants' experiences of the contributions of the BEA and the role of the BEA in how the STA and the ML managed to reach consensus regarding the preferred corridor in the project, followed by the reactions and reflections on the work process with the BEA.

5.1 Contributions

The reaction of nearly all participants was that the BEA offered "concrete", "objective", "neutral" and "factual" descriptions of barrier effects, which was experienced and appreciated as an alternative to the many personal opinions on the project. As ML2 expressed it:

> The analyses give us support when we go through the goals and argue for a certain thing. (…) We know how they are made, and we can have them as proof that this is not just something we have invented.

The BEA were perceived as impartial and trustworthy by both the ML and the STA. ML5 described how she experienced that the work process with the BEA was guided by the content of the project and not by the results that the STA wanted to have, adding that "it feels like it would probably have looked the same if it had been the municipality that had been the client." Moreover, the BEA contributed to a more equal collaboration between the STA and the ML, as they offered an "evidence advantage" (CO5) for aspects other than only those areas that are the responsibility of the STA, such as regional and national accessibility and construction costs that are commonly supported with exact figures.

Fig 4 presents an example of one of the results of the BEA that were used for the traffic impact assessment. The BEA created support that was perceived to be trustworthy, as it was experienced as based on a description of the impacts that the stakeholders agreed upon and that was relevant to their interests and areas of responsibilities. ST3 portrayed the BEA as "a way of meeting", and many officers from the ML appeared to treat the analyses as coming from an independent, third party. As stated by ML2:

> …to get the material from outside as an independent party […] felt good. And I think it was also valuable that the material had been presented to both the ML and the STA at the same time so that we heard the first reactions and could reflect on the material together.

Despite his initial scepticism, ST2 described in retrospect how the BEA also offered benefits to the STA as they created a situation where the STA was able to meet any objections from the ML regarding, for instance, impacts on urban development. As ST2 put it: "This time we went in with, well… all bases covered".

Figure 4 Example of the results of one of the BEA: Analysis of the Steninge corridor for the average detour factor for cycle and pedestrian trips within a radius of 1 200 m from each street segment. Range detour factors between ≤ 1,2 and ≥ 1,5.

Assessing the Steninge corridor

A specific example of the contributions of the BEA is their role in how the STA and the ML reached consensus about Steninge as the preferred corridor. As described in section 3.1, the STA and the ML had very different perspectives on the project, which were summarised well by RE1: "There is still a discussion, is this an urban development project or is it a transport project?". In the initial phase of the route study, the possibility of finding a compromise between the interests of the STA and the ML became less likely. On the one hand, the costs of the tunnel alternatives were estimated to be even higher than expected, making them less acceptable for the STA. On the other hand, the BEA showed that the railway and the station on the ground level version of the Stångebro corridors (see Fig. 5) would create even greater barrier effects in the city than had been assumed, thwarting the ambitions to reduce barrier effects and to expand the city in this area:

> We have started to analyse the urban development opportunities [east of the city centre] where we consider the fact that one first needs to cross [the river] and then go under [the existing railway] and then under the East Link. We now realise even more that this is not good for urban development opportunities (…). Is it even possible to develop this area and feel that it is part of the inner city? Will people even want to go there? (ML2)

At the same time, the BEA started to show the potentials of the Steninge corridor (see Fig 6). Steninge had been developed by CO5 and her colleagues but had initially been met with strong scepticism on both sides. However, the BEA showed both politicians and officers at the ML that Steninge complied better with the municipal urban planning goals than the Stångebro corridor:

> I think that the urban development scenarios and the analyses have also helped to show that [Steninge] corresponds quite well in several respects with the intentions [for urban development] that the municipality has adopted. Even though we had Stångebro as the preferred location for the station (…) we now see that it is possible to [develop the centre] in the Steninge corridor as well, or maybe even more so. (LM3)

