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Accessibility in land-use/transport interaction modelling: LUTI models as a method to determine the spatial-economic effects of high-speed railway infrastructure

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Railway stations: interfaces between railway network development and urban dynamics (RS-URBIX)

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This research project addresses the role of railway stations in urban development. The central question is how the renaissance of railways since the end of the twentieth century (especially the development of high speed rail links) will affect the European cities. The analyses will be carried out with due attention to the broader institutional environment of the railway system such as the shift toward privatized railway companies, internationalization, the occurrence of market and government failures in land markets and private-public sector co-operation in the development of railway areas. The following sub-questions will be addressed:

What are the consequences of competition within the railway sector and between railways and other transport modes for the railway system in general and the development of railway stations in particular?

What is the importance of railway accessibility for locational decisions of firms and households, in particular with respect to business trips and commuting. How severe is mutual competition between railway stations, and competition between railway stations on the one hand and non-railway locations on the other hand?

How do land markets respond to the development of railway stations; what are the impacts on the values of real estate (offices, residences)?

To what extent can co-operation between private and public sector contribute to a more complete exploitation of the opportunities offered by high speed rail developments?

Abstract

This paper's objectives are to evaluate how the accessibility effects of HSR developments might influence the location decisions of firms and to assess to what extent land-use/transport interaction models are suitable to forecast the spatial-economic effects of passenger transport by HSR. We therefore give special attention to the concept of accessibility, which forms the link from the transport subsystem to the land-use subsystem in LUTI theory. Firstly, an introduction is given to the concept of accessibility and its role in the theory of land-use/transport interaction. The crucial question thereby is how (if positive) do corporate decision makers adapt their location choices to changes in accessibility. Secondly, an overview is given of different accessibility measures and their characteristics. Finally, the land-use/transport interaction models are studied with respect to the way they link transport to land use. It is concluded that land-use transport interaction models are able to make a considerable contribution to the discussion about the spatial-economic impact of high-speed railway developments. However, two adaptations are required: the link from the transport system to the land-use system can be improved; and the models should be applicable to larger spatial scales.

1. Introduction

The European high-speed railway network is expanding at a great pace. Since it's opening in 1981 the first TGV line between Paris and Lyon has had, more than had been expected, a favourable influence on the wider region around Lyon. This success led to recognition of the high-speed train's regional development potential. Since then, the indirect effects have played an important role in the cost-benefits analysis towards new high-speed rail infrastructure (Rietveld *et al.*, 2001). Many researches (e.g. Vickerman, 1996; Haynes, 1997) have studied the relationship between the establishment of new high-speed railway (henceforth HSR) infrastructure and spatial-economic developments.

However, the favourable spatial-economic impact of high-speed trains tends to be overestimated. For example, Vickerman (1997: 36) notices an "almost (…) mythical belief that [high-speed rail developments] can solve both transport and regional developments problems wherever they are built. This belief is not well founded in evidence." Under different conditions investments in infrastructure can have very distinct spatial-economic effects for the cities and regions with a HSR station. Disagreement exists among social scientists about the extent of the indirect spatial-economic impacts.

A central factor in the evaluation of the social-economic effects of transport infrastructure is accessibility (Rietveld and Bruinsma, 1998). Moreover, accessibility is the important link between the transport and land-use subsystems in land-use/transport interaction (henceforth LUTI) models, which are an important tool in the long-term spatial-economic evaluation of transport infrastructure. Nevertheless, little research has been done on the impact of the accessibility by high-speed train on the location choice of firms. Most researches on the location choices of firms deal with infrastructure in a rather crude way. Furthermore, in different studies into the effects of HSR on the social-economic development of cities, accessibility is only taken into account in an implicit way.

This paper will focus on a conceptual framework to evaluate how the accessibility effects of HSR developments might influence the location decisions of firms. Accessibility indicators that are currently used to evaluate new HSR developments are considered. Furthermore, it is studied how the spatial-economic effects of passenger transport by HSR can be determined using a LUTI model. Thereby, special attention is given to how the LUTI models deal with the concept of accessibility and its impact on corporate location choices.

Section 2 gives a short overview of theoretical approaches to evaluate the economic implications of new high-speed railway infrastructure. In section 3 a conceptual model is presented that describes the effect of transport infrastructure on the location policies of firms. Subsequently, section 4 focuses on indicators that are used to represent accessibility, which is a key factor in the conceptual model. Section 5 then evaluates how these accessibility indicators are implemented into LUTI models. Finally, in section 6 we give some concluding remarks.

2. High-speed rail and its spatial and economic effects

The relevance of HSR developments for economic developments follows the technical characteristics of high-speed trains. High-speed trains are one of the major innovations in transport technology of the last few decades. They reach higher speeds than conventional trains, thereby shortening travel times, and have higher comfort standards (Van den Berg and Pol, 1997). A major difference between high-speed trains and conventional trains are their route and time schedules. Conventional trains serve strings of places along a transport corridor; high-speed trains have a more air-transport like routing as they serve point-to-point relations (Vickerman, 1997). These distinct characteristics make that high-speed trains can be seen as a new surface transportation mode that can compete with air and road transport on distances of several hundreds of kilometres.

