Quantifying community severance

A literature review

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Abstract

Comparing with other local effects of transport planning, the issue of community severance (or "barrier effect") has been neglected by both policy-makers and researchers. Severance is usually defined as the separation of local communities by transport infrastructure or road traffic. In most countries, the issue is either not included in project appraisal or included using general qualitative scales. A diversity of methods for quantifying community severance has been proposed over the years, but these proposals have very rarely been implemented. This paper reviews the existing research on this topic, including government guidance documents for transport appraisal in several countries, reports to public authorities and academic and technical papers. The focus is on the methods to identify and measure the effects of transport infrastructure and road traffic on local mobility and accessibility, especially in the case of pedestrians. The challenges for the integration of these methods in actual transport planning are also identified.

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1. Introduction

The term community severance is used when describing the effects of transport infrastructure or traffic as a physical or psychological barrier separating a built-up area from another built-up area or open space. The problem has gained increased social and political relevance in recent decades due to greater concern about the vulnerability of some groups, given trends such as population ageing and increase in ethnic diversity, income inequality and spatial segregation in many cities. Claims for the inclusion of severance and local pedestrian mobility concerns in transport planning are justified with their role in social inclusion [SEU 2003, Rajé 2004], environmental justice [Greenberg and Renne 2005, Bullard 2007] and as a social determinant of health [McCarthy 2005, Mindell and Watkins 2011, Cohen *et al*. 2014]. Improved pedestrian mobility is also linked to objectives such as social and environmental sustainability [Dempsey *et al*. 2011, Rogers *et al*. 2013].

Nevertheless, the issue has only slowly been introduced into concrete transport plans and policies. There is a lack of consistent guidelines for the identification, analysis and solution of the problem. When severance is included in transport appraisal, only broad assessments are made, lacking either rigorous quantitative measurements of the incidence and magnitude of the problem or detailed qualitative input from the communities affected by the problem. The assessments are also not used to generate options for projects, or as part of strategic transport and urban planning. Research on the topic is also much less extensive than studies dealing with other external effects of transport such as air pollution, noise and traffic collisions. This relative neglect happens because the severance problem is difficult to define and has complex causes and effects.

This paper looks at the methods currently in use or proposed to identify and measure community severance. The focus of the review is on the physical effects of transport infrastructure and traffic on mobility and accessibility, and not on the wider (second-order) economic, social and environmental effects that stem from those. For example, there is extensive evidence of the negative impact of road traffic on social networks [Appleyard *et al*. 1981, Mullan 2003, Sauter and Huettenmoser 2008, Hart and

Parkhurst 2011] and on spatial segregation [Noonam 2005, King and Blackmore 2013, Mitchell and Lee 2014]. A recent review has also documented the existing knowledge on the effects of severance on public health [Mindell and Karlsen 2012]. Improvements in local walking mobility may also have wide local and non-local economic and environmental effects, if they lead to a shift from motorised to non-motorised modes of transport. Finally, the review does not go into detail about qualitative methods to assess severance, covering these methods only when they are integrated with quantitative methods.

The next section is an overview of the existing body of knowledge on community severance. Section 3 proposes a framework to decompose the problem into a set of questions. Section 4 reviews methods to measure severance found in governmental guidance documents, technical reports and academic studies. Section 5 focuses on the integration of those methods in transport planning. Section 6 concludes the paper by identifying the major challenges and possible directions for future research.

2. Overview

The existing knowledge on community severance is mainly found in technical reports commissioned by governmental agencies. The main limitation of this literature is its lack of dissemination. The reports tend to be difficult to access, especially those produced before the advent of the internet. In most cases, they can be accessed only through the national libraries of each country. In addition, the proposals in these reports have very rarely been adopted by the governments that commissioned them. The few academic studies of severance also suffer from the lack of dissemination, as they tend to be published in technical, rather than academic journals.

The apparent lack of advances in the measurement and valuation of community severance is evident for example by the fact that studies over 20 years old such as the one by Clark *et al*. (1991) are still quoted today as one of the main references on the topic. Official guidance documents about transport appraisal also rely on documents that have not been updated for decades. For example, the UK official approach to the

measurement of severance is based on the 1993 Design Manual for Roads and Bridges [UK Highways Agency 1993].

Some of the technical reports and academic studies of severance have sections reviewing the previous literature, but these reviews offer a partial view of the problem since they focus on the issues related to the purpose of the research project they integrate. For example, Guo *et al*. (2001) give an overview of the concepts that have been used to define community severance (adapted later in Bradbury *et al*. 2007). Tate (1997) reviewed quantitative measures and Tomlinson and James (2005) reviewed government guidance on the monetisation of severance. Quigley and Thornley 2011 synthesized some of those reviews.