When other assessments (see Fig 4) also pointed out the benefits of Steninge, the STA became convinced about this corridor too. In March 2022, the ML issued its formal statement on the route study stating that, even though the municipality still favoured a tunnel corridor, Steninge was now the preferred ground level corridor. “This corridor”, they wrote, “moves barrier effects connected to the existing railway facility away from the city centre while simultaneously a central station location can be achieved.” (Kommunfullmäktige Linköpings kommun, 2022). According to CO9, the BEA had a crucial role in this decision:

> There are a number of analyses that I think have actually opened our eyes, both internally, at the ML as well as at the STA. I think if we had not done all these analyses, if we had not had all these meetings, all these meetings, then it would have been so easy to decide in favour of [the Stångebro corridor]: if we don’t get an agreement, then it will be Stångebro. Period. So yes, it’s a process.

5.2 Work process

In this section, we present the interviewees’ experiences of the work process with the BEA. The work process had three parts: (1) Defining the barrier effect analyses; (2) Selecting and creating input material for the barrier effect analyses; and (3) Communicating the results. In section (2), the challenges related to each of the five determinants of barrier effects are elaborated upon.

Defining the barrier effect analyses

Initially the results of the BEA were to be presented in a separate report on barrier effects, comparable to a noise impact assessment report. However, through interactions between the BEA team and the

