

Road pricing from a geographical perspective: a literature review and implications for research into accessibility

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Abstract

Road pricing policies have been a subject of research for many decades. Even though until now examples of actual implication in the real world are limited, many different road pricing measures have been considered, both in literature as well as in the political debate in several countries. Most literature focuses on economic aspects, more or less ignoring spatial consequences. In this paper we will concentrate on accessibility in relation to road pricing. Accessibility is a specific research field in geography and can be quantified by accessibility measures. However, accessibility measures in the current form cannot be used to describe accessibility effects of road pricing in a realistic way. This paper gives some directions for adapting the impedance function of accessibility measures, while leaving the key characteristics of different accessibility measures intact.

The generalized transport costs approach offers a good basis to start from. But current generalized transport cost functions are not differentiated enough in order to be able to describe accessibility effects of road pricing measures in a representative way. When describing accessibility effects of road pricing account must be taken of the fact that different actors with their accompanying characteristics will perceive accessibility under road pricing conditions in a different way. Furthermore, this perceived accessibility may also be influenced by factors such as traffic conditions and reliability aspects. Therefore, it is important to differentiate accessibility analysis according to key characteristics. Not all accessibility measures are equally adaptable. Two well-known measure types, the potential and contour measures, can be improved with a more realistic impedance function without compromising other advantages and disadvantages linked to the concept of these measures.

1. Introduction

Pricing policy has been a subject of research for many decades. Especially in the last decade pricing policies are getting more and more important in the public debate (e.g. European Commission, 2001) because pricing measures are expected to alleviate many currently existing problems due to traffic and transport (e.g. congestion, environmental problems). Quite a lot of research has been done on pricing policy topics but the amount of research concerning pricing in a spatial context is limited.

The main purposes of this paper are:

- To give an indication of the available literature on pricing policies especially in a spatial context;
- To examine the relation between accessibility (measures) and costs.
- To give directions for needed adaptations of accessibility measures.

Therefore in paragraph 2 the backgrounds and the in different countries increasing importance of pricing policies are discussed. In paragraph 3 literature and research fields concerning pricing policies (road pricing) are outlined. A distinction is made in categories to which many road pricing policy studies can be attributed. In spite of the importance of the geographical aspect in traffic and transport, literature on the geographical impacts of road pricing policies is scarce. Paragraph 3 therefore also gives an overview of some of these scarce studies concerning spatial impacts of pricing

policy. Paragraph 4 elaborates on accessibility that plays an important role in the interaction between land use and transport. First a definition of accessibility is given and then the place of accessibility in the transport cycle is explained. In paragraph 5 an overview and categorization of accessibility measures will be given including advantages and disadvantages. Paragraph 6 deals more specifically with the link between accessibility measures and road pricing. In the various sections a conceptual model of spatial effects of road pricing will be presented, directions for improvement of accessibility measures with regard to road pricing will be given and the suitability of different accessibility measures to incorporate improvement directions will be explored.

2. Pricing policy: backgrounds and (inter)national policy

Road transport is an essential service in any society. Goods have to be transported between producer and consumer and passenger transport, both private and public, allows a person to join activities at different locations and during different time intervals. The benefits of transport are many and varied: an efficient transport system is a major contributor to economic growth, competitiveness and employment. Therefore an efficient transport system is important.

A transport system is highly dependent on the infrastructure and on the level-of-service on the infrastructure. Economic growth and technological development however have put much pressure on the level-of-service of the infrastructure. Traffic intensities are increasing every year and the road supply can often not handle the increasing demand for travel; congestion occurs in and around bottlenecks and especially during peak hours. For an extensive overview of congestion (data, factors influencing congestion etcetera): see Bovy (2001) and Bovy and Salomon (1999). This trend of increasing problems can be seen in the whole modern western world. Time losses, as a consequence of congestion, cause negative economic effects. E.g. the value of the "lost vehicle hours" on the Dutch main road network is approximately 0,8 billion Euro (NEA, 1998). Moreover congestion has an impact (both positive and negative) on road safety, emissions and noise (ECMT, 1999).

In the recent past, public institutions dealt with increasing demands of traffic by building new infrastructure in order to enlarge supply. Forecasts for road traffic showed where capacity problems could be expected, leading to road building schemes (the

"predict-and-provide paradigm"— see Banister, 2002a). Experience has learned however that this boost in supply led to generation of new traffic demand (Goodwin, 1996). This is a cyclic process. Therefore nowadays more and more the opinion of the authorities is shifted to a demand based policy and measures are searched that influence demand, for instance measures that relate costs people have to pay for movements more directly to the users. This means that the variable costs (e.g. kilometre costs) must be given a greater share in total travel costs. Relating travel costs more directly to car use (transferring fixed to variable costs) can enlarge the incentive for actors to reduce car use.