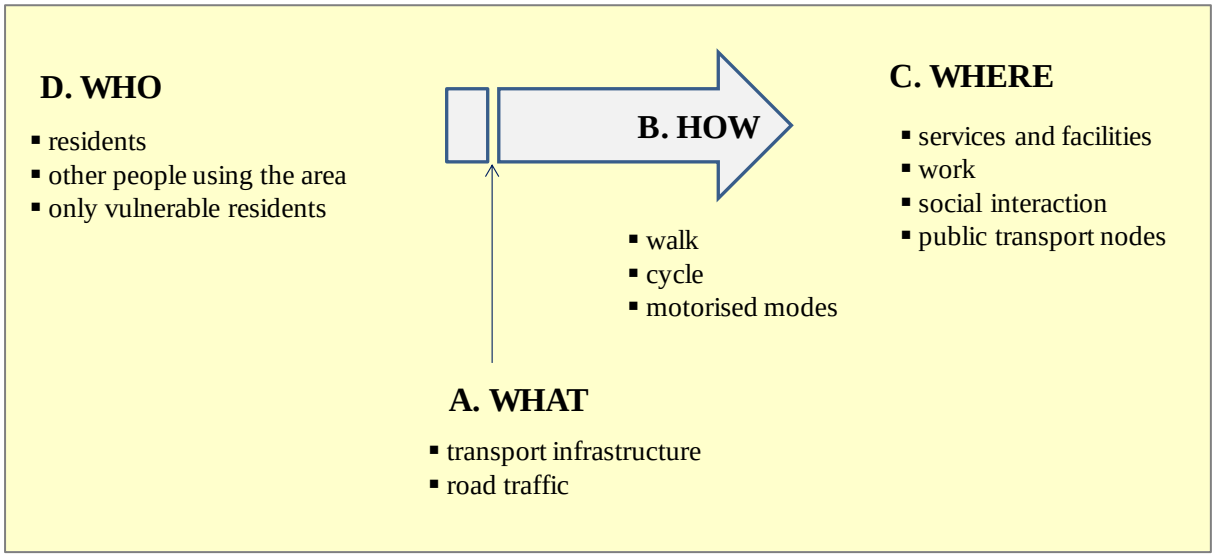
A common characteristic of research papers and literature reviews is that they devote a considerable length to the definition of severance. A comparison of the definitions proposed reveals that there is little agreement on the scope of the problem. Some authors assign the term severance to the impact of traffic and use "barrier effect" to the impact of infrastructure [Litman 2012]. Other authors make a distinction between "physical severance" (the changes in mobility and accessibility) from "social severance" (the wider social impacts arising from physical severance) [Lee and Tagg 1976, Stanley and Rattray 1978, Tate 1997, Read and Cramphorn 2001] and "community cohesion" (state of togetherness and unity within a community) [Quigley and Thornley 2011].

There is also little international dissemination of knowledge in this field, especially of work in languages other than English, despite the wealth of knowledge produced in some countries during the last decades. For example, in a full volume dedicated to severance, Héran (2011a) analyses the problem in the context of past, present and future dilemmas to urban planning and looks at several case studies in France. Several other studies have been produced in France [Loir and Icher 1983, Héran 2000, 2009, 2011b], as well as other countries such as Norway [Lervåg 1984], Denmark [Lahrmann and Leleur 1997, App.14-1, Meltofte and Nørby 2012, 2013], and Brazil [Mouette and Waisman 2004, Silva Jr. and Ferreira 2008, Sousa and Braga 2011].

3. Elements to define community severance

This section decomposes community severance into a set of questions, which are used in the next sections as a framework to characterize the methods found in the literature for measuring and evaluating the problem. The focus is on the effects of severance on local mobility and accessibility [Fig.1]. The four questions to consider are: what are the barriers that restrict mobility, how do people move, where do they go, and who is affected by the problem.

Figure 1: Elements to define community severance



a) What are the barriers?

Severance was defined in the introduction as the problem created by barriers separating a built-up area from other areas. Restricted-access transport infrastructure such as railways, motorways and dual-carriageways are physical barriers because crossing facilities are limited in number (left side of Figure 2). Traffic on the infrastructure can also be a barrier to local mobility, especially in the case of roads with high traffic levels or speeds (right side of Figure 2). In a literature review, Jacobsen *et al*. 2009 identified a consistent inverse correlation between traffic volumes and speeds and levels of walking and cycling. The negative effects of road traffic on pedestrians are labelled by some authors as "dynamic severance" [Guo *et al*. 2001]. Studies have shown that severance is less about road width and traffic volume and composition than about the suitability of

facilities to cross or walk along roads [Poole 2003]. More generally, severance depends on the pedestrian interaction with the environment and with other traffic system users [Hodgson *et al*. 2004].

Figure 2: Static and dynamic severance

b) How do people move?

The usual understanding is that severance restricts the mobility (ease of movement) of pedestrians. However, the issue is also relevant to other means of transport. Cycling is an important candidate, but cited only rarely [Read and Cramphorn 2001, Héran 2000, 2011a]. Methods to analyse severance experienced by cyclists may be different from those for pedestrians, because they travel faster and are not always allowed to use crossing facilities [UK DfT 2014a, p.18]. Severance can also be an issue for road public or private transport, when local traffic is affected by bottlenecks at junctions with main roads. For example, Rajé (2004) reports the case of a neighbourhood where car access is possible only by using a busy roundabout. The need to cross busy roads also reduces the efficiency of services that need to use the minor roads inside neighbourhoods, such as postal distribution, couriers, rubbish collection, public transport, police and emergency vehicles [Héran 2011a, p.31].

Barriers to mobility affect people's wellbeing, due to detours, delays and the discomfort of crossing facilities that are not at-grade. There are also effects on the quality of mobility, including exposure to pollution (air pollution, noise and dust), visual intrusion (reduced visibility, glare of lights and visual blight), perceived danger (from accidents and

crime), reduction of sense of place and general unpleasantness. These factors contribute to a psychological barrier, described in the literature as “felt aversion” [Lee and Tagg 1976, p.270], “feelings of being cut off” [Braddock 1979, p.172], “fear and intimidation” [Tate 1995, p.408] and "alienation" [New Zealand Transport Agency 2013, Part A8.8].

These effects may lead to changes in behaviour, when people avoid severance, further reducing wellbeing. This can be either through suppressed trips (overall or alone), change in destinations or travel modes, route diversion, risky behaviours (informal road crossings) and reduced use of streets as a social space. In the long term households may also respond to the problem by relocating to other areas [McLean and Adkins 1971].

c) Where do people go?

The focus of many of the definitions of severance found in the literature is the "divisive effect" of transport infrastructure [Urban Motorways Committee 1972, Clark *et al*. 1991, Tate 1997]. The operationalization of these definitions requires measures of accessibility, that is, the ease of reaching particular places. Losses in accessibility are especially relevant when they restrict the participation of individuals in activities or access to services that contribute to their social inclusion [SEU 2003]. Clark *et al*. (1991) enumerated 30 types of facilities that an index of severance should consider, grouped in seven categories: health, education, services, social, leisure, shops and transport. Only a few studies mention accessibility to workplaces [UK DOT 1983] and to public transport nodes such as rail stations or bus stops [Braddock 1979].

