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The wrong side of the tracks: quantifying barrier effects of transport infrastructure on local accessibility

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Abstract

Cities can be characterized as distributions of accessibility. Two elements in the urban fabric that influence this distribution of accessibility are motorways and railways. These are powerful connectors in urban traffic systems but can also create strong barriers on a local scale. Based on a literature review, the negative effects of these barriers – also called severance – on social inclusion, health, and access to workplaces are described. Furthermore, it is pointed out that barrier effects are determined by three elements: transport infrastructure, built environment and people's wishes and needs. Two morphological indicators are presented with which some of the barrier effects identified in the literature review can be quantified. One indicator is related to proximity to facilities, measured by network distance. The other relates to accessible offer of facilities, measured as the number of facilities within a given metric radius from each residential address. The indicators are demonstrated in a case study in Gothenburg, Sweden, where a four-lane motorway and railway tracks form substantial restrictions on the urban development of a former harbor area in the center of the city. In the case study the consequences of placing the infrastructure in tunnels is assessed. The analyses show how the increases in proximity to facilities and in accessible offer of facilities are spatially distributed in non-linear patterns. These results demonstrate the importance of taking into account transport infrastructure, built environment and people's wishes and needs when assessing barrier effects. The case study indicates the potential of the proposed indicators for inclusion in a method for the quantification of barrier effects.

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1. Introduction

Transport infrastructure such as motorways and railways create highly effective connections on an urban, regional and national scale. At the same time, these connections can also create barriers in local mobility systems. Through an intricate process of cause and effect, these barriers can have a series of negative consequences on e.g. social contacts within neighborhoods (Bradbury et al., 2007) and between neighborhoods (Anciães, 2013), access to facilities (Clark et al, 1991) and to workplaces (Anciães, 2013), on health (Mindell and Karlsen 2012) and on possibilities for urban expansion (Korner, 1979).

Decisions concerning investment in infrastructure projects are usually based on extensive assessments of their effects. For many of these effects, for example noise and pollution, quantitative and objective ways of measuring have been developed. However, for the assessment of barrier effects usually only qualitative and subjective methods are used (Anciães et al., 2016) which typically consist of written descriptions. This limits the possibility to include barrier effects in the overall evaluation of effects and creates a risk that these important negative consequences of investments in transport infrastructure are undervalued or disregarded.

This paper presents the first investigation of a research project aimed at developing a method for the quantification of barrier effects of motorways and railways intended to be used in planning processes of infrastructure. Central for this investigation is the question how the barrier effects of motorways and railways can be quantified.

The paper has the following structure. First, the main findings are summarized from a literature review of grey literature (technical reports, handbooks) and academic studies concerning barrier effects and methods of measuring these. Secondly, two indicators of barrier effects and the method with which they have been applied in the case study is described. Next, the analyses of the case study area regarding proximity to facilities and accessible offer of facilities are presented. In the discussion section, the results of the case study the potential use of the indicators are discussed. The conclusion points out next steps in the research project.

2. Literature review

In this section, a review is presented of research related to barrier effects and of methods which have been proposed to quantify them. Barrier effects of motorized traffic and transport infrastructure are also referred to as severance and the review includes literature about severance, which is a very related term used in some fields.

2.1. Barrier effects

A central starting point for understanding barrier effects is that they do not originate as an autonomous externality from a system, with a unit of measure of itself, like noise and pollution. This is illustrated by the description by Korner (1979) of the three situations in which barrier effects can arise: 1). Changes in crossability, due to the construction of new infrastructure or changes in design or travel flow on existing infrastructure; 2). Changes in the need to cross, due to localization of new destinations, removal of existing destinations or changes in the attraction of existing destinations; 3). Changes in the ability to cross, due to demographic changes, such as an increase in the number of elderly people or children.

From this description, barrier effects can be seen as the result of the meeting of infrastructure and traffic, the built environment and people's wishes and needs (Anciães et al., 2014; Geurs et al., 2009; Korner, 1979). Assessments of barrier effects need therefore to take into account both the properties of the barrier, as well as the properties of the urban context in which people and the barrier are located, and the wishes and needs of people affected.