Although high-speed trains can run well on conventional tracks, especially the so-called tilting trains (see Van den Berg and Pol, 1997; Vickerman, 1997; Powell-Ladret, 1999), new dedicated HSR infrastructure is being developed between the major agglomerations of Western Europe to facilitate the technical possibilities of high-speed trains. The latest infrastructure developments are stimulated by the European Union, in particular in the context of the Trans-European Networks programme (see Vickerman, 1996; Sichelschmidt, 1999; Vickerman *et al.*, 1999). With the interconnection of the separate national HSR networks in Europe, the European Union aims at removing the barriers between member states thereby diminishing market imperfections. European-wide infrastructure of high quality and good interconnections and interoperability is seen as a precondition for the properly functioning of the European internal market (Pelkmans, 1997: 41).

Several theories and models are available that can explain and forecast the spatial-economic impact of HSR infrastructure. The spatial-economic effects of transport can be derived from the "new economic geography" framework (Krugman, 1991; 1999), that states a trade-off between centripetal forces (*e.g.* scale economies) and centrifugal forces (*e.g.* transport cost). More specifically focussed on HSR, Blum *et al.* (1997) mention economic advantages of HSR infrastructure investments like improved economies of scale, more specialisation and a more equal distribution of real income, but also reckon the disadvantages of an increased concentration of resources and a further limitation of the number of products and industries. General agreement exists on the possibility that transport infrastructure results in economic growth by eliminating bottlenecks (see Biehl, 1991; Martin, 1997). However, there is much discussion (e.g. Martin, 1997; Button, 1998) about the question if HSR can actively stimulate economic growth (the so-called endogenous growth theorem). Some authors find evidence in favour of this theorem, but others claim that good transport infrastructure is only one of the conditions for economic development.

Other authors see different mechanisms in how HSR can influence location decisions. These are typically based on macro-economic theory, micro-economic theory or econometrics. Kobayashi and Okumura (1997), for example, describe a model based on a macro-economic growth model in which they incorporate the knowledge transfer between cities. Knowledge is assumed to be place-specific and the transport system enables cities to exchange their knowledge by face-to-face contact. Migration is based on utility maximisation, thereby incorporating the distribution of knowledge among cities. Another approach is followed by Peeters *et al.* (2000), who based their model on a micro-economic theory: the simple plant-location problem. The distribution of firms over space is based on cost minimisation (including transportation costs), while competing with other firms. An example of an econometric approach is a model constructed by Sasaki *et al.* (1997) in which the regional investment function plays the central role. The national product determines the national private investments, which are thereafter disaggregated according to the regions' accessibilities. Although these three approaches are founded in distinct theories, the framework that is presented in this paper is suitable for all different approaches.

3. The concept of accessibility and its role in the theory of land-use/transport interaction

The different approaches to determine the economic impacts of high-speed trains, all deal with two key aspects: the location of economic activities (particularly firms) and the amount of interaction (e.g. trade or knowledge communication) between these activities. From economics, sociology as well as technical disciplines, several theories have arisen that declare an interaction between the location of activities (*i.e.* land use) and the transport system that enables the interaction between locations. Because these so-called land-use transport interaction (LUTI) theories take account of the feedback mechanism between land use and the transport system, they are suitable to evaluate both indirect effects and long-term direct effects of infrastructure investments. In particular, LUTI models can be used to forecast the consequences for employment and long-term travel patterns.

The several LUTI theories are elaborately described, amongst others, by Webster *et al.* (1988) and Wegener and Fürst (1999) to who we refer for further details on the different theories. In this paper we will focus on the concept of accessibility, which plays a key role in the link between the land-use subsystem and the transport subsystem. Whereas the impact of land use on the transport system has been the subject of a great number of empirical studies, the impact of transport on land use has been given much less attention (Wegener and Fürst, 1999).

Before going deeper into the meaning of accessibility a definition is required. The concept of accessibility is used with very distinct meanings in many research fields, like transport planning, urban geography and marketing. Literature gives many definitions for accessibility (for an overview see Bruinsma and Rietveld, 1998). Obviously the definition choice depends on the research goal. In some researches that deal with accessibility the main subject is infrastructure, while others examine the possibilities to deploy activities (for an overview see Geurs and Ritsema van Eck, 2001). In this research we have defined accessibility as:

> *The extent to which a location can be reached by individuals via the transport system, and the extent to which from this location other activities can be reached via the transport system, given the spatial dispersion of the individuals' origins and the locations of the activities.*

This definition makes clear that accessibility is an attribute of locations (in contrary to 'mobility' which is an attribute of people, cf. Kronbak and Rehfeld, 1999). A distinction is made between individuals coming from outside to visit the location and individuals that have the location as an origin from which they travel to activities elsewhere, since these are two different facets of accessibility. As is mentioned before, freight transport is not included in this research and is therefore omitted from this definition.