Loir and Icher (1983, p27) note that roads restrict access not only to the places one needs to go but also to the places one likes to go, for relaxation or social interaction. Braddock (1979) includes walking for pleasure and visiting friends and strolling. The definition of severance given by the UK Department of Transport in 1983 [UK DOT 1983] also mentioned the separation of people from social networks, although later guidance documents removed this mention.

d) Who is affected?

The phrase "community severance" indicates that the problem respects the effects on residents in a given area. However, the concept of "community" has many different

meanings [Stacey 1969]. Some authors are sceptical of identifying communities as socially cohesive groups living in geographically defined areas in the study of severance [Urban Motorways Committee 1972, Tate 1997]. The emphasis in this case should be on the group of people walking in the affected areas, which might include workers and shoppers as well as residents.

Within a community, there are also differences in mobility and accessibility needs, restrictions, experiences and perceptions. Research may assign priority to severance affecting some groups, due to their vulnerability to losses in pedestrian mobility. This is especially the case for people with disabilities or limiting health conditions. Evidence also shows that the impact of traffic barriers depends on age [Hine and Russell 1993, 1996, Russell and Hine 1996] and leads to the loss of children's independent mobility [Hillman *et al*. 1990, Hüttenmoser 1995, Tate 1995, 1997 Ch.5]. Severance is also an issue when affecting groups facing limitations in the set of residences, destinations or transport modes they can choose, including low-income, unemployed and car-less households and ethnic minorities. Gender is also relevant, as women tend to have lower levels of access to private transport, are responsible for a disproportionate share of domestic chores such as shopping, and are more vulnerable when walking alone.

4. Measurement

This section reviews methods for the quantification of severance, including the methods included in present or past official guidance documents for project appraisal in selected countries, and methods proposed in technical reports and academic papers. A set of issues is identified.

4.1 International practice

The UK Design Manual for Roads [UK Highways Agency 1993] is one of the few guidance documents in use that outlines an explicit approach to assess severance. The first step in this approach is the assessment of travel patterns, through catchment areas of key facilities or by Origin-Destination surveys and pedestrian counts. The second step is the assessment of the impact of delays and detours on the length of trips to alternative

destinations. Change in amenity is assessed separately, using a qualitative method that takes into account traffic volume and composition and the pedestrian environment. Finally, this information is used as a guide for the classification of the effects on a 3-level scale (slight, moderate, severe), based on traffic levels, types of road, crossing facilities, changes in journey length, number of people affected and temporal variations.

While this approach outlines a coherent work flow to assess severance, it does not recommend specific indicators and methods to use at each stage and ultimately it relies on the subjective classification of a large number of variables into levels of severance. The approach in most other countries is also descriptive [Odgaard *et al*. 2005, Mackie and Worsley 2013].

Some countries have used more detailed methods, such as Denmark [Vejdirektoratet 1992] and Sweden [Vägverket 1986] [Box 1]. In both countries, the barrier effect on pedestrians crossing a road was assessed as a function of traffic variables and corrected by the number of crossing facilities. In the Swedish approach, an additional value was calculated for pedestrian delay, based on traffic volumes. The effects were then multiplied by indicators of the need to access different types of facilities. In Sweden values also differed according to age group and context (urban, suburban and rural). These methods were used infrequently and inconsistently and have since been abandoned [Tomlinson and James 2005, p.8-9, Meltofte and Nørby 2012, Ch.3]. More recent versions of document on project appraisal include only general guidance [Trafikministeriet 2003, Trafikverket 2011].

Box 1: The Swedish and Danish approaches for measuring the barrier effect

The formulas below were included in the official guidance documents for assessing community severance in Sweden and Denmark. The formulas produce indicators of the impact of road traffic on pedestrians crossing the road. Separate formulas were included in the documents of both countries for measuring the impact of traffic on pedestrians and cyclists travelling along the road. The indicators for the two types of impact were transformed into monetary values and then combined into a single value.

Sweden

Disturbance effect = Disturbance x Crossing need

Disturbance = $T * (0.667 + 3.33H) * (0.02\,S)^4$

T: Traffic (vehicles/day)
H: Proportion of heavy vehicles
S: Speed (km/h)

Delay effect = Delay x Need

Delay = $1.26 + 4.54 * 10^{-6}T^2$

T: Traffic (vehicles/hour)
Delays at traffic signals, footbridges and underpasses calculated separately

Need: Depends on destinations, age group, context (urban, suburban or rural) and presence of crossing facilities

Denmark

Barrier effect = Barrier x Crossing need

Barrier = $0.1\sqrt{T} * (0.63 + 1.87\,H) * (1 - 0.05\,K * L)$

T: Traffic (vehicles/day)
H: Proportion of heavy vehicles
K: Number of crossing facilities
L: Length (km)

Crossing need: Shops, public offices, schools, housing blocks: 4; Low housing: 2; Summer housing, industrial and recreation city areas: 1; Unbuilt: 0

4.2 Theoretical and empirical developments

a) Crossability

At its most simple, the assessment of barriers to mobility is the measurement of their attributes. In the case of road infrastructure, these attributes are width and number of lanes. The ease of crossing a road for pedestrians also depends on crossing facilities,

which can be assessed regarding their availability (number of formal crossings per length of the road or average distance between crossings), type (at-grade, footbridge or underpass) and quality. This is relevant as poorly designed or maintained facilities may create "secondary severance", if some people cannot access them or if they perceive them as dangerous or unpleasant [James *et al*. 2005, p.57-58]. Roads may also have barriers preventing pedestrians from crossing, such as structures separating pavement and carriageway or opposite traffic lanes, including guard railings, fences, noise barriers, bunds (raised areas) and ditches. On the other hand, elements such as pedestrian refuges reduce the difficulty of crossing a road.