Another characteristic of barrier effects is that they can typically be described as a chain of effects, and many descriptions have been proposed of the complex causal pathway between barriers and their wider consequences for individuals and groups (Anciães et al., 2016; Geurs et al., 2009; Korner, 1979; Marsh and Watts, 2012; Mouette and Waisman, 2004). As the aim of the present research project is to develop a method for the assessment of barrier effects which can be used in infrastructure planning processes, the three-tiered scheme by Korner (1979) is particularly suitable. Korner splits barrier effects up in a primary level, the direct effects of the barrier, a secondary level, the subsequent changes in travel behaviour and a tertiary level, the further consequences in society of these

changes in travel behavior. What makes this scheme suitable to the present study, is that the aspects which can be affected by planning decisions are clearly separated. In the continuation of this literature review, barrier effects are categorized according to Korner's scheme.

At the core of the primary barrier effects are the increase in travel time, distance and effort that a barrier can imply (Korner, 1979). Further primary level effects are the reduction of access to facilities such as education, health care, services, public transport stops, and leisure (Clark et al., 1991; Bradbury et al., 2007). On the one hand, the offer of facilities can be reduced, on the other, the catchment areas of facilities can be reduced (ibid). Also, accessibility of workplaces can be affected, where the infrastructure, as barrier, can limit communication (Anciães, 2013), but, as improved connection, can also increase accessibility to workplaces (Nimegeer et al., 2018). Another primary effect is the reduction of transport efficiency of services such as freight, mail, waste collection, public transport, and emergency services (Cline, 1963; Héran, 2011).

Secondary barrier effects concern the changes in mobility behavior caused by primary effects. These involve changes in frequency of visits, in choice of destination, in changes in mode of transport and in change of route (Bradbury et al., 2007; Marsh and Watts, 2012)

Changes in mobility behavior can have extensive tertiary barrier effects on society. An often-mentioned effect is the reduction of social contacts within neighborhoods (Bradbury et al., 2007; Grigg and Ford, 1983; Lee and Tagg, 1976; Nimegeer et al., 2018). The studies of the effects of traffic on the livability of streets by Appleyard et al (1981) are frequently referred to in this context. Although these studies have made a vital contribution to a critical discussion about motorized traffic in cities, a weakness is the fact that they demonstrate a correlation, but not any clear support for a causal relation between traffic levels and social contacts (Stanley and Rattray, 1978). Other, more detailed studies point out that the presence of barriers can lead to an increase in car use, which in turn reduces the possibilities for informal social contacts between residents (Bradbury et al 2007). Tertiary effects concerning health are described by Mindell and Karlsen, (2012), who point at the consequences of reduced conditions for active travel, the reduced livability of the street which reduces possibilities for children's unsupervised play and social interactions of the elderly, and the reduction of access to shops that offer low-fat, low-sugar food products

2.2. *Methods for quantification*

Most of the literature presents, besides a description of barrier effects, also methods for their quantification. The Swedish Transport Administration, Trafikverket, for instance, provides a quantitative method for measuring barrier effects (Jarlebring et al., 2002). The method describes a rather elegant and effective way of calculating how local trips of residents are affected by a barrier, using statistics of the local travel behavior of residents, divided into different age groups. The extra travel time the barrier imposes on these local trips, is monetized, using general monetary values which have been established for these types of cost-benefit analyses. A limitation of the method is that it ignores the spatial distribution of barrier effects. Another limitation is that the consequences of barrier effects are far too complex to make the use of extra travel time as proxy adequate (Quigley and Thornley, 2011). In practice, the method is rarely used.

A method which does take the built environment into account, has been developed by Clark et al (1991) for the British Department of Transport. It is proposed that barrier effects could be quantified by estimating the number of residents for whom access to facilities is affected. For this, facilities are identified and catchment areas for these facilities are drawn. Within these catchment areas the number of residents is estimated, both the total number of residents and separately the number of persons who may be considered especially vulnerable for barriers, such as older people, children, people with a disability, and people with strong community ties. Clark et al (ibid) propose that Voronoi polygons should be used for the definition of catchment areas, as the use of fixed radii could lead to some residential addresses being left out. A limitation of the 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 also be measured by changes in the number of choices of destinations that are available to residents within a given travel time. This is an aspect that is rarely touched upon elsewhere.

In his study of barrier effects of motorways in Lisbon, Anciães (2013) proposes indicators for what he defines as "population-interaction potential" between neighborhoods on either side of motorways. With these indicators,

Anciães shows how a newly constructed motorway reduces the potential for residents from different neighborhoods to meet, compared to the situation ten years before the motorway was built. Anciães' method is the only one in the literature that was studied, that offers a way to quantify the reduction of potential for social contacts.