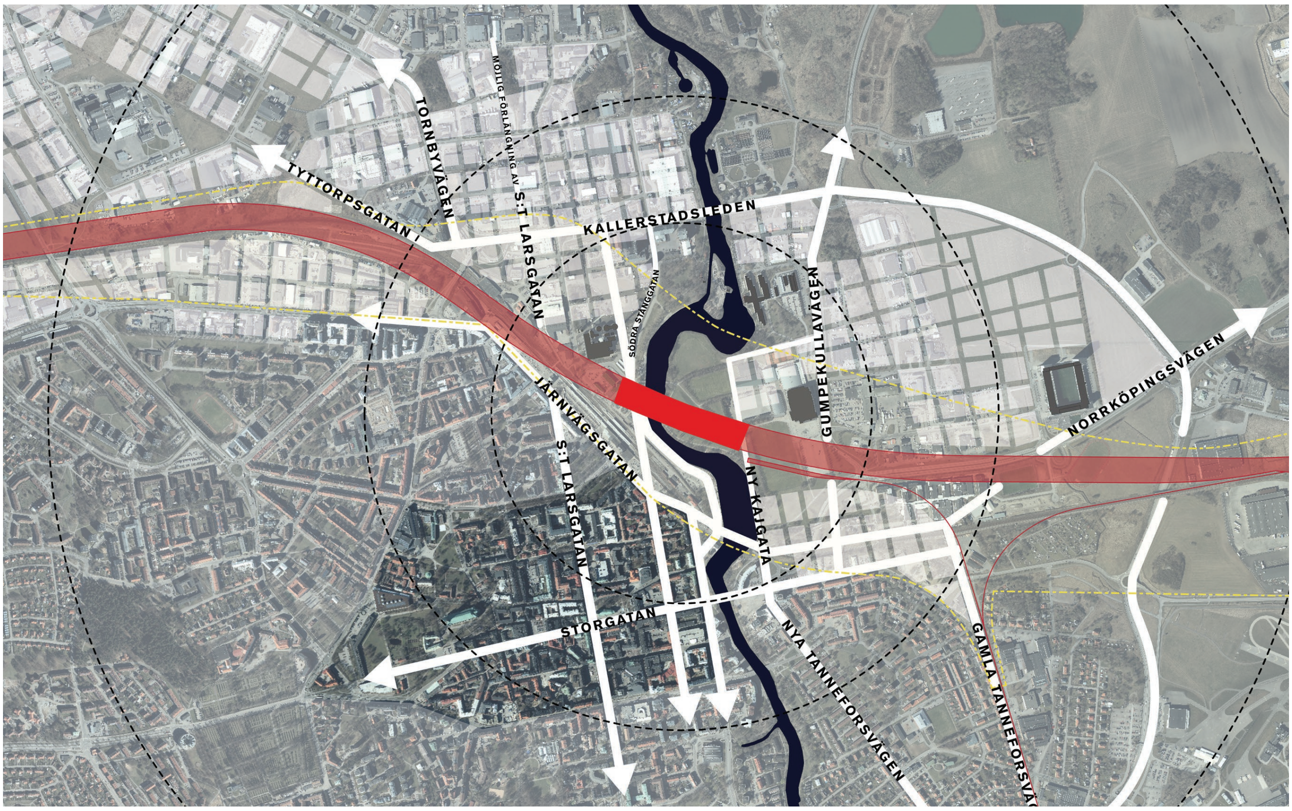

Figure 5 The Stångebro corridor

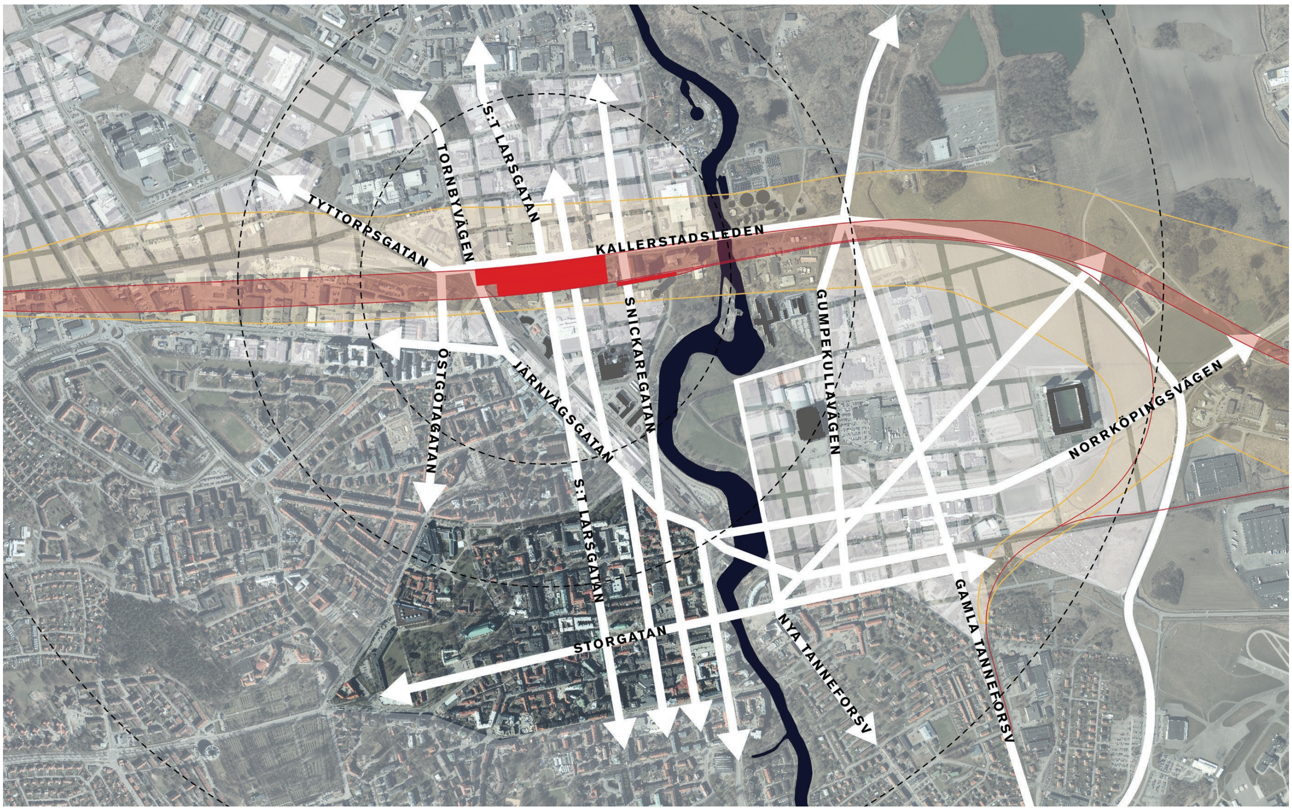

Figure 6 The Steninge corridor

practitioners using the analyses (hereafter called end-user) it became clear that the role of the BEA was to provide support to the impact assessments. Therefore, the setup of the BEA needed to be defined in close collaboration with the analysts and the end-users. Many participants from the ML and the consultancies expressed that they would have preferred a more iterative work process where they could have tested and adjusted different setups of the BEA. This communication is needed to create the right focus in the BEA, as what is significant for the assessment of barrier effects might not necessarily correspond with the focus of the project in general (CO10).

Selecting and creating input material for the barrier effect analyses

The BEA required different types of input material, both in the form of existing GIS-data as well as material that needed to be created specifically. The work processes required for producing this material led to some challenges in the collaboration between the STA and the consultancies, as well as within the consultancies. These issues are more than just problems with gathering data for analyses. In fact, they form the central challenge of taking all the relevant barrier effect determinants into consideration, which is essential for the analyses of barrier effects of transport infrastructure (see section 2).

Transport features

The characteristics of the railway and the station in the corridors are mostly defined by technical requirements. However, these technical drawings could not be used for the BEA; rather, an architectural investigation was needed of the spatial impacts of the features on the built environments surrounding them. At the start of the project, it was unclear for the STA and the project management team of the consultants how these spatial impacts in the different corridors could be assessed. The STA has no established methods for the assessment of the impacts of transport infrastructure in urban environments[1] (ST3) other than