In the case of road traffic, the relevant attributes are volume, composition, speed, and direction. It is important to notice that the impact of traffic volume as a barrier is not linear, because after a certain level it causes a reduction in speed. Congestion, measured using indicators such as traffic density (the ratio between volume and speed), can also be relevant. However, Smith and Gurney (1992) found in a survey in London that congestion does not increase perception of severance. Related variables that were found to be relevant in empirical studies of severance include the presence of parked cars (especially kerbside parking) [Hine and Russell 1993, 1996, Hine 1996], road layout (especially gyratories and roads with many turn lanes) [Smith and Gurney 1992] and the ratio between pedestrians and motorised vehicles [Héran 2001a, p.112].

The "crossability" of a road can be measured by observing pedestrian behaviour. On-spot observation can produce variables such as pavement flows, crossing flows, pavement counts and insights into pedestrian behaviour such as crossing location, path, speed and hesitation. This information can be classified by age, group size and mobility impairments. The analysis of pedestrian behaviour has been facilitated by recent developments in the geographical analysis [Lassarre *et al*. 2012] and topological modelling of walking trips [Papadimitriou 2012].

Indicators of “crossability” can then be estimated. Sisiopiku and Akin (2003) measured compliance rates of pedestrians using different types of crossing facilities. Another possibility is the use of crossing ratios, that is, the number of pedestrians crossing the road as a proportion of the pedestrians walking in a section of the road [Russell and Hine 1996, Hine and Russell 1996]. However, the use of these ratios to

compare different streets or to assess changes in one street must take into account several factors, such as differences in types of land use, location of points of attraction and characteristics of the population walking in the area.

The impact of traffic barriers can also be given by the sum of the barriers on specified pedestrian routes. Tate 1997, p.30 suggests a "conflict index" given by the number of trips crossing a road multiplied by traffic volume. This type of index can be weighted with variables related to the type of infrastructure and land use. Clarke *et al*. (1991) also propose a "mitigation factor" for the presence and quality of crossing facilities. This factor may vary with the characteristics of the population who needs to use them.

Severance can also be measured in terms of pedestrian delay, an approach used in early studies of pedestrian mobility [UK Ministry of Transport 1963, Appleyard *et al*. 1981, Ch.4]. The official guidance in the UK estimates delay at crossings using formulas taken from Goldschmidt (1977) for the relationships between mean pedestrian delay and traffic flows for different types of crossing facilities. There is also a long history of research on crossing delay based on the distribution of gaps between vehicles in the traffic flow ("acceptance gap"). Hunt and Williams (1982) used this method to derive indicators for pedestrian mean delay, the proportion of pedestrians delayed and proportion of pedestrians with a delay greater than a specified level. Hunt and Abduljabbar (1993) also defined a crossing index that takes into account different crossing strategies. Pedestrian delay can also be measured through video surveys, which account for local road characteristics and traffic conditions that are not captured by statistical models. Information on crossing delays can then be used in the estimation of journey times. For example, in the official guidance for transport appraisal in Germany, severance was measured in terms of pedestrian time losses, based on waiting times and the number of times that local residents crossed the road [BMVBS 2003, Part IIIb].

A final alternative is the assessment of the obstacles pedestrians face when walking. For example, Olszewski and Wibowo (2005) modelled the relationship between walking trips to train stations and characteristics of routes taken. The model was then used to estimate trade-off values between the distances walked and the effort to overcome obstacles [Box 2]. Jones *et al*. (2005) also calculated trade-off values between walking

times to bus stops and characteristics of the walking environment, including road traffic, finding differences according to gender, age and mobility impairment.

Box 2: Measuring obstacles to pedestrian routes

The study of Olszewski and Wibowo (2005) in Singapore used survey data to model the probability of walking to a rail station as a function of the characteristics of the routes taken, including walking distance, number of road crossings (both signalized and non–signalized), number of ascending steps (with slopes converted to equivalent number of steps) and traffic conflicts encountered along the route (crossing of car parks or access driveways).

The model was then used to estimate trade-off values between distances walked and effort to overcome obstacles. These values are the ratio between the model coefficients of the variables measuring obstacles and the coefficient of walking distance. The table below gives the results found:

Obstacle	Trade-off with walking distance
Crossing one road	55.4 m
Climbing one step	2.81 m
Cross one car park or access road	36.3 m

The "equivalent walking distance" of a given route can then be found by adding the actual distance walked and the effort of overcoming obstacles (measuring in terms of their trade-off value with walking distance).

This approach can be applied in the study of severance because it estimates objective indicators of the impact of transport infrastructure and road traffic on walking mobility, based on the actual preferences of pedestrians.

b) Accessibility

The assessment of the impact of barriers on people's accessibility requires, by definition, the specification of the potential destinations for walking trips. Most existing methods rely on a set of local facilities, such as schools, health centres, or community centres. According to the UK guidance these facilities should be selected based on their general level of use, use by vulnerable groups, availability of alternatives and importance [UK Highways Agency 1993]. In the specification of quantitative indicators, the facilities can then be weighted by the measured number of trips they attract or by factors based on their importance. For example, the Danish guidance assumed that it is four times less important to cross the road to access a recreation space than to access shops, offices, schools or housing blocks.

Changes in accessibility caused by road barriers can be approached from the perspective of the destinations. Clark *et al*. (1991) proposed an index for use in the UK that estimates the population potentially affected by severance, by calculating the residents living in the catchment areas of facilities to which access is impaired due to a busy road. The index then combined population affected, traffic flow and a mitigation factor. The method does not take into account the non-resident population and relies on the assumptions that catchments areas are mutually exclusive and people use the nearest alternatives, within a certain walking threshold. The index was not specified in the paper but some of its main aspects informed the approach currently in use in UK. The paper also influenced the proposal by Tate (1997) for the New Zealand Transport Authority, which added proxy variables for measuring the effect on suppressed trips. This proposal was also never implemented.