The definition also explicitly refers to the transport system (twice) and to the spatial dispersion of the origins of individuals and the locations of the activities. Accessibility is a combination of the location on a surface relative to relevant origins and destination, and the characteristics of the transport system linking points on that surface (Vickerman, 1974). Furthermore, the formulation of this definition emphasizes the context of land-use/transport interaction. After all, the definition thereby incorporates a major part of the land-use transport feedback cycle: only the link from the eventual accessibility to location choices is absent.

This definition can now be used to study the indirect spatial-economic impact of HSR infrastructure. When focussing on the indirect spatial-economic impact of transport infrastructure, the crucial question is how (if positive) do corporate decision makers adapt their location choices to changes in accessibility. A new HSR connection has consequences for the time, cost, comfort and other components of the level of service that is provided by the transport system. Firms will perceive these effects as a change in the accessibility of locations.

We suppose that from a firm's point of view the accessibility of a location has three dimensions:

- the extent to which the firm can have sufficient adequate (potential) employees commuting to and from the firm's location,
- the extent to which the firm can make and maintain contacts with business partners from the firm's location, and
- the extent to which the firm can have sufficient (potential) customers travel to and from the firm's location.

Hereby we mean with the 'extent': the inverse of the generalized costs. As this study focuses on passenger transport only, we will not examine the fourth accessibility factor: the delivery of goods.

Together with external factors the different accessibility items determine the attraction of a location for a firm. The importance of each of the three dimensions for attractiveness of locations differs among different categories of firms, but also within a dimension different attributes may be important to a firm. Different firms do, for example, valuate accessibility by private car and accessibility by public transport in a distinct way (Rietveld and Bruinsma, 1998: 208-209). From most researches the accessibility by private car appears to be more important than the accessibility by public transport. Still, firms do appreciate the accessibility by public transport and more firms would prefer a location with good railway accessibility than is actually the case. According to the so-called 'office market survey' in the Netherlands by Twijnstra Gudde (Venema and Kloosterman, 1997) only 17 percent of office firms is located on what the ABC location policy[1] denotes as an A location, whereas 31 percent of these type of firms prefer being located at an A location.

Categorization of firms, or better: establishments, can take place on different attributes, such as the number of employees and the branch of industry. The activities performed in the establishment determine the importance of a good accessibility and the nature of the accessibility that is desired. In a theoretical evaluation Wegener and Fürst (1999) distinguish between housing, industry, offices and retail. For housing, locations with a good accessibility towards working, shopping and other facilities are assumed to be the most attractive. These locations will have higher land prices and will be developed earlier than similar locations that lack this good accessibility. Locations with good connections to the motorway and railway networks are attractive for use by manufacturing industry. For some office activities besides of a good accessibility by road and rail connections also a good accessibility of airports is important. Finally, for shops the accessibility of consumers and the proximity of other shops are decisive elements for the development and for land prices.

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[1] The ABC location policy distinguishes four location types:

- A locations with a very good accessibility by public transport but poor accessibility by car.
- B locations with reasonable accessibility of both car and public transport,
- C locations with good accessibility by car but a poor accessibility by public transport,
- R locations with poor accessibility for both car and public transport

Each of these location types are suitable for different types of activities. For more information on the ABC location policy see for example: Martens and Van Griethuysen (1999).

Another important categorization criterion in the case of HSR is the spatial orientation of the firm. Dependent on a firm's spatial orientation its accessibility for different trip lengths will be important. Research suggests that high-speed rail will be most competitive to other transport modes on distances between 200 and 600 kilometres (Vickerman, 1997). On shorter distances HSR cannot overcome the advantage of cars of being flexible, whereas on longer distances air transport has a competitive advantage because of its faster line-haul speed. An indication of the spatial scale on which the major impact of HSR on accessibility can be expected, is given by the concept of daily return journeys. HSR enables daily return journeys up to 750 kilometres, without HSR daily return journeys are reasonable up to 400 kilometres (Vickerman, 1997). Where daily return journeys are important for business relations, Blum *et al.* (1997) focus on the effect of HSR on the labour market. For commuting trips much shorter travel times are required. HSR has in particular an impact on accessibility if a network exists that connects cities with travel times of 20 to 40 minutes. A region with such a HSR network is referred to by Blum *et al.* (1997) as a functional region, i.e. a region with a high intra-regional accessibility.

The above is summarized in Figure 1 below. The valuation of transport modes and of the three accessibility dimensions is subject to the individual characteristics of the firms, such as its spatial orientation, the activities performed in the firm establishment and also subjective factors. From this framework it does not appear how the accessibility per transport mode appears from the transport system; this will be the subject of the next section.

4. Overview of accessibility indicators

To convert the conceptual model from the previous section into a mathematical model, indicators must be selected to quantify the variables. Quantification of variables is also necessary for the verification of the conceptual model by statistical analysis. We will therefore now shortly introduce a number of relevant accessibility indicators. For more elaborate overviews of accessibility measures we refer to Bruinsma and Rietveld (1998) and Geurs and Ritsema van Eck (2001).