impacts assessments related to noise and air pollution. In the route study in Linköping, the brief of the main consultancy of the project did not include creating a design for the station area. To CO10, it was clear that it would be impossible to assess the impacts of the corridors without developing detailed spatial design proposals for the station and railway. Therefore, the project management team invited an architectural firm to the project as a sub-contractor to make proposals for the railway and station through maps, plans, elevations and 3D-visualisations. At a later stage in the project, these analyses of the spatial impacts of the railway in the city proved to play a prominent the role in the process, causing CO9 reflect that: “If I could redo this project, I think I would have put more focus in the beginning on making sure that everyone knows what a railway actually looks like, the place it takes, the height...”.

Street network and crossing facilities

In the early stage of the planning process, the STA usually does not consider the adjustments that need to be made in the street network due to the new infrastructure, and does not take into account networks for pedestrians and cyclists. These are normally considered to be a municipal responsibility. In line with this, the assignment for the architectural firm was limited to developing planning scenarios for the station and its direct surroundings only. However, as CO10 and CO5 saw it, more was needed to be able to assess the impacts of the project on urban development:

> The architects and I saw from our background that we couldn’t answer the question of how this would look like, what consequences this will have, if we were not allowed to

1 Shortly after this case study was done, the STA published a method for ‘integrated urban environment effect analysis of infrastructural transformations’ (Berghauser Pont et al., 2022).

> investigate it. And then you have to sketch quite deeply to see if you even think it is possible to find a solution. And then this may not be the final solution, but if you can't find a solution, then you're kind of groping in the dark (CO10).