Changes in accessibility can also be approached from the perspective of residential locations. A popular indicator of potential accessibility is Hansen's gravity-type measure [Hansen 1959], which is the sum of the attractiveness of all possible destinations for people living in a certain place, inversely weighted by travel time. In this indicator, the effect of severance is either a reduction of the number of accessible destinations or an increase in travel time. This type of measures can be adapted for the measuring the accessibility of non-motorized modes of transport [Iacono *et al*. 2010].

The assessment of the effects on leisure walking trips, for exercise or socializing, is less-straightforward than the one for access to facilities, as assumptions are needed regarding the places where people meet (such as public spaces or each other's houses). Anciaes (2011, Ch. 2.3) proposed an indicator based on the loss in the potential for population interaction, that is, the restriction to access nearby locations, weighted by a function depending on population density.

The proposals above are indicators of the effect of roads on potential accessibility, not taking into account people's actual mobility patterns, including commuting. Household and on-street surveys and travel diaries can be used to estimate the effects of busy roads on actual trip origins and destinations, modal choices and route choices, and to examine how these effects depend on factors such as individual characteristics, trip purpose, distance, availability of suitable alternatives, and provision of facilities to

mitigate the barrier effect. Survey data can then be validated against pedestrian counts in different locations or before and after a project is implemented.

c) Walkability

Relevant information can also be given using indicators of the ease of walking in local areas. A 2004 literature review has found that the propensity for walking for transport and for recreation is associated with a series of dimensions of the local built environment [Owen *et al*. 2004]. Since then, a large body of literature had been produced measuring "walkability". Lack of walkability can be understood as a dimension of severance or as an effect of the severance caused by transport infrastructure or traffic.

Walkability may be assessed by the availability of local destinations for pedestrians. For example, the walking opportunities index [Kuzmyak *et al*. 2006] is based on the number, character and desirability of activities within walking distance. Instead of specific destinations, we can consider walkable catchment areas (known as "pedsheds"), the areas within a circle drawn around a given point (usually a train station) that are judged to be accessible to pedestrians. This judgement may consider aspects such as street layout, connectivity and safety [Porta and Renne 2005] or perceived barriers to walking such as busy roads, gradients and poor lighting [Jones *et al*. 2005]. A ratio can then be calculated between the accessible area and the total area within the circle defined. Catchment areas can also be used to map pedestrian access to major facilities and to assess the effects of changes such as the construction of large transport and non-transport infrastructure and new residential areas or facilities without considering or reformulating the existing street network [Héran 2011a, Ch.4].

Walkability also depends on the street layout, and especially on connectivity, which have been shown to be related with social cohesion [Cooper *et al*. 2014]. Connectivity can be assessed by variables measured on the street network of a well-defined small area. Examples include the ratio between intersections and links, street length or area; the ratio between street area and total area; the ratio between the street network distance and straight line distance between pairs of points; the ratio between catchment areas around some point calculated using network distance and straight line distance;

and the average distance between junctions, and the number of route choices between pairs of points.

Busy roads also affect walkability because they can restrict the area accessible to pedestrians to one side of the road, where conditions for pedestrians may be worse than in the area on the other side. The literature gives a large number of possible indicators to measure these conditions, such as residential density and land use mix [Frank *et al*. 2005], the "social width" of the road (space available for social interaction) [Porta and Renne 2005], the density of 4-way intersections and the ratio between roadside parking area and carriageway area [Parks and Schofer 2006] and indicators of aesthetic, safety and pedestrian conveniences in the area [Neckerman *et al*. 2009].

The presence of large transport infrastructure has a clear impact on measures of neighbourhood walkability, but the full assessment of this impact requires the use of methods of space syntax, to analyse in detail the characteristics of the local street network, the relationships of this network with the rest of the urban street network and the actual effects on pedestrian behaviour.

d) Safety and amenity

Traffic barriers can also be assessed in terms of their impacts on the quality of local mobility. One of the impacts is on people's perceived risk of being victims of collisions. Perceived risk can be measured directly, using surveys [Davis 1992, Tate 1995, 1997] or estimated by a formula, such as in the Danish official approach, which was based on traffic variables and facilities for pedestrians and cyclists [Vejdirektoratet 1992]. An alternative is to analyse patterns using collision data [Appleyard and Lintell 1972, Hine and Russell 1993]. If severance reduces the number of people walking, there is also an indirect effect on people’s perceptions of safety in relation to crime. These effects can also be captured by surveys, but it may be difficult to isolate the links between road traffic, pedestrian traffic, and perceptions of safety.

Traffic also has an effect on the amenity value of walking. This effect is especially relevant if we define severance as an issue affecting not only people crossing the road, but also people walking or cycling along the road [James *et al*. 2004, Héran 2011a, p.70]. The effect on cyclists was included in the Swedish official approach as a function

of the number of vehicles overtaking, which depended on average traffic speed [Vägverket 1986]. In general, the assessment of amenity requires information about the attributes of the pedestrian environment, such as existence, width and quality of pavements and their distance from traffic, street furniture and planting, lighting, information, maintenance and appearance. These aspects can be assessed and converted into numerical scores using systems such as the Pedestrian Environment Review System (PERS) developed by the Transport Research Laboratory in the UK.

e) Perceptions

The objective indices based on the measurement of attributes of the transport infrastructure, road traffic and street network and on the observation of pedestrian behaviour cannot capture psychological barriers. For example, suppressed trips and other changes in behaviour can only be identified with attitude surveys [Hine and Russell 1996]. Pedestrian injuries and fatalities are also imperfect indicators of risk as "the fact that a road has a low accident rate might mean not that it is safe but that is so terrifying dangerous that few people try to cross it" [Adams 1988, p.346]. Lee and Tagg (1976) and Read and Cramphorn (2001) argue that severance is defined by people's perceptions, cognitions, attitudes and behaviours in the face of barriers. Information on these reactions, obtained by surveys, interviews or focus groups, should then complement the objective measurements of the barriers.