There exists a large variety of accessibility indicators. All of these indicators have their own advantages, disadvantages and application possibility (see Bruinsma and Rietveld, 1998). Not all accessibility indicators that can be found in literature satisfy the definition of accessibility that is formulated in section 3 above. Particularly, not all indicators give attention to the spatial dispersion of the origins of individuals and the locations of the activities. Some of them are also not clearly defined as an attribute of locations but are more a property of the transport system. Other indicators do correspond to the definition of accessibility, but are less relevant for application in LUTI models. This is for example the case for time-space accessibility measures. We will not deal with these measures, but instead restrict ourselves to a number of indicators that do satisfy the definition of section 3 and that are commonly used in LUTI models.

Firstly, there are the potential accessibility indicators. Most of these indicators measure the economic potential of a location as a function of attraction and impedance factors. An example of this type of indicator comes from the San Francisco Bay Area study (Cervero *et al.*, 1997):

$$A_i = \sum_j E_j d_{ij}^{-\gamma} \quad \textbf{Equation 1}$$

Where:

A_i = accessibility index for housing zone *i*,

E_j = an attraction factor, in this case employment: the number of workers in zone *j*,

d_{ij} = an impedance factor, in this case the distance in miles, distances by speedway between the centroids of zone pairs *i* and *j* with distance of less than 45 miles,

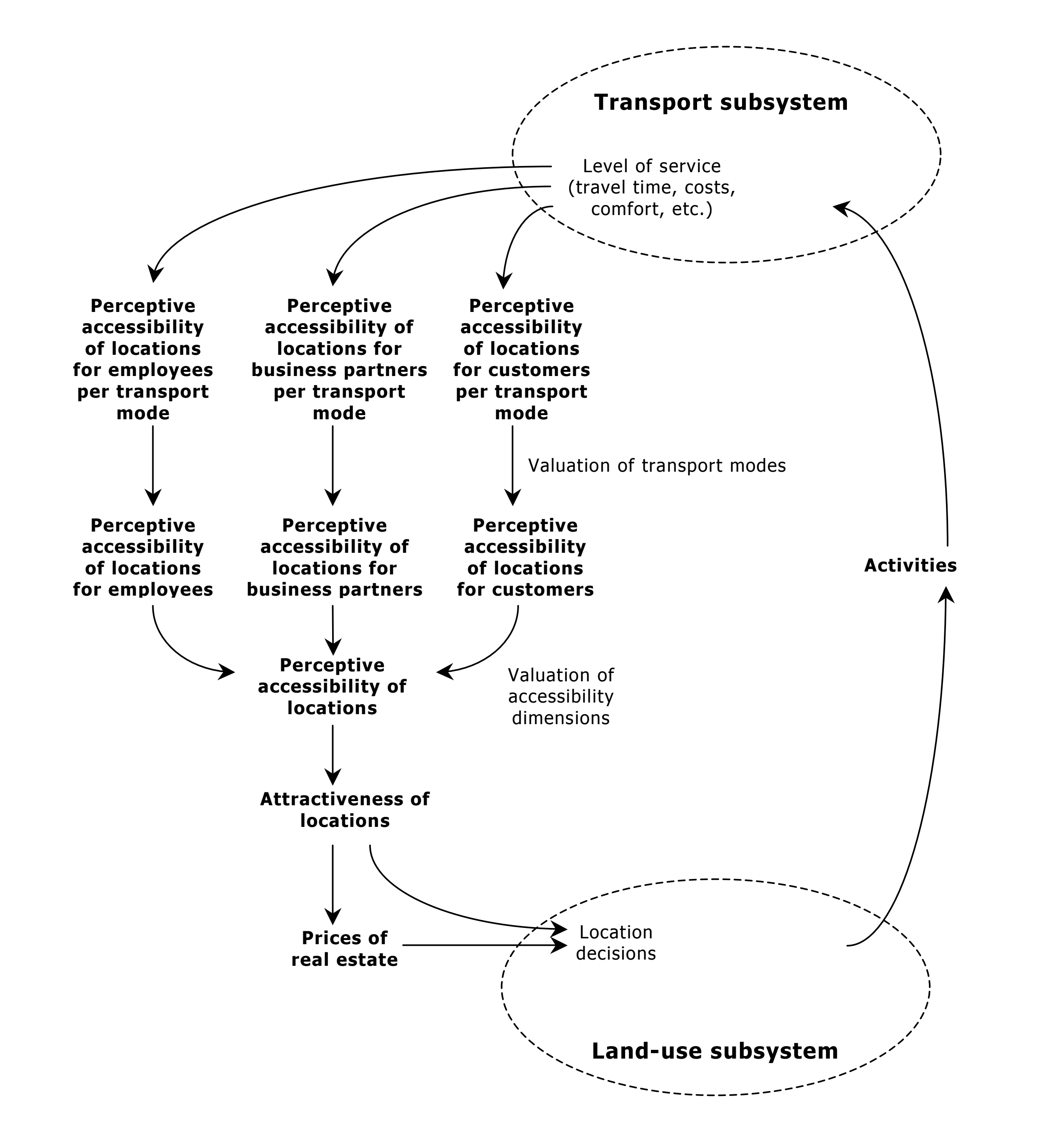

Figure 1: Accessibility in the land-use transport feedback cycle. We are aware that factors not related to accessibility affect the attractiveness of location, the prices of real estate and the eventual location decisions, but for simplicity these factors are omitted from the diagram. The relationship between the attractiveness of location, the prices of real estate and the location decisions of both real estate developers and firms is rather simplified as well. Freight transport is also not included in this diagram.