In another research project, Anciães and Jones (2018) developed a stated-preference method for the quantification of barrier effects. In the method the value of barriers was estimated by presenting people with different road designs and asking whether they would be willing to cross the road in order to access a cheaper shop. This approach is not applicable to assessments of motorways and railways, as traffic calming measurements are not relevant in these infrastructures.

Summarizing, it becomes clear that it is important to consider three elements in the assessment of barrier effects: infrastructure and traffic, the built environment, and people. For this, some relevant indicators have been developed for catchment areas of facilities (Clark et al, 1991), offer of facilities (Forkenbrock and Weisbrod, 2001) and for the potential of social contacts (Anciães, 2013).

3. Method

This section introduces the case study, the data used in the analyses and the method used for the analyses. The aim of this study is to develop an assessment method which is to be used in planning projects, and therefore the focus in the present case study is on primary barrier effects, as these effects are related to aspects that can be affected by planning decisions.

3.1. Case study

The case study is located in the northern part of Gothenburg, Sweden, where a four-lane motorway, Lundbyleden, and a railway track, Hamnbanan, form substantial restrictions on the urban development of a former harbor area in the center of the city and the surrounding areas in general. The city council has formulated a number of policy documents expressing the ambition to unite the city as a whole and to improve its contact with the river. In reaction to this, the Swedish Transport Administration has issued a pre-study in 2008, in which seven alternatives for Lundbyleden and Hamnbanan are presented aimed at reducing the negative effects of the infrastructure on the surrounding areas. The negative effects that have been identified are: noise, pollution, and barrier effects. In the case study presented in this paper, the alternative has been analyzed in which the motorway and railway are placed in tunnels. The reduction of barrier effects has been measured by comparing this tunnel alternative with the present situation, using a model based on the street network, facilities and residential addresses.

The street network is based on the road center line map of Gothenburg, consisting of roads and paths that are accessible for pedestrians and cyclists (Berghauser Pont et al., 2017). The new street networks which are proposed for urban development in the areas surrounding the infrastructure (White Arkitekter, 2018; Göteborg Stad, 2014) have been added to the road center line network. For the tunnel alternative, a version of the network has been created in which the new connections were added, which have been proposed in the planned urban developments in the study area (White Arkitekter, 2018; Göteborg Stad, 2014). Assumptions have been made for new connections in the urban development of those undeveloped areas for which there are no plans yet. In the tunnel alternative, the number of cross-connections increases from 8 to 24 and connections are added along the former location of the motorway and railway.

For data on residential address points and facilities in Gothenburg, data sets from Open Street Map (OSM) and the municipality were used, which together contain around 79,000 residential addresses and 135 types of facilities. In this experimental phase of the research project, the analyses were restricted to three types of educational facilities, seven types of health care facilities, and public transport stops. As the area of the case study is located near a river, and contact with water is highly valued in Gothenburg, a dataset was generated with locations in the road network with access to the waterside. In the urban renewal areas residential addresses, facilities for education and health care, public transport stops and places with access to water have been distributed according to the plans of the municipality (Göteborg Stad, 2014; White Arkitekter, 2018). This distribution of addresses and facilities was used in the analyses of both the tunnel alternative and the current situation.

3.2. Indicators

The case study focuses on quantifying the following barrier effects: increase in travel distance and time, reduction of access to facilities from residential addresses, and reduction of offer of facilities accessible from residential addresses. The analysis of the present situation and the tunnel alternative started with the most basic indicators of barrier effects, the effect that barriers have on the distance between origin and destination (Korner, 1979); in this case study between residential addresses and facilities. This indicator is referred to as proximity.

Using the road center line networks of the present situation and the tunnel alternative and the data sets from Gothenburg, the metric network distance between each address point and the nearest location in each type data set was measured. To get a clearer result, outliers with a value over three times the standard deviation plus the mean value of all distances measurements were deleted. After this, the values were scaled, and to create a higher barrier index for a shorter distance, the values were inversed using (1).

$$P_1(i) = 1 - \frac{d_{ij}}{\max d_{ij}} \quad (1)$$

where:

d_{ij} = metric network distance between residential address i and the facility j of type 1, which is closest to i

$\max d_{ij}$ = highest value of d_{ij}

$P_1(i)$ = indicator value for proximity to facility type 1 from residential address i .