Therefore, CO5 and her colleagues at the architectural firm chose to expand their assignment and made urban development scenarios for the entire north-eastern part of the city instead of only the immediate surroundings of the station (see Fig 7 for an example of such an urban development scenario). The approach of CO5 was much appreciated by the officers from the ML, however, both representatives of the STA and members of the project management team of the consultants were quite sceptical, as they considered scenarios at this geographical scale to be irrelevant for the project. From the perspective of CO5 and other consultants, however, the street networks have the same function as the railway centre lines produced by the railway engineers, for estimating construction costs and for calculating noise levels. Like the railway centre lines, the street networks were only intended to function as input material for the BEA, describing plausible scenarios for urban development following construction of the railway and the station. CO5 reflected:

> I believe the STA often wondered what we were doing. They didn't understand anything about the meaning and use of these sketches. (…) There seems to be a lack of knowledge about what an architectural drawing is. A drawing is also an investigation, an investigation whether something is possible.

Figure 7 The urban development scenario for the Steninge corridor (Trafikverket, 2022b)

Another point of disagreement was about the planning horizon for the adjusted street networks. The urban development scenarios had a 100-year planning horizon. However, CO3, CO7 and CO8 did not consider this suitable for their impact assessments. Following the praxis for STA projects, their reference point of the assessments was the year 2040, when the project was estimated to be completed. Further, the architects had not considered the demands of motorised traffic (CO3). Therefore, anno 2040 versions of urban development scenarios had to be produced for these assessments. Due to lack of coordination and time restraints, this was done without any involvement of the ML. As the pivotal role of the street networks became apparent during the project, a majority of the officers at the ML and the consultants agreed in hindsight that these anno 2040 networks should have been defined by a working group involving the STA and their consultants, and the ML.

Crossing facilities played a minor role in the assessments at this stage of the project, as the STA applies a "one for one" policy in their infrastructure projects, meaning that every existing crossing facility is replaced with a new one and a tunnel or a bridge is proposed for new crossings. However, in the next planning stage, the crossings will probably play a bigger role, and create an even stronger need for collaboration regarding the definition of the street network and the crossings. As expressed by ML5:

> We need to think whether we are satisfied with the "one for one" principle; we might want to invest in more crossings, because the railway is already a problem today. This [project] is the only opportunity to (…) get more crossings.

People's abilities

The analyses were based on pedestrian and bicycle networks as it is predominantly these slow modes that are affected by barriers. In only a few instances of the BEA, the qualities of the crossing facilities and the street networks were considered in relation to the ability to cross in particular social groups. An example is the assessment of segregation (Trafikverket, 2021b), where the abilities of people were considered through the identification of areas where residents are more vulnerable to barriers due to lower levels of car ownership. CO4 commented on the lack of consideration of differences in abilities of residents. The street network and the BEA were presented as being a general representation of the built environment; however, what is commonly called 'general' represents mostly the perspective of able-bodied adult men. CO4 and ML2 noted a clear example of this, namely the way tunnels or desolate areas in the city create conditions for concern about personal safety that limit freedom of movement for certain social groups, but those parts in the street network were still modelled in the same manner as the others.

Land use

The selection of destinations was an important part of the impact assessments. For the Traffic assessment (Trafikverket, 2022b) and the Architectural Program (Trafikverket, 2022c), the segments in the street networks functioned as generic representations of destinations. For the Recreation assessment (Trafikverket, 2022d), the destinations were selected by the experts of ML, the STA, and the consultants. The destinations or the Child Impact assessment (Trafikverket, 2021a) were selected by experts from the ML and the consultants, and verified through a survey among school children (n=780). A more detailed description of the data that were used in the different BEA can be found in the Accessibility Impact Assessment (Trafikverket, 2021c). The fact that only existing land use was included in the BEA was experienced as a limitation by several officers from the ML. They felt a need for scenarios of how the city would look like in the future, in terms of land use and urban development. ML7 perceived this as a fundamental problem affecting most projects of the STA. This was confirmed by ST2, who explained that land use developments are not part of the STA's assignment.