Also the general opinion in new policy is that road users have to take full account of the cost they cause. This means that road users have to take the external costs into account. External costs partly consist of some costs inside the transport system (the in-system costs), such as congestion and accident costs. Furthermore all costs outside the transport system are part of the externalities. These costs consist of environmental costs, such as noise nuisance, local air pollution, acidification and climate change (Van Wee, 1995). External costs arise whenever the well being of an individual is affected by the activities of others who ignore this "spill over" when taking their decisions (European Commission, 2001). Therefore external costs have to be internalised (the polluter pays). From an economic point of view this means that the marginal willingness to pay must be equal to the total marginal social costs. The internalisation of the externalities can be reached by levying a toll, which represents both the external congestion and environmental costs (see for example: Blauwens, 1998; De Wit and Van Gent, 1998; Van Wee, 1995; Verhoef, 2000). A way to make travel costs more variable and to saddle polluters with external costs is to introduce road pricing policies (e.g. congestion pricing).

The importance and actuality of the view that externalities have to be internalised and that the share of variable costs has to be increased, can be deduced from the fact that in policy documents these issues are getting more and more important. A former Dutch government seriously considered different kinds of road pricing policies (Ministerie van Verkeer en Waterstaat, 1999). Some countries have already introduced some form of road pricing; good examples can be found in Norway (see: Hårsman, 2001; Odeck and Bråthen, 1997) and Great Britain. Apart from the very recent introduction of congestion

charges in London, the importance of road pricing policies in Great Britain can also be deduced from several studies (e.g. Banister, 2002b; May and Milne, 2000; Smith *et al.*, 1994; Steiner and Bristow, 2000). Outside Europe the most well known example is Singapore (Phang and Toh, 1997). Furthermore, the United-States have carried out (pricing) research concerning toll-lanes (Golob, 2001).

It can thus be concluded that road pricing policies are gaining terrain. However, it must be remarked that most of these road pricing policy projects are not (totally) concerned with internalising external costs. The intention for introducing toll pricing in Norway for example was to be able to finance infrastructure costs, whereas the aim for implementation in Singapore and London was a reduction of traffic congestion. For different forms and categories of road pricing (policy) see Geurs and Van Wee (1997) or Van Wee (1995) or Victoria Transport Policy Institute (2001).

3. Categories of transport pricing literature

This paragraph gives an overview of relevant literature concerning pricing policies, firstly by describing main categories to which many existing pricing policy studies can be attributed and secondly by giving a literature review on spatial effects of pricing policies.

3.1 Categorization of literature pricing policies

In general there are three categories of studies on (the effects of) pricing policies; economic-theoretical studies, studies to get insight into social acceptability of pricing policies and network related applied/impact studies.

Pricing policy first of all is a popular research topic in *economic theory*. This is mainly due to the typical economic aspects, which can be found in the theory of pricing policy, such as the pricing of a scarcity (infrastructure in this case). Since nearly all forms of transport are associated with externalities like congestion and emissions, there has been a great deal of interest in various ways to price these externalities. Among economists a widely accepted benchmark solution in the regulation of road transport externalities is the first-best pricing (Pigouvian marginal external cost pricing). Assumptions belonging to the first best pricing are that optimal charging mechanisms are available, allowing the regulator to set perfectly differentiated taxes for all road users and on all links of the

network; that first-best conditions prevail throughout the economic environment to which the transport system under consideration belongs; and that all users and the regulator have perfect information on traffic conditions and tolls (see also Verhoef, 1996). These conditions/assumptions of first-best pricing are not only causing almost unsolvable difficulties concerning technical implementation but also high resistance by actors (acceptability perceptions). Therefore almost equally commonly recognized is that the necessary assumptions for the practical applicability of this first-best pricing will seldom, if ever, be met in reality. Therefore second-best pricing issues, in which the strict assumptions of first-best pricing are relieved, have accordingly received ample attention in literature (a recent example: Verhoef, 2000). Examples of other recent literature economic based studies of pricing policies are Ferrari (2002) and Blauwens (1998).

Regarding the *social acceptability* of pricing policies several studies can be found concerning the public attitudes towards acceptance of road charging (Boot *et al.*, 1999; Golob, 2001; Jakobsson *et al.*, 2000; Jones, 1991; Rienstra *et al.*, 1999). In some papers emphasis has been put on how to lower implementation barriers. Especially Hårsman (2001) and Odeck and Bråthen (1997), concerning the Norway example, can be mentioned in this light.

Finally, *studies on effects* of pricing policy are mostly dealing with the network effects of pricing policies. These studies aim particular on the effects such policies have on congestion reduction. May and Milne (2000) for example study the effects of four road pricing systems on network performance in Great Britain. The charges are based on cordons crossed, distance travelled, time spent travelling and time in congestion.

3.2 Literature on spatial effects of pricing policy

The available studies on the spatial effects of road pricing can roughly be subdivided into theoretic, analytical based studies on the one hand and modelling studies on the other hand.

In the theoretical studies expectations of spatial effects of different forms of road pricing are often made based on research on related topics, such as for example location behavioural studies. Banister (2002b), as a first example, indicates in his article that

congestion pricing must be seen in a broad perspective. He explains possible effects of congestion pricing but also argues that the effects may not be very large. A great obscurity exists with regard to the actual effects and it is not reasonable to assume automatically that congestion pricing leads to (spatial) centralization.