Finally, an indicator value for proximity was calculated for each address point, by taking the average of proximity to the 12 different facility types.

Following Forkenbrock and Weisman (2001), an indicator for the offer of facilities which are accessible from each address point was then defined. This indicator is referred to as accessible offer. Again, using the networks of the present situation and the tunnel alternative and the data set from Gothenburg, the number of locations within a 3-km radius around each address point were counted, within each of the 12 facility types separately. The radius is measured as network distance. A 3-km radius was chosen to include both pedestrian as well as bicycle traffic. To get a clearer result, outliers with a value over three times the standard deviation plus the mean value of all distances measurements were deleted. After this, the values were scaled using (2):

$$A_1(i) = \frac{a(i)}{\max a(i)} \quad (2)$$

where:

$a(i)$ = number of locations of facility type j within a network 3-km radius from residential address i

$\max a(i)$ = highest value of $a(i)$

$A_1(i)$ = indicator value for accessible offer for facility type 1 for residential address i .

Finally, an indicator value for offer was calculated for each address point, by taking the average of accessible offer for the 12 different facility types, for each address point.

The analyses based on the proximity indicator and on the accessible offer indicator are presented in two maps, showing the increase of proximity and accessible offer that the construction of tunnels and increasing the number of cross-connections from 8 to 24 implies, compared to the situation as is. The increase of proximity was calculated as in (3), and increase in accessible offer was calculated as in (4):

$$P_{\text{increase}}(i) = \frac{P_{\text{tunnel}}(i) - P_{\text{present}}(i)}{P_{\text{present}}(i)} \times 100 \quad (3)$$

$$A_{\text{increase}}(i) = \frac{A_{\text{tunnel}}(i) - A_{\text{present}}(i)}{A_{\text{present}}(i)} \times 100 \quad (4)$$

4. Results

Fig 1 shows the increase of proximity brought by the tunnel alternative, compared to the present situation. As the maps shows, the increase is distributed in rather irregular patterns over the area surrounding the barriers. The highest increase of proximity is 15 % and is found in Backa (1). This increase in proximity implies that the distance between the residential addresses in this area, and the nearest education facility, health care facility, public transport stop or place with access to water, on average would become up to 15 % shorter. There is also a clear increase of proximity in parts of Ringön (2) and the southern part of Kvillestaden (3). Yet in Frihamnen (4) and the northern part of Kvillestaden (5) proximity stays more or less the same.



Fig. 1 The increase of proximity on the northern shore of the river Göta in Gothenburg

Fig 2 shows the increase of accessible offer that the tunnel alternative implies, compared to the present situation. Also, this effect is spread irregularly over the area around the barriers. The highest increase of accessible offer is 38 % in the southern part of Kvillestaden (6) which means that the residential addresses in this area would have access to up to 38 % more education facilities, health facilities, public transport stops or places with access to water. Accessible offer also increases in the western part of Rambergsstaden (7) despite its relatively long distance (530 m)

from the barrier and in Backa (8). Yet in the northern part of Kvillestaden (9) in Frihamnen (10) and Ringön (11) accessible offer does not increase significantly when the barriers are removed.