γ = empirically determined distance friction, in this particular case 0,35 for commuting displacements.

This equation is often called the Hansen equation after the first application of potential models for the calculation of accessibility (Hansen, 1959). Many adaptations of the original equations can be found in different studies and models. The differences can be a distinct distance decay functions than the power function from the San Francisco Bay Area study, weighting after the total number of possibilities by origin, or disaggregation by transport mode.

A second type of potential accessibility indicators are the inverse balancing factors of a doubly or singly constrained gravity model. In case of a doubly constrained model these factors come in pairs, following the equations (Geurs and Ritsema van Eck, 2001)[2]:

$$A_i = \sum_j \frac{E_j}{B_j} f(d_{ij})$$ **Equation 2**

$$B_j = \sum_i \frac{O_i}{A_i} f(d_{ij})$$ **Equation 3**

Where:

A_i = accessibility index for zone i with respect to trips originating from this zone (e.g. the accessibility for housing locations for employees),
B_j = accessibility index for zone i with respect to trips destined for this zone (e.g. the accessibility for firm locations for employers),
E_j = an attraction factor of zone j for trips originating in zone i,
O_i = a repulsion factor of zone i for trips with destination in zone j,
$f(d_{ij})$ = an impedance function dependant on an impedance factor d_{ij}.

The difference of this accessibility indicator and the economic potential of Equation 1 is that the attraction factor E_i is weighted with respect to the accessibility B_i of the destination zone. The accessibility B_i of the destination zone j, as follows from Equation 3, is similar to the accessibility A_i of the origination zone i from Equation 2. With this approach every zone has two values for accessibility: one for trips originating in the zone and another one for trips with a destination in the zone. Which value to take depends on the purpose of the accessibility analysis. In case of a singly constrained gravity model only one balancing factor takes the form of Equation 2 or Equation 3; the other balancing factor (which is often formulated implicitly) takes the form of the economic potential of Equation 1. In line with this, an unconstrained gravity model can be seen as having two balancing factors consistent with Equation 1.

The major advantage of the use of inverse balancing factors of a constrained gravity model instead of the more conventional economic potential indicator is that it takes account of possible competition between actors. Not taking account of the possible competition between actors is one of the weaknesses of many accessibility indicators (Van Wee *et al.*, 2001). With 'possible competition between actors' we mean that, for example, the ease with which a firm is able to recruit new employees depends not only on the absolute number of potential employees in the surroundings of the firm's location, but also on the number of other firms that is trying to employ the same persons. By weighting the attraction factors with respect to their accessibility, the inverse

[2] The Equation 2 and Equation 3 are adaptations of the more customary notation of the balancing factors, being $a_i = \left(\sum_j b_j E_j f(d_{ij})\right)^{-1}$ and $b_j = \left(\sum_i a_i O_i f(d_{ij})\right)^{-1}$

These can be converted to Equation 2 and Equation 3 by setting $A_i = 1/a_i$ and $B_j = 1/b_j$

The notation of Equation 2 and Equation 3 makes comparison with Equation 1 easier than with the more customary notation.

balancing factors take in this example more account of employees that have less opportunities for employment. Although there are certainly aspects of accessibility in which competition is not playing a dominant role, for several accessibility factors taking account of competition is a significant improvement. A minor disadvantage of this accessibility measure is that the mutual dependency of the two balancing factors requires an iterative process for calculation, which is time-intensive.

Another type of accessibility indicators that has a relation with LUTI models and thus requires a further explanation, are the utility-based accessibility measures. These accessibility measures are the logsum of the observed part of utility for trips from or to the zone of interest (Handy and Niemeier, 1997):

$$A_i = \ln\left(\sum_j \exp\left[V_{ij}\right]\right)$$ **Equation 4**

Where:
A_i = accessibility index for housing zone *i*,
V_{ij} = the observed component of the utility for a trip from zone *i* to zone *j*.

Thereby, the utility component can consist of a large variety of attributes, thus making the accessibility measure customisable to many applications. Utility-based accessibility measures are often used for the economic valuation of accessibility. In the current paper, the utility based accessibility indicators are relevant as they can be seen as the natural logarithm of the denominator of a multinomial logit model of combined route and mode choice (Handy and Niemeier, 1997; Geurs and Ritsema van Eck, 2001). Multinomial logit models are often applied in LUTI models, as we show in section 5 below.

Among these accessibility indicators it is not possible to point out one accessibility indicator that is better than the others in all cases. The goal of a research or model is decisive for the choice of the accessibility indicator that is used. For research on the spatial-economic effects of high-speed rail a measurement of accessibility is needed that takes into account the way enterprises choose their location. It is likely that multiple accessibility indicators are necessary to account for the different facets of accessibility that are of importance for the location choice.