Needs of people

Data on the needs of children to reach destinations was gathered through a survey, other estimations regarding the needs of people were based on expert judgements. It is important to be aware that this last approach only relates to potential needs. The BEA for Recreation for instance, showed conditions for reaching green areas but does not give any information about the actual use of these areas (ML7). The geographical scale of the project and the diversity of social groups living there created huge challenges for estimating the needs of people. Also, the railway and station will have impacts on the city that can last for more than a century. It is difficult to foresee how the needs of citizens will evolve over time. Furthermore, decisions about the project are made by politicians who must consider the needs of their voters and the needs of future generations. ML2 describes this situation as follows:

> This station will have its effect in 40 years, in 60 years, in 100 years. But [politicians] are just looking towards to the next election and then they want to make two park benches here and […] to block off a street for bus traffic there. This is a huge challenge.

Communicating the results

The participants mentioned potentials for improvement regarding the way the results of the BEA were presented. ML4 stressed the importance of the communicative phase of the BEA, in which the detailed maps need to be to "scaled down" to emphasise what is important and to make it communicable to a broader audience. RE1 agreed with this and pointed out that it was a limitation that many BEA were lacking an indicator that would make it possible to compare the results and draw conclusions from them. The absence of threshold values for the BEA was also mentioned as a limitation. However, ML7 emphasized the the role of the analyses was not to provide final answers; the analyses themselves do not say what is good and bad. Instead, the BEA constitute a basis for discussion where a qualitative judgement can be made based on the results. Moreover, for grounded decisions to be made there is also a need to understand what exactly is being communicated. A map often expresses: "Hey, I'm trustworthy, look at me!" (CO4), but the results that are presented on a map are only valid and relevant if the right questions have been asked in the first place.

6 Discussion

The participants expressed in the interviews that the BEA offered trustworthy material for the impact assessments, that was concrete, factual, and originating from what was experienced as a 'third party'. Even though the STA was responsible for the analyses, their quantitative nature and the transparent work process created trust between the stakeholders, vital for information sharing and taking risks in collaboration (Huxham and Vangen, 2005). Based on this trust and on how the BEA addressed the interests of both organisations, the analyses formed "a way of meeting" (ST4) and a "common language" which is important for collaboration (Gil Solá et al. 2018, Rye & Isaksson 2018). Under these conditions, the stakeholders were able to reach consensus about a planning alternative.

The maps produced in the BEA did not function as standalone documents such as noise investigations and air quality reports, but provided support for impact assessments in the project and so are intimately connected to the questions of the impact assessments. Interaction was needed throughout the different stages of the work process between analyst and end-users, confirming the conclusions of Te

Brömmelstroet and Bertolini (2010). The first phase was concerned with the definition of analyses. The model of barrier effects worked as checklist for deciding on suitable types of analyses, and relevant social groups. Although the analyses only dealt with direct barrier effects, they provided support for analysing indirect and wider barrier effects.

The selection and creation of input material for each of the five determinants were central activities in the work process and involved several challenges related to the inter-organisational and inter-disciplinary collaboration. The spatial impacts of Transport features, the railway and station, were hard to grasp for participants from both organisations, requiring some architectural competence for visualisation. It is fairly unusual that the architectural investigation of spatial impacts plays an active role in the early stages of infrastructure projects, rather than just visualising the results of engineering decisions. The Street network constituted the main variable in the BEA. The pivotal role of this determinant was not obvious at the start of the project and the different versions of the street network that were needed for the analyses were created without collaboration with the stakeholders. The challenges here were to determine what geographical scale and which planning horizon were suitable for the analyses, and which modes needed to be considered. These challenges can be seen as examples of the difference in perspectives in this project, whereas the STA is responsible for the project up until completion, the municipality's main interest is from completion onwards (Enel, 1998). The STA was reluctant to be involved in the development of adapted versions of the street network as the organisation needs to avoid additional costs to the project for consequences that the STA is not responsible for. This is also expressed in the "one for one" policy regarding how many crossings the STA is willing to finance. The determinant Land use was related to the selection of destinations in the BEA. This selection was partly based on a survey among children but for most BEA destinations were defined using only expert judgement. As pointed out by Rajé (2007), assessments based on expert judgement may risk neglecting important aspects due to lack of local knowledge and the absence of insight in the perspective of the specific social groups referred to. Likewise, the determinants People's abilities and People's needs were based only on expert judgement instead of dialogue with citizens. Thus, the perspective of the general public was neither included through a representation of interests in a SIA, nor through direct participation. Insufficient dialogue with citizens can be seen as a missed opportunity for good governance (Rye and Isaksson, 2018). Furthermore, the regional authority responsible for public transport in the region, was invited late in the process and was not given an opportunity to include the interests of public transport in the BEA. Consequently, the perspective of public transport was not incorporated in the BEA.