MuConsult (2000) carried out a very extensive study concerning the spatial effects of pricing policies. The aim of this research was to obtain insights into the spatial effects of pricing policies with regard to persons/households and firms. The studied road pricing measures were: kilometre charge, cordon charging and parking charge. An important subdivision made in this research is the distinction into short-term and long-term effects. Short-term effects are transport network effects consisting of possible changes in trip pattern, such as changes of mode or changes in departure time. Long-term effects are defined as changes in location choice of households and firms as a consequence of road pricing. An important conclusion from the study is that a considerable part of employees can transfer costs on their employers. For this group the incentive to change behaviour is very low. Spatial effects for most firms are considered to be small, because transport costs only form a minor part of the total operational costs. The effects of this study confirmed the study of Blok *et al.* (1989), who carried out a mostly qualitative exploration of the possible spatial effects of a cordon charge variant.

In the category of applied modelling studies impacts of pricing policies on location choices are theoretically modelled, often by using utility functions. Sometimes these utility functions are used in a model structure with linked equations (e.g. Arnott, 1998). Other studies (e.g. Eliasson, 2002) estimate logit models based on utility functions and subsequently use these models to determine trip and location effects. Some examples of these studies are given below.

First of all, Anas and Xu (1999) conclude that in case of a congestion charge, two spatial effects work against each other. In dispersed cities, congestion tolls would drive up central wages and rents and would induce centrally located producers to want to disperse closer to their workers and their customers, paying lower rents and realizing productivity gains from land to labour substitution. On the other hand tolls would also induce residents to want to locate more centrally in order to economize on commuting and shopping travel. In the developed general equilibrium model, the centralizing effect

of tolls on residences dominates on the decentralizing effect of tolls on firms, causing the dispersed city to have more centralized job and population densities.

This centralizing (or less dispersed) effect of road pricing can also be found in Eliasson (2002). He uses a simulation approach to study the location and transport effects of two forms of road pricing: a congestion charge and a cordon charge. The study concludes that based on congestion pricing, road pricing makes the city in general less dispersed. However, it is not primarily the city centre that grows denser, but rather the innermost rings of the suburbs. The outer suburbs lose households, workplaces, shops and service establishments. Besides, the price level of the road pricing may affect the location pattern too and effects in that case will not be so obvious anymore. When looking at a toll ring/cordon charge, location effects depend strongly on where the toll ring is located. If the area enclosed is large, locations outside the toll ring become less attractive (centralizing effect). Conversely, a small toll ring will cause households, workplaces, shops and service establishments to move outside the ring.

Arnott (1998) states that account has to be taken of the possibility of a congestion charge to reallocate the traffic over the peak period. The effects of toll charging on the urban spatial structure in this case would probably be less definite than originally thought. The standard model without inclusion of departure times leads to a spatial concentration of economic activities, whereas the effects are not so clear when using a bottleneck model with inclusion of departure time. As both models can be seen as unrealistic in some respects, Arnott states that in reality effects presumably lay somewhere in between the results given by both methods.

It must be remarked that the model studies mentioned concern effects of road pricing on an urban level. Other spatial levels (e.g. regional level) are not considered. Furthermore the studies focus on quite simple urban structures. Some use a mono-centric city approach (e.g. Arnott, 1998). Other ones look at more polycentric cities (e.g. Anas and Xu, 1999; Eliasson, 2002). Of course these studies do not particularly have the purpose to study the accessibility effects of road pricing. Among the mentioned studies, Eliasson (2002) uses potential accessibility implicitly in his modelling structure to determine the location and trip effects of road pricing. But the accessibility effects of road pricing in isolation are not studied in his research.

4. Accessibility: definition and place in transport cycle

In many countries accessibility plays an important role in transport geography. In the Netherlands for example a key role is reserved for accessibility. In spite of the important role no unambiguous definition of accessibility can be found in literature. Many scientific articles concerning accessibility for example, refer to a quote of Gould (see for example De Jong and Ritsema van Eck, 1996; Huigen, 1986; Ingram, 1971):

“Accessibility... is a slippery notion... one of those common terms everyone uses until faced with the problem of defining and measuring it.”

This paper is aiming at the concept of accessibility and in particular at geographical accessibility. An extensive and recent definition of accessibility, which fits well in this case, is given by Geurs and Ritsema van Eck (2001):

The extent to which the land-use/transport system enables (groups of) individuals or goods to reach activities or destinations by means of (a combination of) transport mode(s).

It makes a large difference whether accessibility is studied from a traffic/transport or a

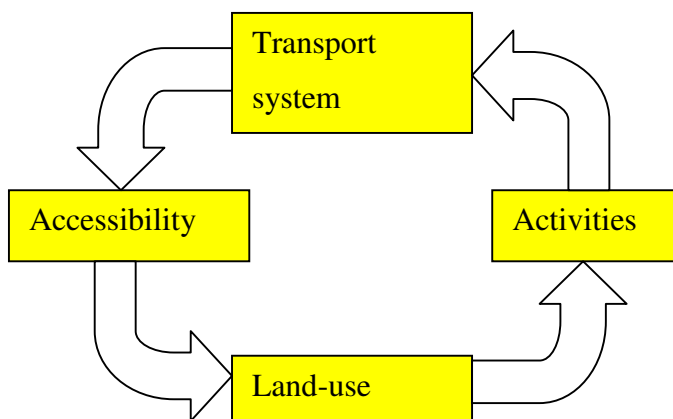


Figure 1: land-use transport feedback cycle
(source: Wegener and Fürst, 1999)

combined spatial/transport point of view. If a traffic or transport approach would be used, the Randstad¹ for example would be the worst accessible place in the Netherlands, because of the congestion on the highway network. However a geographical approach would give another result. The number of activities

(e.g. jobs) in the Randstad is very high. Many activities are located in a close range. In that case accessibility in the Randstad will be higher than in other parts of the

¹ Randstad is the most heavy populated urban area in the western part of the Netherlands. Major cities in the Randstad are: Amsterdam, Rotterdam, The Hague and Utrecht.