5. The role of accessibility in land-use/transport interaction modelling

There is a large variety of LUTI models among which there exist several different ways of how to link the transport subsystem to the land-use subsystem. Elaborate overviews of these models are given by Wilson (1998), David Simmonds Consultancy (1999) and Wegener and Fürst (1999). LUTI models differ from each other in both their purpose and their theoretical approach. In general a distinction can be made between on the one hand models that are designed to forecast the (long-term) effects of infrastructure changes and transport policies on land use and transport, and on the other hand models that are designed to determine the optimal configuration of land uses and infrastructures. LUTI models are often combined with environmental models to determine the impacts of transport on the environment (Hayashi and Roy, 1996). Many LUTI models focus primarily on the urban level; model applications that work on a regional level often have a hierarchical structure of connected sub-models that work on different spatial scales. The author is not aware of any LUTI model applications on an international scale, which are relevant for research on HSR developments.

Recent LUTI models are comprehensive and often consist of many subsystems (Wegener and Fürst, 1999). There are very different modelling approaches used among the variety of modern LUTI-models. In general, a distinction is made between entropy-based, spatial-economic and activity-based models (*e.g.* David Simmonds Consultancy, 1999; Wegener and Fürst, 1999), although due to the emergence of dynamic modeling approaches a convergence of the different approaches has started (Wilson, 1998). Dynamic LUTI models generally use multinomial logit models, which are compatible to both the entropy-maximising and utility-maximising approaches (Anas, 1983). For the evaluation of accessibility indicators that are used in LUTI models, methodological differences are therefore of minor importance.

To illustrate how corporate location choices depend on the transport system in currently operational LUTI models, we will shortly discuss how accessibility aspects are incorporated in four well-known models. Subsequently, a concept is described that explains how the outcome of LUTI models might differ from actual location choices due to a poor representation of accessibility. Finally, we will evaluate the way accessibility is incorporated in LUTI models by using the theoretical concepts that have been described in this paper.

5.1 Accessibility in four operational land-use/transport interaction models

Nowadays, there are numerous LUTI models available for application; Wegener and Fürst (1999) describe no less than seventeen of these models. It is not the intention of this paper to discuss all these different models, but to illustrate the how link between the transport system and the land-use system is implemented in LUTI models by focussing on four LUTI models: the Dortmund, IMREL, LILT and MEPLAN models. These particular models have been taken as examples, because they are well described in literature have been applied to several study areas, and as a consequence can be regarded as well known. A summary of how accessibility is incorporated in these models is given in Table 1 below.

The Dortmund model (Wegener, 1983) deals with accessibility in an explicit way. This is not a common feature among LUTI models: among the seventeen models that were reviewed by Wegener and Fürst (1999) ten models use accessibility indicators as a separate variable. Although not all LUTI models explicitly calculate accessibility, all LUTI models do take account of accessibility in some way. Therefore, we argue that all of them have one or more accessibility indicators incorporated, either explicitly or implicitly. The Dortmund model uses accessibility factors that show resemblance to logit models. These functions can be seen as variations on the classic economic potential indicator of Equation 1 in section 4 above.

Another example of a LUTI model that uses explicit accessibility indicators is the IMREL model (Anderstig and Mattsson, 1991). This model uses a potential accessibility indicator where the attraction factor is the number of households. The impedance function depends on the generalized travel costs per mode and is more complex than the impedance function of Equation 1. In the IMREL model this accessibility indicator is one of the factors that determines the location of employment in a multinomial logit model. Other accessibility factors, such as the accessibility to other firms, are not taken into account.

In models that do not make use of distinct accessibility indicators, the accessibility factors are embedded in more extensive functions to forecast corporate location choices. For example, the spatial-economic models of the MEPLAN type calculate matrixes of disutilities for buying goods or services from other sectors (Abraham and Hunt, 1999). The disutility of trading a specific good or service (including labour force) from a zone to another zone is influenced by the disutility for transporting the good from the origination zone to the destination zone, among other utility and cost factors (including transport costs made when transporting production factors to the production site in the origination zone). The accessibility indicator is in this case a utility-based accessibility indicator represented as the denominator of a logit function for a destination constraint simultaneous origin, mode and route choice.

Another way of implicitly taking account of accessibility is through the use of doubly and singly constrained spatial interaction models, as for example is the case in the LILT model (Mackett, 1993). We already noticed in section 4 that the inverse of the balancing factors of a gravity models can be seen as accessibility factors. Three kinds of gravity models are used: unconstrained gravity models for simultaneous job and home choice for households who are changing both home and job and two kinds of singly constrained gravity models for households who are only changing home or job respectively. The author is not aware of the use of other accessibility factors (except the accessibility to employees) to determine the location of employment.