Finally, the need for interaction between the analyst and the end-user was emphasised in the interviews. The results of the BEA need to be communicated to people who often lack the time and technical competence for interpreting the results. Therefore, a translation of the results into less technical language was needed. Further, there was discussion about the risk that maps look like they are presenting the truth without acknowledging the things that they do not show. It is important to be aware of how strategic documents can be disconnected from their author(s) and retain an authority of their own (Paulsson et al. 2018). Similarly, the results from the BEA in the shape of maps are disconnected from their input material and models once they are published. Another reflection relates to the transferability of the experiences in this case study. Several participants mentioned how they experienced the BEA as coming from a 'third party', which possibly can be related to the fact that the analysist doing the analyses was both consultant and an academic researcher. As not every infrastructure project is subject of a research project, this external character of the analyses must be discounted in the interpretation of the results.

7 Conclusion, policy implications and further research

To improve the applicability of existing assessment methods, van Eldijk et al. (2022) developed a conceptual model and an overview of barrier effects analyses (BEA). In this paper, we present a case study of the use of those tools in practice, focusing on the practitioner's experiences of what the BEA contributed to the project, and how the work process with the BEA functioned.

Our findings show that the BEA created a common language for discussing the impacts of the different alternatives. This created trust between the stakeholders and contributed to reaching consensus between the parties about the preferred planning alternative, turning what had become a trench war into a dialogue. It is essential that the analyst and the end-user interact during every stage of the process. What is analysed and how needs to be closely related to the questions of the impact assessment. Furthermore, as the street network is the main variable of the BEA, the adjustments of the street network are of great importance for the impact assessments. However, due to the different perspectives and areas of responsibility, challenges arose in the development of the alternative versions of the street network that were needed for the analyses.

Based on these findings, some policy implications and directions for further research can be indicated. As part of the transition to governance-based decision processes, there is reason for transport administrations and municipalities to reconsider the formal requirements of how barrier effects are assessed in transport infrastructure projects. These requirements relate to a need of more transparent and fact-based methods in which the crucial role of the street network needs to be acknowledged. The role of the street network can be compared to the role that railway centre lines play in, for example, noise assessment and calculation of construction costs. Further research is needed to formulate methods for the development of alternative versions of street networks. Further, there is a need to develop methods for assisting municipalities in their role as stakeholder in large-scale infrastructure projects. Municipalities may lack experience of the processes involved and commonly don't have access to the assessment tools they need. Furthermore, developing a standardised work process with the BEA could reduce the urgency of interaction between analysts and users of the BEA. In turn, this could make the analyses quicker, cheaper, and potentially more trustworthy with more room for quality control. However, a fully standardised process may be less flexible and lead to simplifications and aggregations that neglect the specificities of the project. Also, there is a need to develop principles related to which stakeholders must be included in the assessment of barrier effects and how they can be included. Finally, we see a need for more case studies on the collaborative processes of barrier effect assessments, as this knowledge is a requirement for making the existing tools for the quantification of barrier effects more applicable in practice. The urgency of this focus is emphasised by Enel (1998) who concludes: "In many respects, the interaction between stakeholders seems to contribute more to the reduction or aggravation of the barrier effects than the physical configuration of the site or the technological solutions that are applied."