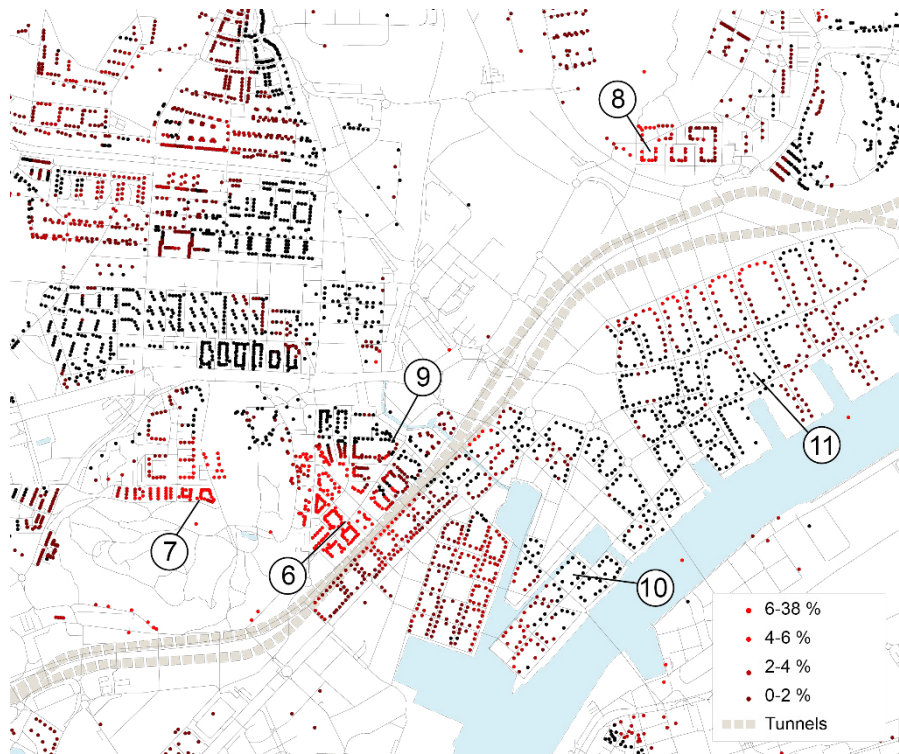


Fig.2 The increase of accessible offer on the northern shore of the river Göta in Gothenburg

5. Discussion

Central for this study has been the question of how barrier effects of planned motorway and railway infrastructure projects can be quantified. The case study demonstrates how the indicators that are proposed can give insight in the complex patterns in which barrier effects are spread over the area surrounding the barriers. Increases of proximity and of accessible offer are not distributed in a linear way from the barriers outward. Instead, these effects are subject to specific network conditions in the built environment and locations of facilities and are distributed in irregular patterns which appear difficult to predict. These insights can be of value for assessing where costly investments in infrastructure, such as tunnels, have the highest impact.

The two indicators cover only two of the many effects of barriers and need to be complemented with other indicators covering a wider spectrum of effects. Also the proposed indicators require further revision. One aspect which needs to be assessed further is the fact that the indicators show relative change and not absolute change. This implies that e.g. the analysis might show high values which relate to large relative changes in proximity, which in fact can be related to insignificantly absolute changes. Another limitation of the study is that the analyses do not indicate which of the 14 facilities are the most significant for barrier effects. And there might also be other facility types which are more important, such as shops and workplaces.

In the continuation of this research project, the intention is to develop indicators for the effects of barriers on catchment areas, on accessibility of workplaces, and on transport efficiency. Another step in the project is to study the effects that removing the barriers have on other facility types, next to the 14 types that were part of this case study.

The third element of barrier effects, people's wishes and needs, is another important factor in barrier effects, as different social groups are affected in different ways by barriers (Clark et al., 1991; Korner, 1979; Tate and Mara, 1997). This aspect will be dealt with in the next step of the project. In those studies, the focus will be on analyzing conditions for different social groups in general, rather than for specific groups living in the case study area today, as the aim of the research project is to develop a method for decision-support concerning interventions being executed in ten- or twenty-years' time, when the composition of the population may have changed considerably.

6. Conclusions

The purpose of this paper has been to make some first explorations in the development of a method for the quantification of barrier effects of motorways and railways to be used in planning processes of transport infrastructure. The literature review presented in the paper indicates how barrier effects arise in a particular meeting of transport infrastructure, the build environment and people's wishes and needs (Korner, 1979; Geurs et al., 2009). The importance of addressing these three elements is further illustrated in the review of existing methods for assessment of barrier effects.

Two indicators that take into account these three elements of barrier effects have been demonstrated: proximity to facilities, and accessible offer of facilities. In a case study, the indicators have demonstrated their potential to quantify particular barrier effects and to visualize the distribution of these effects. The results of the case study indicate that these indicators could make a valuable contribution to creating a method for the quantification of barrier effects.

With the possibility of quantifying barrier effects, their reduction can potentially be prioritized in decision making processes concerning investment in infrastructure. A reduction of barrier effects can have far-reaching societal impact, from an increase of accessibility to facilities and people, which may reduce social segregation, to improving health by creating more potential for active travel, such as walking and cycling. Furthermore, a method for quantification could provide local stakeholders such as municipalities and local communities with objective arguments in negotiations about infrastructure projects.

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