Netherlands (see also Van Wee and Dijst, 2002). As shown in figure 1, accessibility takes an important place between the transport system on one hand and the land use system on the other hand. The transport system enables people to unfold activities on different locations and makes it possible that these locations are accessible by different transport modes. The accessibility of locations increases with a good working transport system. Accessibility in its turn determines the attractiveness of locations and thus governs in part the land use. Furthermore, the physical locations of activities determine activity patterns of households and firms. Finally, the distribution of human activities in space requires spatial interaction and therefore trips have to be made to bridge the distance between activity places (transport system).

5. Accessibility measures and impedance

Accessibility can be quantified by accessibility measures. With such measures a value can be given to accessibility. This paragraph aims on explaining the different sorts of accessibility measures that can be found in literature and on examining the way impedance is incorporated in the different measures. In table 1 a subdivision in accessibility measures is shown (Geurs and Ritsema van Eck, 2001). Divisions in measurement types are more or less similar amongst different studies (see Appendix table A1, but also Hagoort, 1999; Bruinsma and Rietveld, 1998; Van Wee *et al.*, 2001). In this paper the study of Geurs and Ritsema van Eck (2001) has been used as a guideline for the division process.

As can be seen in table 1 different measures can be distinguished (table A2 in the Appendix gives a summarizing overview of the different accessibility measures including some important characteristics). Infrastructure-based measures, as a first category, do not contain a spatial component. They can often be regarded as indicators in traffic and transportation research. The impedance component can sometimes be seen as accessibility in itself. Travel time on a link for example is an indicator for resistance on that link. Other examples of these types of measures are congestion severity and operating speed on a road network.

In contrast, activity-based measures do take the spatial component along in various ways. Table 1 shows five types of activity-based measures. Distance measures, as the first category, simply express accessibility as the distance or impedance between

locations. Contour measures indicate the number of opportunities that can be reached within a certain specified reach or impedance (e.g. travel costs). Contour measures indicate that accessibility increases if more opportunities (e.g. jobs) can be reached within a given impedance value.

Accessibility measures
1. <u>Infrastructure-based accessibility measures</u>
2. <u>Activity-based accessibility measures</u> <ul style="list-style-type: none"> • <u>Distance measures</u> • <u>Contour measures</u> • <u>Potential measures</u> • <u>Inverse balancing factors</u> • <u>Time-space geography</u>
3. <u>Utility-based measures</u>

Table 1: categorization accessibility measures Geurs and Ritsema van Eck (2001)

Potential measures represent the potential number of opportunities weighted by distance/impedance to reach those opportunities. These potential measures consist of an opportunity component and a

distance/impedance decay function. The inverse balancing factors are based on the principles of gravity modelling. Shorter distances between activities lead to higher interactions. These measures are not specifically handled in table A2 because they partly show resemblance with potential measures: the general form of the singly constrained spatial interaction model is similar to the inverse of the basic potential accessibility measures. Besides the singly constrained measures, doubly unconstrained measures exist (Wilson, 1971). The main advantage of doubly constrained measures is that they account for competition effects (e.g. demand for and supply of work). Inverse balancing factors are however not easily explained, because of an iterative process to estimate the outcome of the accessibility analysis.

All (activity) based measures have their own advantages and disadvantages and the use of them often depends on the scope of the research. Some advantages and disadvantages of the inverse balancing measures were already given. Furthermore, distance measures (see also Ingram, 1971) are especially suitable when the fact whether or not locations are connected is important. In geographical accessibility analysis however, contour and potential measures are more applicable and used more often. Contour measures use a very stepwise impedance function. A major advantage of the measure is that it is simple and easy interpretable. The lack of differentiation that exists between opportunities

adjacent to the origin and those just within the specified reach can be seen as an important disadvantage. Potential accessibility measures follow a more gradual path. The impedance part is formed by a continuous decay (e.g. distance, travel time, etcetera) function. This is sometimes an advantage over contour measures. However, the measure also exhibits some disadvantages. There is for example usually no scientific motivation for the choice of distance decay function and for the decay parameter used, but the actual choice may greatly influence the outcome. Furthermore extreme short distances may heavily influence the results.

Time-space accessibility is analysed from the viewpoint of individuals; the measures examine whether and how observed or assumed individual or household activity programmes can be carried out, given certain time and place restrictions. Time-space accessibility can better be seen as an approach and easy quantifiable measures often do not exist. Therefore, no simple accessibility analyses can be done in this field of research. Time-space analyses need a large amount of data. This is in contrast to more easy applicable analyses based on contour or potential accessibility measures. On itself however theory behind the time-space approach is more sound than theory behind other activity-based measures. For further information see Dijst (1995), Geurs and Ritsema van Eck (2001) and/or Miller (1999).