Table 1: Accessibility in four operational land-use/transport interaction models

Model	**Primary literature source**	**Accessibility indicators**	**Accessibility aspects**	**Remarks**
Dortmund	Wegener (1983)	Adapted economic potential indicator.	Several types of activities or facilities are used as attraction factors; the impedance factor is a Cobb-Douglas utility function of travel time and travel costs.	No details about the attraction factors that are used to model corporate location choice are known to the author.
IMREL	Anderstig and Mattsson (1991)	Adapted economic potential indicator.	The number of households is the attraction factor; the impedance factor is a combination of generalised travel costs and a mode-specific constant.	
LILT	Mackett (1993)	Balancing factors of singly constrained and unconstrained gravity models to model housing and employment location choice.	The impedance factor is the generalised travel time, dependant on the costs and time of both travel and interchange.	No details about the attraction factors that are used to model location choices are known to the author.
MEPLAN	Abraham and Hunt (1999)	Multinomial logit model of origin-destination choice.	Depends on level of consumption in the destination zone and the trade or travel utility, in which transport disutility and accumulated transport costs are incorporated.	

5.2 How differences between modelled and actual location choices occur

The major differences in the representation of accessibility in LUTI models, together with the different forecasts these models give when evaluating the land-use effects of transport policies[3] in comparative studies (*e.g.* Webster *et al.*, 1988; Mackett, 1993), suggest that the validity of the link between the transport subsystem and the land-use subsystem is not optimal in all models. We will therefore now focus on how differences between modelled and actual location choices can occur. Hereby, we assume that corporate decision makers gather information in three steps:

1. the corporate decision maker will determine what accessibility (and other) aspects are important to him (for example: accessibility by rail, accessibility by car, accessibility of customers, accessibility of employees),

[3]) Different implementations of policies are a possible explanation for differences in model results (Mackett, 1993: 195)

2. the corporate decision maker will evaluate how these accessibility factor are of important (for example: the extent of the parking facilities, the distance to a large railway station, the number of potential employees living in the proximity),
3. the corporate decision maker will acquire information that resembles the way in which accessibility aspects are of importance (for example: estimated distances from a road map, number of subscriptions to nearby employment agencies).

The corporate decision makers will further process this information and will eventually come to a location decision. This is the stage of the location decision process that is actually modelled by LUTI models. In our view, there are two factors of validity that can cause a difference between the accessibility that is measured with objective accessibility indicators and the accessibility as it is actually perceived by corporate decision makers and on which the eventual location choices are based. These factors are shown in Figure 2 below.

Firstly, the corporate policy makers are not likely to execute comprehensive accessibility analyses, using GIS databases and state-of-the-art analysis tools. Instead, they might be using much less detailed data that is subjectively interpreted. Corporate decision makers may in this way have a biased impression of accessibility-related factors, such as travel times and costs. Furthermore, firms may take into consideration more and/or other accessibility related aspects of a location than is modelled in current LUTI models.

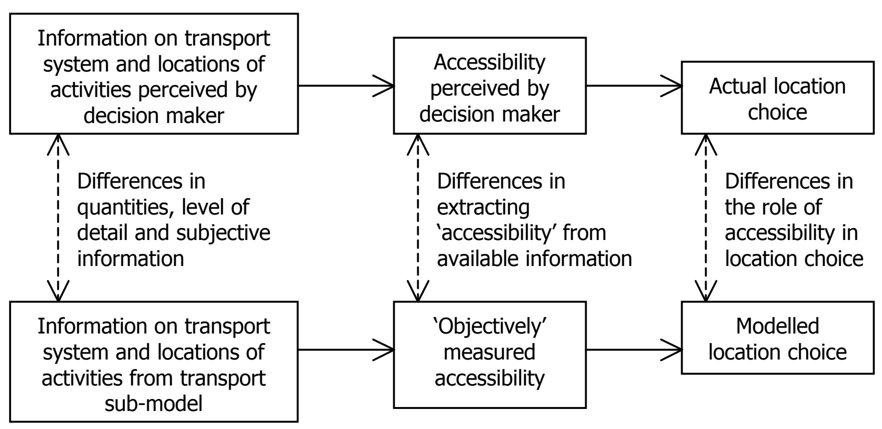

Figure 2: Possibilities for the occurance of differences between actual and modelled location choices as caused by the representation of accessibility in LUTI models.

Secondly, firms may take account of the accessibility aspects in a different way than is represented by the accessibility indicators in LUTI models. LUTI modellers should be aware that the purpose of the accessibility indicators that are used in LUTI models should not be to find the optimal accessible location, but to reflect realistically how corporate policy makers determine the accessibility of a location. In this evaluation we deal with two aspects of accessibility indicators that can make the indicator more or less realistic. The first aspect is whether or not the possible competition between actors is taken into account. We already noted this in section 4 above. The second aspect is whether or not the properties of supply and demand are taken into account. This addresses for example to the question what part of the working population does have the right skills for a certain vacancy. As the composition of the labour market differs per region, an accessibility measure based on the whole population may not be a good approximation of the ease with which a firm is able to find appropriate new employees. Several authors have pointed at the relevance of this 'match' between supply and demand (*e.g.* Cervero *et al.*, 1997; Shen, 1998). The problem can be overcome by segmentation, for example on educational level. It is therefore no shortcoming of the accessibility indicators itself, but of their application.