These methods can be used to obtain quantitative variables. For example, Tate (1995, 1997 Ch.5) measured perceptions of danger as the proportion of parents who stated that they would allow their children to cross the road unaccompanied in locations with different traffic volumes, compositions and speeds. Mouette and Waisman 2004 used multiple correspondence analysis to model the relationships between variables obtained from a survey of people's perceptions about severance, considering different levels of impacts [Box 3]. In a Brazilian study, Silva Jr. and Ferreira (2008) used the Likert scaling method [Likert 1932] to derive scores for perceptions of impacts of roads, such as changes in number of trips, detours, perceived danger, crossing difficulty and environmental disamenity.. The analysis determined the relative importance of a set of alternative variables used to define each of those impacts.

Box 3: Multivariate analysis of surveys to people's perceptions

Surveys of people's perceptions about severance usually produce information about several categorical variables. This information can be analysed using multivariate statistical analysis. For example, the study of Mouette and Waisman (2004) assumed that the effects of severance form a hierarchical chain, where the effects at each level create conditions for the occurrence of effects at the next level. The analysis considered five levels:

Level 1	Causes of severance	Traffic level, speed and composition, parked cars
Level 2	Direct impacts	Ease of crossing the road, safety, delay
Level 3	Impact on trip patterns	Changes to number of trips, modal choices and independent trips
Level 4	Impact on behaviour	Changes in participation in activities, walking locally, routes used
Level 5	Impact on social relationships	Number of local acquaintances, neighbourhood perceptions

The survey asked people's perceptions about the effects in all five levels. The structure underlying the multiple relationships between the effects was determined using multiple correspondence analysis. This method analyses the correlations between all variables, allowing for the identification of strong relationships between pairs of variables in consecutive levels. In a second stage, fuzzy logic was used to build rules of inference (functions relating outcomes with premises defined by logic conditions).

This type of analysis allows the comparison of the effects of severance on different groups in living in the same neighbourhood. In an application of the model in two neighbourhoods in Leeds, UK, the study found differences in the effects felt by children, older adults and younger adults (subdivided into three groups: parents, carers of people with restricted mobility, and other adults).

Qualitative methods can also provide spatial information useful to assess perceptions. Appleyard and Lintell (1972) used dots, lines and polygons to represent people's gathering places, acquaintances and "home territories" respectively. Lee and Tagg (1976) also translated the effect of new roads as a series of spatial variables derived from surveys, such as the size adjustment and shift of people's perceived neighbourhood and "bridging" perceptions and behaviour across the road [Box 4]. Mental maps can also transmit information about psychological barriers, while still accounting for the factors that continue to draw people across busy roads, for example the attractiveness of destinations on the other side of the road [Tate 1997, p.27].

Box 4: Translating qualitative information into spatial variables

The use of qualitative methods is often criticised for the difficulty of generalising the rich information they produce. However, when the object of survey is linked to geographic aspects, it is possible to translate qualitative information into maps or spatial variables.

Lee and Tagg (1976) used interviews to assess the effects of road-based severance in seven case studies in the UK. Participants were asked about their social activity (contacts and trips), to identify local "landmark points" presented to them in show cards, and to draw maps defining the boundaries of their neighbourhoods. The information collected was then geo-referenced, allowing for the construction of several variables that relate the participants' answered with the location of busy roads. These variables were grouped into three categories:

Size adjustment	▪ Area of neighbourhood map ▪ Number of points included in neighbourhood ▪ Total number of points known in the neighbourhood
"Bridging"	▪ Perceived neighbourhood boundary crossing road line ▪ Proportion of landmark points included from the "other side" ▪ Known points on the "other side" ▪ Proportion of crossover trips ▪ Proportion of crossover social contacts
Shifting	▪ Displacement of neighbourhood "centre of gravity" from home, in direction away from the road ▪ Disequilibrium of "other side" landmarks in distance rank ordering

Photographs and video recordings can also be used to synthesize objective information to be used in conjunction with surveys. For example, the analysis of results of surveys of perceptions can be compared to recordings of traffic conditions [Hine and Russell 1993] or pedestrian behaviours [Sisiopiku and Akin 2003]. Conversely, recordings of traffic conditions [Hine 1996] or photographs of crossing locations [Montel *et al*. 2013] can be shown to interviewees in order to elicit their responses.

4.3 Challenges

a) Inputs

Indicators of severance are particularly sensitive to the value of some inputs. These include for example the set of pedestrian destinations included when measuring loss of accessibility. Clark *et al*. (1991) mentions a study where not including a facility underestimated severance effects, especially those of vulnerable populations. Results

also depend on the type of barriers included. The incidence of barriers caused by railways, motorways and busy road varies within an urban area [Anciaes 2011, Ch. 2.3].

Different values can also be defined for the traffic levels or speeds thresholds that define severance – which may vary according to the composition of the population affected In official guidance in the UK, "severe severance" is defined as traffic above 16,000 vehicles per day- enough to include 88 % of all traffic counting points in London in 2012. May *et al*. (1985, p.95) also give thresholds above which there is a possible change in walking perceptions and behaviour triggered by specific reasons. For example, annual average daily traffic values of 40,800, 24,000 and 16,800 lead to annoyance due to delays, exposure to noise, and perceived danger respectively. Values over 31,200 and 9,600 leads to suppressed walking trips of adults and children due to perceived danger.

Results are also sensitive to the choice of indicator used to measure speed and traffic volume. Tate (1995, 1997 Ch.5) show different associations of pedestrian behaviours with speed measures such as the space-mean, time-mean and percentile values and with traffic measures such as peak hour traffic, week day average daily traffic and 16-hour flow.

Another important input is the “normal” or reasonable walking distance. Studies of pedestrian accessibility usually consider 400m, 800m or 1km, depending on the type of destinations visited. Braddock (1979, p.177) report tables with the results of a survey showing that distances walked to bus stops and shops tend be similar, while distances walked by pedestrians strolling or visiting friends are considerably longer. It should be noted, however, that the reasonable walking distance for certain sections of the population, especially for elderly people, is lower than the average [Burton and Mitchell 2006].