The last category consists of the utility-based measures. They do not really represent accessibility but rather the valuation of accessibility by individuals. Therefore these measures are often used on a lower aggregation scale than the more geographical based measures (e.g. contour or potential measures). Utility-based measures assume that people choose an alternative with the highest utility. These types of measures are often used in the economic field for cost-benefit analysis. The potential of these models is large, because extensive functions can be built. However complexity also increases quite rapidly. In conclusion, these measures do not really represent accessibility, but have a large potential and can easily be adjusted to a specific situation.

6. Pricing policy and accessibility measures

Many studies can be found treating pricing policies and accessibility separately. Studies combining accessibility and road pricing are scarce as was discussed in paragraph 3. However, looking at road pricing effects from an accessibility point of view may be

very important. Often only mobility effects of road pricing are regarded. The pricing measure in that case has to cause a decrease in network congestion. However, mobility per se is not a reasonable goal for transportation policy. Instead improved mobility is desired to improve accessibility. Higher mobility does not necessarily mean higher accessibility. A higher level of service for example can have the effect that activity patterns will be spread more in space. This does therefore not necessarily mean that accessibility increases (see also Levine and Garb, 2002).

This paragraph will focus on the link between accessibility and road pricing and more specifically on the link between accessibility measures and road pricing. In 6.1 a conceptual model of spatial effects of road pricing is presented. 6.2 gives directions for improvement of accessibility measures with regard to road pricing and 6.3 finally, examines in an exploring way the suitability of different accessibility measures to incorporate improvement directions given in 6.2.

6.1 Conceptual model

Accessibility (and accessibility measures in particular) consists of an opportunity and an impedance component (figure 2). The opportunity part represents for example the activity locations. The resistance to get from one to another activity location is the impedance. Road pricing is a cost component and influences the impedance. The impedance consists of factors such as travel time and/or travel distance but for example also costs. This impedance or resistance is influenced by independent variables (e.g. income).

Instead of "objective accessibility", as can be calculated with traditional indicators, perceived or "subjective accessibility" might be relevant for understanding reactions on changes in accessibility, for example due to pricing policies. These perceptions may also play an important role for the acceptability of pricing policies. Due to road pricing the objective accessibility may increase because of higher objective costs. However, perceived accessibility may either increase or decrease. Because of road pricing travel times on a network may decrease. Especially people with high time valuations may benefit in this case, because they may perceive time gains as more important than the higher costs due to road pricing. Objective measures in that case would indicate an accessibility decrease whereas in reality perceived accessibility may increase. On the

other hand, people who are very cost sensitive may perceive a larger decrease in accessibility than objective measures would indicate. The key issue therefore is how people but also firms perceive accessibility, because this perceived accessibility is the actual accessibility and forms the basis on which people may decide to make changes in their behaviour. Objective computed accessibility in that case would give results that are not realistic.

Based on perceived accessibility households may feel the intention to make changes in their trip pattern. They can decide to change route, mode, departure time, frequency of making trips and even to work more at home. Households can also decide to make changes in their short/medium term destinations, such as for example their shopping location. For households, changes in work or residential location are partly dependent on the effectiveness of changes in the trip pattern. If households can mitigate the costs of road pricing by making changes in trip pattern they might not feel the intention to change locations. For firms a more direct relation between perceived accessibility and intentions to relocate will exist. In the end short and/or long term changes are made to improve perceived accessibility.