Acknowledgements

We would like to thank the 22 officers from the STA and the ML and consultants that participated in the interviews for their time and willingness to share their experiences, which made this study possible.

Funding

This work was supported by the Ramboll Foundation (grant dated 23-12-2015), Ramboll Sweden Ltd (grant dated 16-05-2016), InfraSweden2030 (grant number 2019-01150), Trafikverket (grant number TRV 2016/10608), and Trafikverket's Skyltfond (grant number 2015/84777). The funding organisations have had no involvement in the design of the study or the interpretation of the results.

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Appendix A – Interview guide

Introduction

- Thank you for participating.
- We will take a step back and reflect on how things have gone.
- Some words on my role as a researcher and as the one who has developed the indicators and carried out the analyses. Feel free to be honest in your evaluation of the indicators and how they have performed. Please also describe things that you and I already know.
- Purpose of the project: Knowledge about impact assessment of barrier effects; Contribute to better impact assessment of barrier effects of transport infrastructure.
- Research question for the study: What have the barrier effect analyses contributed to? How did the collaboration on the analyses work?
- Other interviews, handling the recording and transcription, sharing the article, publishing, and presentations.
- The interview has three parts: The work process, evaluation of the use and evaluation of the contribution to collaboration.
-

A. Description of the work process with the analyses (short answers please)

- Have you previously worked with a barrier in a project?
- What methods did you use then?
- How would you describe the collaboration between the municipality and the Swedish Transport Administration within the project as a whole?

B. Evaluation of use for assessment of goal-compliance

- Could you mention where in your work you found the analyses useful?
- Did the analyses provide new knowledge or insights?
- Could you describe what role the analyses have had in assessing goal achievement?
- Did the analyses facilitate opportunities to communicate about consequences and goal achievement? Any example?
- Have the analyses affected the way you work? Any example?
- Were there any challenges in using the analyses? Any example?
- Is there anything that you will bring to the next project? Any example?
- Is there anything that could be done differently in the next project? Any example?

C. Evaluation of contributions to the collaboration

- Have the analyses contributed in any way to the collaboration between the municipality, the Swedish Transport Administration, and the consultants? Any example?
- Have the analyses had any effect on the communication between the municipality and the Swedish Transport Administration? What role did they play at the goal achievement workshop in June?
- How was the internal collaboration around the analyses?
- Do you feel that you can trust the material and assessments contributed by other parties? Why or why not?
- Did the indicators make the impact assessment work more or less effective? Any example?

Closure

- Is there something you want to ask me?
- Who do you think I should interview other than those persons who I have invited already?
- Summary + interpretation + verification
- What did you think of the interview?
- Thank you for your time!

Appendix B – Themes and codes

Theme	Code Category	Code	Description
What are the perspectives of participants on barrier effects?	Different perspectives on barrier effects	Conflicts of interest	Conflicts of interest between TRV and ML
		Project definition	
		Prognose-/goal orientation	Conflicts due to professional background
		Responsibility	What do the participants perceive to be the responsibility of their respective organisations? What do they perceive as the responsibility of others? How do they define the project?
How was the collaboration in the project?	Collaboration	Collaboration between consultants	
		Collaboration TRV-ML	
		Collaboration TRV-consultants	
		Collaboration ML-consultants	
How did the participants work with the analyses?	Working process	Working process	
What feedback did the participants have on the analyses?	Feedback	Limitations	
		Method development	
What did the analyses contribute to the collaboration between Trafikverket and Linköping kommun?	Understanding of the project	New insights about the alternatives	
		Nature and scope of the projects	
		Alternatives west of Stångån	
	General understanding of barriers	Interaction between barriers	
		Types of barriers	
		Influence on urban development in history	
	Support in communication	Objectivity	
		Pedagogic value	
		Equality	The analyses created more power balance between ML and TRV, i.e. more power for ML