Hypotheses about pedestrian route choice may also influence the results of empirical analyses of severance. Studies relying on straight-line distances miss relevant detail which can only be captured by modelling routes on the street network. The potential bias of using straight-line distances is revealed, for example, when comparing pedestrian conditions within straight-line and network-based buffers around some point [Frank *et al*. 2005] or in buffers with different radius [Manaugh and El-Geneidy 2011]. The modelling of pedestrian routes should recognise that pedestrians do not necessarily take the

shortest route, especially when walking for pleasure. Walking is also influenced by the pedestrian environment [Guo 2009], gradient, land use, and by the need to use crossings not at-grade. Elderly pedestrians also face micro-level barriers to walking, such as steps, slopes, and obstructions on the pavement [Mackett *et al*. 2008]. The estimation of optimal routes is also limited by the network data used as input, as maps tend to miss out some pedestrian pathways.

b) Space

Effects depend on the spatial context. The features of the problem identified in the study by Boddington *et al*. (1977) about severance in rural areas contrasts sharply with the bulk of other research, which is based on urban areas. The differences can be independent of traffic levels and speeds. For example, Poole (2003) reports the results of surveys that show that the worst cases of severance in terms of people's willingness to walk and perception of quality of life were in towns and villages that straddled old, two-lane roads and not in dense urban neighbourhoods near dual-carriageways. For this reason, the results of research about severance can only be generalized if they are based on information obtained in different contexts. The Swedish methodology accounts for urban-suburban-rural differences, but more detailed distinctions of population density and land use could increase its robustness.

The aggregation of severance effects to use in project appraisal also depends on assumptions regarding how those effects decrease with distance. Lee and Tagg (1976) used samples at successive 200m from a road and concluded that familiarity with the area across the road and number of trips and social activity in that area do not decrease linearly with distance from the road. Loir and Icher (1983, p.18-19) also argue that people living farther from the road are more able to separate severance from more tangible effects such as noise, so have a clearer perception of the problem. In addition, it is not distance as such but the type of land use between the residence and the road that counts. However, it is also possible that severance affects the whole road and street network in a neighbourhood. Minor roads can be used by rat-running traffic to escape congestion, and access roads to the main roads may suffer congestion. These aspects are only rarely considered in the literature [Smith and Gurney 1992, Appleyard *et al*.

1981 Ch.3, Ch.9]. Loir and Icher (1983, p.32) also note that at a higher scale (of the city), severance can affect the homogeneity, spatial equilibrium and integration of the urban fabric

There is also a cumulative effect of the presence of transport infrastructure alongside other infrastructure, limiting the number of access points to areas outside a neighbourhood. Jacobs (1961, Ch.14) talks about "border vacuums" created by transport corridors, industrial areas, car parks, university campuses, administrative centres and hospitals, which fragment the city in units that are not self-contained. Héran (2011a, p.75-77) adds ports and airports, goods yards, car parks, cemeteries, quarries, shopping centres and public parks (at night). In an empirical study, Anciaes (2011, Ch. 2.3) mapped the cumulative effects on severance of barriers caused by transport and industrial barriers in an urban area.

c) Time

The time dimension is also relevant. Accessibility needs vary with day of the week, with routes to work being more important during the week and recreational routes on weekends. The impacts of road traffic on people's wellbeing also vary by time of the day. James *et al*. (2005, p.51) argue that traffic levels are more relevant during the day and traffic speeds during the night. Methods used to collect on-the-spot traffic data and pedestrian counts should also take into account daily variations due to meteorological conditions.

There is also a need to forecast variables and update the inputs and specification of the indicators over time, to account for changes in traffic conditions, mobility needs and residential and land use patterns. Read and Cramphorn (2001, p.33) suggest that model parameters should be revised every 5 years to account for change in “systems, technology and physical environment”.

The relevance of the problem for the local populations also depends on the time over which the barrier has been present. The hypothesis of Appleyard *et al*. (1981, p.39) is that street satisfaction depend on local environmental changes, time of residence and expectations of alternative residence. Lee and Tagg (1976) analysed perceptions and behaviours in communities separated for different lengths of time, concluding that over

time, the communities start to differentiate. The assessment of severance then needs to consider whether communities already had few links when the barrier was built [Loir and Icher 1983, p.30, 38]. The past and present degrees of community cohesion are also relevant, and can be assessed by variables such as average length of residency, type of dwelling and socio-economic and mobility differences between the populations on opposite sides of the barrier.

5. Integration in transport planning

The integration of quantitative measures of severance in public policy can occur in several instances, such as in the planning or design of new transport infrastructure, redesign of existing infrastructure, implementation of traffic policies, and monitoring of existing infrastructure.

Measures and values of severance can be integrated into appraisal procedures, which are usually required at the planning stage of major transport infrastructure. The UK guidance recommends the assessment of the overall balance between changes in severance and the number of people affected in different locations [UK DfT 2014a, Ch.5], although the effort devoted to the analysis of walking schemes should be proportional to the scale of the project [UK DfT 2014c, p.1]. After converted to monetary terms, severance effects can also be compared against the benefits that roads and railways bring to their users and to the communities they cross, within formal procedures such as cost-benefit analysis (CBA).

Distributional issues are usually accounted for in project appraisal by separating and using different methods to measure the impacts on vulnerable groups [UK Dft 2014b, Ch.6]. An alternative is to weight the impacts of the projects according to the groups affected. For example, the Swedish approach to assess severance [Vägverket 1986] used observed trip frequencies to measure the potential need for walking for each age group, which in the case of elderly people were corrected to account for higher propensity to suppress trips where barriers already exist. Rintoul (1995, cited in Forkenbrock and Sheeley 2004, p.157-161) adapted this approach by using different

values for both the need for walking and the disruption caused by traffic barriers on different age groups.