The problem of accessibility indicators not reflecting the way policy makers judge a location's accessibility, can be overcome by carefully choosing the optimal accessibility indicator. However, the problem of corporate decision makers relying on different information than is used for modelling is more difficult to deal with.

5.3 Evaluation of accessibility measures in LUTI models

The indicators that are used in the various operational LUTI models differ from each other in both aspects of validity. Concerning the information that is used to calculate accessibility, the four examples that were described in this section all take account of possible employees as an attraction factor. However, the IMREL and LILT models do not consider the impact of the accessibility to other firms on the location choice. We claim that for certain categories of firms the location of (potential) business partners is very likely to have an impact on location choices.

With regard to the transport component in the location choices the models are more harmonious. The impedance factors in accessibility indicators are usually both travel time and travel cost. However, we argue that corporate decision makers are not likely to calculate travel times. Beside of that, they might also give attention to other factors than travel cost and travel time, such as the ease with which locations give access to the transport networks that are most relevant to them. Concerning the accessibility by rail, factors such as frequency and the number of direct connections with other cities (*i.e.* factors that express the ease of travelling) might be of importance (Willigers, forthcoming, 2003).

The four LUTI models that are considered in this section all use different indicators to take account of the accessibility factors. The two models that use explicit accessibility measures both use indicators that can be classified as adaptations of the classic potential accessibility indicator (Equation 1). In both models the impedance function is adapted by using exponential and power functions. A disadvantage of this type of indicators is that it does not take account of competition between actors.

In the MEPLAN framework a logit model is used to determine flows of goods and services (including labour force) from the disutility of interzonal 'trade'. This does also not incorporate competition. However, the LILT model uses both unconstrained and singly constrained gravity models to model job and home changes. The model thereby introduces competition to both the job and labour markets.

All four of the models divide the household population in a number of segments, thereby taking account of the properties of supply and demand in this part of the model. However, from the literature it seems that the firms' side of the model is inferior to the households. Only the MEPLAN model has with its input-output structure an extensive segmentation among firms (or rather employment as firms are implicit in all four of the LUTI models). It also takes account of interactions between segments in a great detail.

Summarizing the above, we can conclude that the various LUTI models deal with a small number of accessibility factors often in a complex way. The complexity is thereby often incorporated in the impedance function of a potential accessibility indicator. Several models do not explicitly calculate the accessibility of locations, but instead calculate interaction between zones directly from the attraction factors and impedance coefficients. Some models also omit accessibility aspects, which we presented in the conceptual model in section 3. This is especially the case for business-to-business relationships. In our view firms take account of several accessibility factors, but in a less complex way than is represented in the LUTI models.

6. Concluding remarks

This paper's objectives are: to come to a conceptual framework to evaluate how the accessibility effects of HSR developments might influence the location decisions of firms; to use this framework to assess to what extent land-use/transport interaction models are suitable to forecast the spatial-economic effects of passenger transport by HSR. We therefore give special attention to the concept of accessibility, which forms the link from the transport subsystem to the land-use subsystem in LUTI theory.

Nowadays, numerous LUTI models exist worldwide that are used to evaluate the indirect effects and long-term direct effects of transport policies and infrastructure investments. LUTI models can particularly be used to forecast the consequences for employment and long-term travel patterns. The location of economic activities and the amount of interaction between these activities are crucial aspects for the different approaches to determine the economic impacts of high-speed trains; therefore LUTI models are able to make a considerable contribution to the discussion about the spatial-economic impact of HSR developments.

However, some adaptations should be made to the LUTI models before they are suitable for the evaluation of HSR. Firstly, the link from the transport system to the land-use system is susceptible for improvement. Many LUTI models use a variant of the economic potential indicator with travel costs and time as impedance factors. This accessibility indicator, however, might be more complex in structure and at the same time encompassing less accessibility factors than how firms judge the accessibility of a location in reality. LUTI models may be improved by incorporating more accessibility factors to determine land-use changes. To accommodate this, empirical research is needed on how firms take account of accessibility in their location decisions.

A second adaptation that should be made is the spatial scale on which the model works. Most, if not all, land-use/transport interaction models that are in use, work on an urban or regional level. The spatial influence of a high-speed rail link is assumed to work partially on a much larger scale. Since HSR is especially competitive to other transport modes on distances between 200 and 600 kilometres (Vickerman, 1997), the model should be able to handle a spatial scale of this order. In this context, also the spatial orientation of the firms is important. HSR is assumed to have an effect primarily on firms with a national or international orientation. But also on smaller spatial scales effects may be expected, because HST station locations will be competing for firms with other station and airport locations in the same region.

With these adaptations, LUTI models may shed more light on the extent of the indirect spatial-economic impacts of HSR developments, thus rationalizing the HSR's mythical state. Moreover, the accuracy of long-term predictions of direct impacts may be improved. And last but not least, they can be helpful tools for cost-benefits analyses of railway infrastructure projects.

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