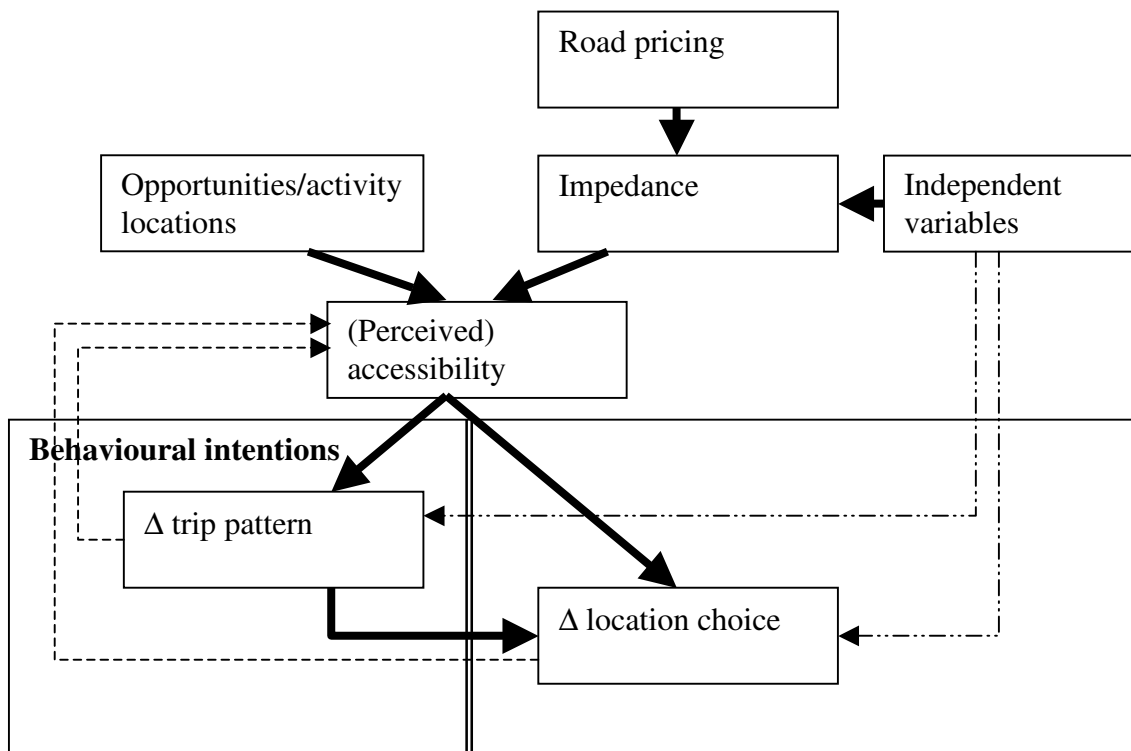


Figure 2: general conceptual model

6.2 Directions for improvement of impedance functions

In regularly applied accessibility measures such as the contour and potential measures often only travel time or travel distance are used as impedance component. In ordinary types of impedance functions it is not possible to include a cost component of road pricing, because in that case the relation between distance and costs has to be derived first. Instead a generalized cost function should be used to incorporate costs; in this function resistance factors such as travel time are monetarized. By multiplying travel time with a value of time (VOT) one derives a cost component. When travel time is expressed in such a component, road pricing costs can easily be added into the impedance function. However, currently applied generalized transport cost functions are too simple to describe accessibility effects of road pricing in a representative way. Different actors for example will not perceive accessibility under road pricing conditions the same. Therefore, it is first of all important to make a distinction between firms and households. These two actor groups form totally different entities, which will have different perceptions of accessibility.

In the second place a subdivision within actor groups has to be made. Households with diverging characteristics will perceive accessibility under road pricing differently. An example is trip motive; business trips can in most cases be characterized by a high valuation of time, whereas leisure trips may go together with a low time valuation. For business trips therefore, timesavings may be more important than higher costs due to road pricing. As road pricing can decrease travel time on the network, this may increase on its turn perceived accessibility of people making a business trip, whereas accessibility of persons making the leisure trip may decrease.

Next to making a distinction in personal/household characteristics, firm properties are important too. Take for example the type of firm. Transport companies will be influenced in a more direct way by toll costs than regular offices. This might well affect perceived impedance and thus accessibility. Thus, recognition of characteristics of households and firms is important, but their attitudes cannot be ignored either. Attitudes that can be of influence in the field of road pricing are for example attitudes regarding transport mode or the current activity locations. Van Wee *et al.* (2002) show that within homogeneous groups of people (with respect to variables such as income or age) certain preferences or attitudes may have an impact on the influence of land use on travel

behaviour. Also Kitamura *et al.* (1997) and Bagley and Mokhtarian (2002) show the importance of attitudes as an explaining factor for travel demand. These studies at least give an indication that attitudes could be important in road pricing research.

Next to differences in actor groups and characteristics, which can lead to changes in perceived impedance, the relation between road pricing level and travel time has to be regarded. Price level differences may for example occur in the case of variable tolls: higher tolls in peak than off-peak periods. These higher levels of toll may reduce travel time in a congested network in a stronger way than lower toll levels do. Furthermore, with higher tolls the actors that continue driving a car (or new car drivers) may have a higher value of time. This means for example that when the price level of road pricing rises, time valuation of car drivers may increase (Hensher, 2001). This gives an indication that it is important to at least acknowledge the fact that the price level might affect travel time on the network and influences the valuation of time. Furthermore, it is worthwhile to mention that travel times may not be valued constantly: the so-called non-constancy of travel time valuations. Gunn (2001) shows that the size of the timesavings leads to different valuations. Moreover, Gunn (2001) and Wardman (2001) both remark that time losses are valued more highly than timesavings. These losses however are less interesting in the case of road pricing because tolls result quite likely in travel time decreases. As a final component trip duration may influence the valuation of travel time. Gunn (2001) for example states that the value of the travel time saved increases with trip duration.

Closely related to valuation of time is the valuation of reliability of travel time (VOR). As that road pricing may decrease travel times in a congested network, the reliability of the travel time may increase. Reliability is therefore a factor, which has to be taken into account when studying accessibility effects of road pricing. Examples of studies in the reliability field are Bates *et al.* (2001), Lam and Small (2001), Noland and Polak (2002) and König and Axhausen (2002).

6.3 Suitability to adapt different types of measures

When looking at the suitability to adapt different accessibility measures with suggested improvements in 6.2, a good starting point is to remark again (see paragraph 5) that the spatial/geographical component is an essential factor in accessibility and thus plays an

important role when considering effects of pricing policies. This implies that accessibility measures, which are only aimed on the infrastructural side, are less relevant. The infrastructure-based accessibility measures therefore are not suitable for adaptation from a geographical point of view.