Community severance can also be included in methods of transport appraisal other than CBA. For example, multi-criteria analysis can be used to compare alternatives based on attributes that are not necessarily expressed in the same units, for example, different of aspects of severance. Measures and values of severance can also be useful as a part of local assessments, integrating frameworks such as the Accessibility Planning in the UK [SEU 2003] and Community Impact Assessment in the USA [US DOT 1996]. In these cases, severance can be used alongside other variables (such as levels of public transport accessibility) to derive an in-depth understanding of the role of transport in social exclusion and community cohesion. Finally, quantitative measures of severance can be included in environmental assessment regulations, providing an objective scale for measuring standards that should not be exceeded. For example, transport appraisal in Germany relies on a "red flag" procedure signalling projects that violate certain environmental constraints [Gühnemann 2013]. Measures of severance could be included in the specification of these constraints.

Indicators of levels of severance can also be used in the design of new transport infrastructure. One possibility is to include those measures alongside other variables in an objective function used to generate options or derive optimal projects. For example, the optimal alignment for a road can be defined as the one that minimizes a cost function that includes the costs of severance effects across the neighbourhoods crossed by the road [Anciaes 2013]. Loir and Icher 1983 (p.71-96) also discuss some factors to take into account in route design, such as the location of urban limits and borders of different types of land use, and the impact on local accessibility in areas crossed by the road. Decisions about the location and characteristics of crossing facilities and pedestrian amenities can also be informed by information provided by quantitative measures of severance.

Indicators of severance can also assist in the design of schemes to reduce severance, for example, through the redesign of existing infrastructure (for example, calming traffic, reallocating space or improving the pedestrian environment) or traffic policies (such as the reduction of speed limits). The information helps the assessment of the desirability of

the schemes, analysing the impact of the schemes on people's mobility and accessibility (especially regarding actual levels of usage of crossing facilities) and balancing the benefits with the costs that are imposed on other road users (due to delay) or shifted to other communities (due to traffic diversion).

Finally, quantitative measures can be used for monitoring severance associated with specific infrastructure or at a city or regional level, generating information to inform strategic transport and land use planning. In this case, some procedures may have to be simplified, for example by focusing on parts of the network or geographically coarse areas or using simple catchment areas [UK DfT 2011]. Héran (2011a, Ch.5) proposes that plans for the prevention of severance should be compulsory in big cities, similar to the plans required by European regulations for noise reduction. As in this case, the plans for severance should be supported by a cartographic diagnostic, to be used by practitioners and made public. Some French cities have included maps of severance "hotspots" in their walking plans [Communauté Urbaine de Strasbourg 2012, p.17]. The mapping of levels of severance in an urban area can also help to identify priority areas, and groups at a disadvantage, and analyse the evolution of the problem, assessing the effects of past or future plans and policies [Anciaes 2013, Ch. 2.3] or compare conditions on neighbourhoods with different socio-economic compositions [Neckerman 2009].

6. Conclusions

This paper reviewed methods for the measurement of community severance caused by transport infrastructure and traffic. Official guidance documents for project appraisal rely on general qualitative scales open to different interpretations. A variety of methods have been proposed in technical reports and academic papers, which have had little dissemination and applicability. There is a need for objective indicators that can be used in a consistent way for understanding the nature, incidence and intensity of the problem, especially when affecting vulnerable groups. The use of quantitative measures also contributes to the public acceptability of transport plans causing or reducing severance, which tend to be based on ad-hoc political decisions.

Research on this topic has focused on the impact of road traffic and not on the road infrastructure itself. In addition, there is little guidance, methods or evidence on issues such as railway-based severance. Most of the indicators found are based on potential effects, considering a relatively small number of trip destinations. More research is needed on the effects of barriers on realised mobility (the way people actually move), taking into account the individuals' accessibility needs and the ways they use the street network, including structures built to mitigate severance such as footbridges and underpasses. In general, the existing methods tend to be more useful for assessing the effects of large transport projects rather than for assessing smaller schemes or for monitoring severance after the projects are implemented.

The development of tools to address a poorly understood issue such as severance requires evidence-based research, which can be costly and time consuming. This is especially the case for methods of assessment of traffic barriers, which rely on video surveys, and stated preference surveys. This is a limitation for the applicability in routine practice by local authorities and transport professionals. The use of indicators and monetary values found elsewhere is an alternative but should be used with caution, because the characteristics of the problem may not be comparable across different contexts.

This review also revealed that there is a tendency for the simplification of methods for measuring severance. This is evident for example in the fact that countries such as Sweden and Denmark have abandoned recommendations for the use of detailed formulae. The official guidance documents in the UK have also become more concise over the years. However, the concept of severance as used by researchers has become wider, and has expanded from the original meaning of barrier to mobility. Empirical analyses of severance become more complex if they deal with issues such as the effect of busy roads limiting access of cars and buses to neighbourhoods, or the disamenity effect on pedestrians walking along roads.

The reduction of a complex problem such as community severance to a single indicator also carries some risks. Tomlinson and James (2005, p.10) suggest this is the reason why countries such as Sweden and Denmark abandoned formulae for the detailed assessment of severance. The risks of reductionism can also be addressed by the

construction of multidimensional indices, disaggregated according to different aspects of the problem, or to the group affected, and allowing for sensitivity tests on each dimension.

It is important to bear in mind that the barrier effect of transport infrastructure and traffic on mobility and accessibility is at the beginning of a complex chain of wider impacts on the economic, social, health and environmental wellbeing of local communities. The assessment of these impacts needs to consider the relationships between variables of the transport infrastructure and variables of the built and social environment [Loir and Icher 1983, p.25]. As such, the development of indicators such as those reviewed in this paper should involve not only transport geographers, but also experts in urban design and public health, and the results should be useful not only for transport planning but also for spatial planning and social policies.

The development of objective methods to measure and value severance can also facilitate the inclusion of local communities in the planning process, if these methods integrate practical tools that are made available for the public. The development of these tools can benefit from the engagement of researchers with the communities, in order to understand whether and how the problem affects wellbeing and behaviour, especially in the cases of groups who do not usually participate in public consultation.

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