Contour, potential accessibility measures and measures of time-space geography however, explicitly take the spatial component into account. All these measure traditionally deal with impedance functions that can be replaced by a generalised cost function. Contour measures can be regarded as the number of opportunities reachable within a certain "amount of" resistance. Within a certain chosen fixed cost barrier the number of reachable opportunities can be computed. Among households for example the values of time (VOT) may differ. With given values of time and reliability and a given road pricing level, this can lead to different possible (actor) travel times within a chosen cost limit. This leads to different accessibility profiles for various actor types. Thus, it is possible to adapt contour measures with the suggested improvements. However, this does not solve the disadvantage of contour measures that all opportunities reachable within the chosen cost limit are equally desirable.

Secondly, the potential accessibility measures have a high adaptability potential; the decay function can easily be formed by a generalized transport cost function. However, the same advantages and disadvantages related to the type of measure still remain. Nevertheless, the continuous decay function is sometimes an advantage compared to the contour measures because a more differentiated insight into effects of road pricing can be obtained.

Measures of time space geography study activity spaces of individuals. Time space geography is often used as a theory and because of the disaggregate level, relatively easy interpretable measures cannot be found. Furthermore, to estimate accessibility of individuals much information is needed such as all kinds of (time) constraints. Therefore in conclusion time space geography gives an excellent framework to explain individual accessibility patterns, but more general accessibility measures are not available, making them also less suitable to include pricing policies.

Finally, the utility-based measures have to be mentioned. With these functions the utility of an individual to undertake a trip can be modelled in an elaborate way. Many possible influencing factors can be implemented in a utility function. Thus, the potential flexibility of utility-based measures is large. The utility function has a standard form and consists of a systematic component or "representative utility" and a random component reflecting unobserved individual tastes (see i.e. Louviere *et al.*, 2000). As was mentioned, utility-based accessibility measures do not represent accessibility but rather the valuation of accessibility by individuals and are often used in economic based research. This is in contrast with the geographical activity based measures. However, it is not always easy to make a clear distinction between utility theory and the activity based measures, because the concept of generalized transport is related to utility theory (see also Bates *et al.*, 2001). Therefore adjusting activity-based accessibility measures such as contour or potential accessibility measures with an improved generalized cost function can be seen as a combination of utility components with activity-based measures, which causes that the theoretical distinction between utility-based and activity-based measures cannot be drawn so sharply anymore.

7. Conclusions

From the article, it can be concluded in the first place that literature concerning pricing policies can particularly be found in the economic field. As far as congestion and road pricing is concerned this is because infrastructure can be seen as a scarce good. Furthermore studies on public acceptability of pricing policies are also quite common and applied studies of pricing policy usually are restricted to transport network effects. In contrast to the network effects of pricing policies, the spatial effects of pricing policies have been underexposed in research. This is strange because the spatial component plays an important role in transport generation and distribution.

The article showed that the concept of accessibility takes an important place between the transport system on one hand and the land use system on the other hand. The advantage of accessibility is that it connects land use with the infrastructure and therefore takes account of spatial and network components. Accessibility can be operationalized by accessibility measures. These measures make quantitative evaluations possible. An overview of the different types of accessibility measures was given including the important advantages and disadvantages of the various measures.

We have seen that costs are often not, or not in a realistic way included in current accessibility measures. Frequently only travel times or distances are used as an indicator for impedance. This makes it difficult to add an extra cost impedance component due to road pricing. The application of a generalized transport cost function gives the opportunity to add up travel times, expressed in costs, and costs due to road pricing. However, generalized transport cost functions as often used are not differentiated enough in order to be able to describe "perceived" accessibility effects of road pricing measures in a representative way. To monetarize travel time in a generalized transport cost function, values of time can be used. In that case a road pricing cost component can easily be added into an impedance function. To make such a function better, VOT-parameters have to be estimated for different actor groups (e.g. household versus firms), actor types and characteristics (e.g. high versus low income) and for different traffic conditions. Furthermore a value of reliability parameter (VOR) has to be included into the impedance function. The same subdivision into actor groups, actor characteristics and traffic situation for the VOR has to be made too. Next to these factors, account must be taken of the fact that VOT values are not constant in time, when improving generalized cost functions.

Finally the article looked at the possibilities to adjust current accessibility measurement types with the suggested improvements. It can be concluded that potential accessibility measures and contour measures can be adapted with the suggested directions for improvement. The continuous decay function in potential accessibility measures forms an advantage above the fixed impedance step that is used by contour measures. However, these improvements do not change already existing fundamental disadvantages related to the different measurement types. Utility-based measures finally, do not give a representation of accessibility but indicate the valuation of accessibility by individuals. Besides, these types of measures are often used for (economic) cost-benefit analyses. However, the generalized transport cost, which can also be used in activity-based measures, has a relation with utility theory. Therefore a dividing-line between activity-based and utility-based measures cannot be drawn so easily as it seems. An important practical issue from a geographical point of view is to adapt already available (geographical) accessibility measures in such a way that they are able to describe road pricing effects in a more differentiated and thus realistic way. The

framework for potential and contour measures already exists, and therefore these measurement types offer a good basis and starting point for describing accessibility effects of road pricing in a more representative way.

It would therefore be a large improvement by implementing suggested adjustments into relatively simple and often used geographical accessibility measures, such as the contour and the potential accessibility measures. Further research will focus on implementing these proposed changes. The needed value of time (VOT) and value of reliability (VOR) parameters including the proposed differentiations will be obtained from a large empirical research.

As the improvements imply that changes in both travel times and travel costs due to the introduction of pricing policies should be included in the accessibility measures, an important implication is that a model is needed to calculate values of accessibility measures. A fixed matrix of travel times, as often used in geographical accessibility measures is not sufficient anymore because travel times will change due to pricing policies. A more or less traditional transport model can be used to calculate impacts of pricing policies, but because the land-use pattern might be influenced by the pricing policies (see figure 2), it is preferred to use a Land-Use Transport Interaction (LUTI)-model.

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This study in which accessibility measures will be improved with a realistic cost component forms a part of a PhD-research, in which the spatial effects of road pricing policies are studied. Next to improvements in accessibility measures, the research will focus on changes in destination and location choices of households and firms under road pricing conditions. This PhD-research is a part of a project called a Multi-Disciplinary study of Pricing policies In Transport (MD-PIT). In this project (next to the geographical perspective) the road pricing effects are studied from an economic, traffic engineering and psychological perspective. The MD-PIT project is funded by Connekt/NWO.

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Appendix: categorization and explanation accessibility measures

<i>Accessibility measures</i>			
Geurs and Ritsema van Eck [2001]	Hilbers and Verroen [1993]	Handy and Niemeier [1997]	Makrí and Folkesson
<p>Infrastructure-based accessibility measures</p> <p>Activity-based accessibility measures</p> <ul style="list-style-type: none"> • Distance measures • Contour measures • Potential measures • Inverse balancing factors • Time-space geography <p>Utility-based measures</p>	<ul style="list-style-type: none"> • Characteristics of access • Position in network • Potential accessibility • Actual accessibility • Actual use and level-of-service quality of a transport system • Accessibility related to activity patterns 	<ul style="list-style-type: none"> • Cumulative opportunities measures • Gravity-based measures • Random utility theory 	<p>Place accessibility measures</p> <ul style="list-style-type: none"> • Distance measures • Cumulative-opportunity measures • Gravity measures • Utility-based measures <p>Individual accessibility measures</p> <ul style="list-style-type: none"> • Space-time measures

Table A1: overview accessibility measures

<i>Measure</i>	<i>Example</i>	<i>Impedance component</i>	<i>Remarks</i>
Infrastructure-based measures			No spatial component
These measures do not include spatial components and are quite simple i.e.: travel time, trip length, speed in network	Travel time on a link	In most cases the measures themselves represent the impedance	There is no link with the locations of activities
Activity-based measures			Spatial component
<u>Distance measures:</u> The degree to which two places (or points) on the same surface are connected or the degree of interconnection of a point with all other points on the same surface	Each person must have a bus stop within 500 metres from home	Fixed impedance step (e.g. 500 metre). No continuous function. If more than two destinations are analysed, a contour measure can be derived	Measure is useful if destinations are unknown and is only useful if connections are important but travel times and distances are not (Van Wee <i>et al.</i> , 2001)
<u>Contour measures:</u> The number of opportunities that are reachable within a given travel time or distance	Number of jobs accessible within 45 minutes by car	An (discrete) impedance step has to be chosen (e.g. 45 minutes travel time). Within the impedance boundary no difference in accessibility exists (no differentiation)	All opportunities are regarded equally desirable, the isochrones are selected arbitrarily and lack of differentiation exists between opportunities adjacent to the origin and those just within the isochrone (Geurs and Ritsema van Eck, 2001)
<u>Potential accessibility measures:</u> The potential number of opportunities weighted by an impedance (travel time, distance) to reach those opportunities	Accessibility of a person living in zone i to opportunities (e.g. jobs) in zone j is a function of the (number of) opportunities in zone j and the impedance between zone i and j	A real (continuous) impedance function exists. An example of this is a distance decay function (longer distance, then higher impedance).	A strong link with real travel exists because of (distance, time etc.) decay functions. The distance decay parameter has a large influence on the computed accessibility.
<u>Time-space approach:</u> Accessibility related to activity patterns: Possibilities for the desired activities (of an individual) given transport system characteristics (Van Wee <i>et al.</i> , 2001)	Description activity space of individuals (Van Wee and Dijst, 2002)	(Easy) computable measures do not exist. Impedance is individual based and time plays an important role.	Approach is useful for analyses on the individual level, especially in case of complex activity patterns or poor transport systems. In some literature time-space is considered as the actual activity-based approach.
Utility-based measures			Spatial component
These measures are characterized by the fact that they are not measures to determine accessibility in itself. The measures represent the valuation of accessibility by individuals.	The benefit an individual living in an area i derives from opportunities D which can be reached at (zone) j, given the cost to get there (c_{ij}). [Geurs and Ritsema van Eck, 2001].	It is possible to model utilities of individuals in an elaborate way. All kinds of components can be added as impedance components in the utility function. However it represents the valuation of accessibility.	The indicators have a good theoretical basis. They make the valuation of accessibility possible. Disadvantage is (among other things) the difficult interpretation. These measures are often used in cost-benefit analysis.

Table A2: description accessibility measures